# Carbon sequestration and storage potential along the Trans-Canada Highway corridor in Chilliwack, BC.

**by**
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BSc. Biology, University of Northern British Columbia, 2017

Project Submitted in Partial Fulfilment of the

Requirements for the Degree of

Master of Science

in the

Ecological Restoration Program Faculty of Environment (SFU)

and

School of Construction and the Environment (BCIT)



SIMON FRASER UNIVERSITY

BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY

2021

## Declaration of Committee

| | |
|---|---|
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| **Degree:** | **Master of Science** |
| **Title:** | **Carbon sequestration potential along the Trans-Canada Highway corridor in Chilliwack, BC.** |
| **Examining Committee:** | **Chair:** Anayansi Cohen-Fernandez<br><br>Supervisor<br>Faculty, BCIT<br><br>**Examiner 1:** Ken Ashley<br>Committee Member<br>Faculty, BCIT<br><br>**Examiner 2:** Ruth Joy<br>Committee Member<br>Faculty, SFU |

## Dedication

I dedicate this applied research project to Kathleen “Aunty Kay” Mark-Haelford. Wish you were here to see me graduate not once but twice. Would have been fun to share my accumulated knowledge with you.

## Acknowledgements

I would like to acknowledge all those that helped me. To my field assistant and Dad, Pat Cathcart. Thank you for coming out with me and being patient while I figured out what I was trying to do. To my Mom, Christine Cathcart. Thank you for buying me snack and chatting with me when I needed a break. To my partner, Robert Powell. Thank you for supporting me through graduate school, from working hard as a lawyer to making me laugh when I really needed it. You are an amazing partner. To my cohort. You guys are the most amazing classmates and friends I have ever had. I don't think I could have made it through this program without all of you. I only wish we had more time together. Hopefully we can stay in contact, whether that's through social media, work, or coffee shop catchups. You are all amazing and will do amazing things. Lastly, to my supervisor, Anayansi. Thank you for sticking with me and helping me along through all the ups and downs. Doing a graduate program is no easy task, especially during a pandemic. I really appreciated all your encouragement and kind words to get me through this.

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# Executive Summary

As of 2017, more than 4 billion people live in urban areas (Ritchie 2018). As people continue to move from rural to urban areas, the concentration of greenhouse gases (GHGs) in urban areas will continue to rise. However, this may be mitigated by increasing carbon sequestration by expanding urban forests (Baines et al. 2020). While the BC government has implemented reforestation projects on logged, provincial land, and has released a Community Toolkit for municipalities to increase their treed environments, there is still available land to be planted between the provincial and municipal land (Cullington et al. 2008). Trees are an important tool for $CO_2$ sequestration and storage. The open landscapes of the Trans-Canada Highway right-of-ways presents an underutilized opportunity to increase the treed environment for carbon sequestration and storage along this open vehicle corridor. This project seeks to model the current carbon sequestration level and the carbon sequestration potential for different vegetation types along the Trans-Canada Highway and develop recommendations for revegetation plans to increase carbon sequestration along this heavily used vehicle corridor.

The study site resides along a 20 km stretch of the Trans-Canada Highway in Chilliwack, British Columbia. This area was chosen as it is an agricultural community with very few treed areas. The area was split into the Chilliwack North Polygon (CNP) and the Chilliwack South Polygon (CSP) on ArcMap, on which a grid of 20 m by 20 m squares were laid, which is necessary for transferring the data collected in the field into i-Tree Eco v6.0 (n.d.). The program i-Tree Eco uses measurements, such as diameter at breast height (DBH) and ground cover class, taken in the field to estimate ecosystem services and structural characteristics of the Chilliwack area. Throughout the CNP and CSP areas, 12 were selected based on accessibility, safety, and site representation. The program i-Tree Canopy v7.0 (n.d.) was also used to bolster this information by estimating tree cover and tree benefits for the Chilliwack area through satellite imagery by randomly selecting 500 sampling points throughout the CNP and CSP areas. Grass surveys were conducted in 1 m by 1 m quadrats placed in an area representative of the selected 20 m by 20 m quadrat (i.e. a homogenous area that represents the majority of the vegetation in the plot). Grasses were identified on site to genus or species whenever possible, and their percent cover measured. Soil samples were also taken within the 1 m by 1 m quadrat within the first 15 cm. As these sample sites house anthroposols, sampling within the first 15 cm was selected to capture conditions in the root zone for plant growth. The soil samples taken were used to determine soil

texture and soil pH for planting purposes. Finally, a review of highway management practices was done to identify areas where improvements can be made to increase carbon sequestration. Practical management suggestions are based on the results from the above-mentioned analyses.

The program i-Tree Eco v6.0 (n.d) indicated that the CNP had the greatest carbon storage of 172,787.3 kg/ha, while the CSP had 15,270.8 kg/ha. The CNP is able to store 11,554.2 tonnes of carbon while the CSP was only able to store 546.1 tonnes of carbon. However, the CNP had an annual net carbon sequestration of - 57.2 tonnes/yr while the CSP has 2.5 tonnes/yr. Red alder (Alnus rubra) comprised 52.3% of tree species recorded and had the highest carbon storage of 6,322.7 tonnes, followed by bigleaf maple (*Acer macrophyllum*) with 3,186.0 tonnes, black cottonwood (*Populus trichocarpa*) with 1416.3 tonnes, western hemlock (*Tsuga heterophylla*) with 1155.6 tonnes, and paper birch (*Betula papyrifera*) with 19.7 tonnes. The annual net carbon sequestration of red alders however was - 2.2 tonnes/yr, while bigleaf maple had the highest with 3.7 tonne/yr. The program i-Tree Canopy v7.0 (n.d.) indicated that overall, there was 125.37 tonnes of carbon sequestered annually in trees within the CNP and CSP, with 3,734.34 tonnes stored. The ground cover composition of the CNP had a greater composition of shrub (61.1%) and tree (16%) compared to the CSP, while the CSP had greater plantable space (65.4%).

This data was used to characterize the study area and model the current carbon sequestration and storage. New management strategies were proposed and native vegetation suitable for the study area was identified.

# Introduction

As of 2017, more than 4 billion people live in urban areas (Ritchie 2018). As people continue to move from rural to urban areas, the concentration of greenhouse gases (GHGs) in urban areas will continue to rise. With urban centers increasing in population, the surrounding suburban and rural areas are experiencing population increases as well, leading to increased average commute times for those traveling from rural to urban areas for work (Ritchie 2018). With urban sprawl comes the increased influence of GHGs in our more natural and rural landscapes.

Over the past three decades, there has been a global effort to limit atmospheric carbon dioxide ($CO_2$), through emission reductions and various types of carbon sequestration (Smyth et al. 2014). Globally, many countries have signed international accords, such as the Kyoto Protocol (UNFCCC 1997) and the Paris Agreement (UNFCCC 2015) under the United Nations Framework Convention on Climate Change (UNFCCC), in an effort to limit and reduce GHG emissions. Canada is a signatory for both agreements and has implemented the Pan-Canadian Framework on Clean Growth and Climate Change, committed to reducing methane emissions from the oil and gas sector by 40%-45% by 2025 and to phase out coal-based electricity by 2030 (NRC 2020, May 26). One solution that many countries have implemented to increase carbon sequestration is by expanding urban forests (Baines et al. 2020).

Forests in general play an essential role in the global carbon (C) cycle. Globally, forests sequester about 9.3 +/- 3.8 Gt $CO_2$/year, and between 1990 and 2010 they removed about 30% of anthropogenic $CO_2$ emissions from the atmosphere (Lempière et al. 2013). Deforestation, wildfires, and disease have hampered global forests' abilities to sequester atmospheric carbon. However, changes to global forest management practices are helping (Hof et al. 2017). In Canada, the deforestation rate has declined over the last 27 years, from 64,000 ha/yr in 1990 to 35,000 ha/yr in 2017 (NRC 2020, May 20). The government of Canada has since pledged $3.16 billion to plant two billion trees by 2030 across the nation to increase carbon sequestration (Canada 2019).

The government of British Columbia has also implemented carbon neutrality and offset projects to reduce carbon emissions, with the BC government investing over $23.7 million in projects to offset 1.92 million tonnes of carbon emissions (Sanscartier et al. 2015). One such offset strategy is BC's Forest Carbon Initiative (FCI), which includes the reforestation of areas affected by natural disturbances, which will accelerate the return of these areas to carbon sequestering locations (BC n.d.). The BC government has also released a Community Toolkit for municipalities to increase their treed environments, to create "urban forests" that will sequester carbon in urban areas (Cullington et al. 2008). However, there is land available to be planted, in between the large areas of provincial land being reforested by the province, and the smaller sites on municipal land available to increase urban forests. The open landscapes of the Trans-Canada Highway right-of-ways presents an underutilized opportunity to increase the treed environment for carbon sequestration and storage along this open vehicle corridor.

Revegetation mixes that are applied along BC highway roadsides during highway construction are made up of standard grass seed mixes (BC MoTI 2016). Typically, a mix of grass seed is applied along with fertilizer and mulch, to newly excavated or filled slopes by hydroseeding to prevent soil erosion, runoff, and invasive plant establishment (BC MoTI 2019). While there are instructions for the replacement of all plants found dead or failing during construction, there is no indication that trees are considered to be planted in the highway right-of-ways at the end of the construction period (BC MoTI 2016). This project seeks to model the current carbon storage and sequestration level and the carbon storage and sequestration potential for increased tree density along 20 km portion of the Trans-Canada Highway in Chilliwack British Columbia and develop recommendations for revegetation plans to increase carbon sequestration along this vehicle corridor. Vegetation and soil will be characterized to create a model of the carbon storage and sequestration of the study area. This information will then be used to determine highway right-of-way management practices to increase carbon storage and sequestration.

## Objectives

The effects of climate change are increasing exponentially effecting areas such as the Lower Mainland more acutely (Climate Action Initiative 2015). The chance to increase carbon sequestration and storage in Chilliwack along the Trans-Canada Highway is a simple step forward in BC's and Canada's goal to decrease carbon emissions as well as plant more trees to fulfill the 2 million trees planted goal (Canada 2019). The data collected from the right-of-ways in Chilliwack was entered into i-Tree Eco and used to determine the vegetation structure, function, and the carbon sequestration and storage value of the peri-urban forest in Chilliwack, British Columbia. This work will be presented in two sections: The Ecological Function and Social Function of the urban forest along the Trans-Canada Highway in Chilliwack, BC. There is some interplay between each section therefore each section will sometimes refer to similar subjects.

Ecological Function

1) I characterized the study area and determined the current vegetative and soil conditions and quantified the woody and non-woody vegetation to determine percent cover.
2) I modelled the carbon sequestration and storage in the study area in Chilliwack.

Social Function

3) I conducted a literature review to determine current right-of-way management practices.
4) I identify native plants that would be best adapted to the areas in the right-of-ways.

# Methods

## Study Area

The study site is located along a 20 km stretch of the Trans-Canada highway in Chilliwack, British Columbia (Figures 1 and 2). The Chilliwack North Polygon (CNP) and the Chilliwack South Polygon (CSP) total 102.6 $ha^2$, with the CNP being 35.7 $ha^2$ and the CSP being 66.8 $ha^2$. The widths of these polygons vary from less than 10 m wide to more than 60 m due to variability of the landscape and municipal/private land borders. This area was chosen as there is a high vegetative contrast between the Ministry of Transportation and Infrastructure (MoTI) owned right-of-ways (typically grass covered) and the adjacent private and municipal properties (various vegetative covers) (Figure 3). During this study, the carbon sequestration potential of the vegetation along the Trans-Canada Highway was estimated within these right-of-ways.

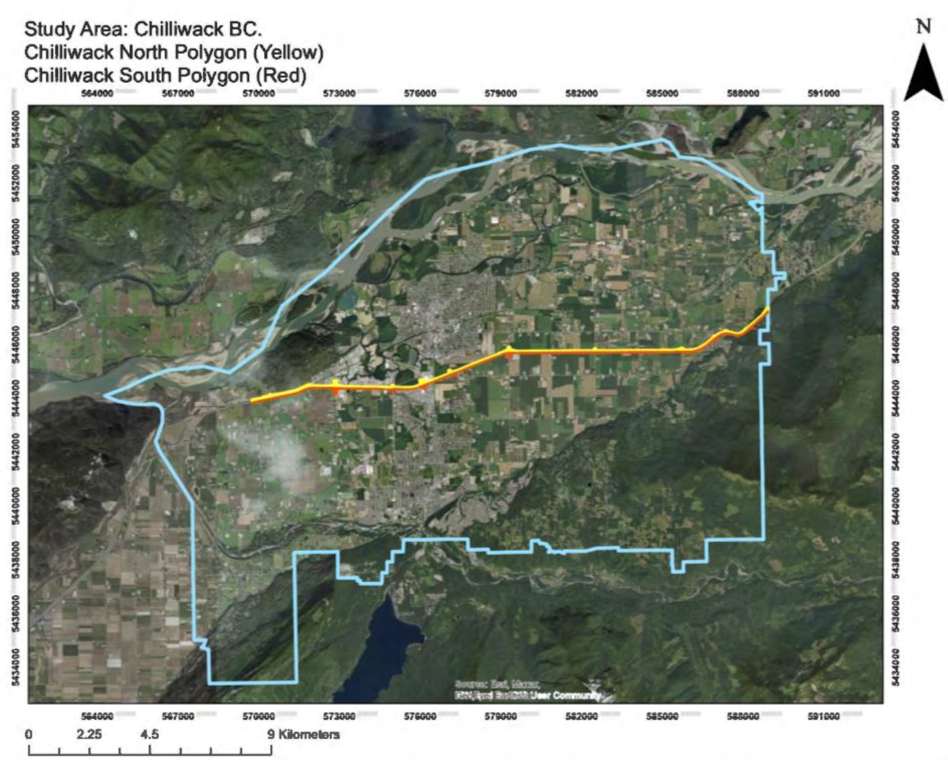


Figure 1. Chilliwack study area outlined in blue with the Chilliwack North Polygon outlined in yellow and the Chilliwack South Polygon outline in red. The polygons appear as lines but are the outlined areas of the right-of-ways.

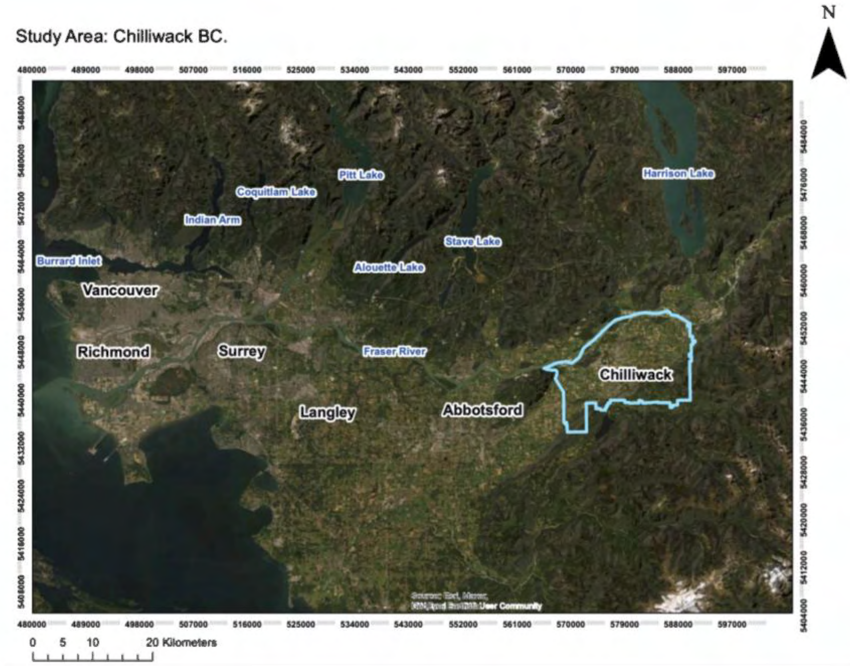


Figure 2. Chilliwack, outlined in blue, is the municipality where the study area resides, situated within the lower mainland of British Columbia, east of Abbotsford.

Figure 3. An example of a site on MoTI land covered in grasses shaded in yellow, adjacent to a private property with trees shaded in blue.

During highway construction, the revegetation mixes that are applied along BC highway right-of-ways are made up of standard grass seed mixes (BC MoTI 2016). The seed mix, known as the Vancouver Island Mix, that would have been used in the right-of-ways after constructing the highway consists of perennial Ryegrass (*Lolium perenne L.*), Creeping Red Fescue (*Festuca rebra ssp. Rubra*), Alsike Clover (*Trifolium hybridum L.*), Hard Fescue (*Festuca trachyphylla (Hack.) Kraj*), Common Timothy (*Phleum pretense L.*), White Clover (*Trifolium repens L.*), Canada Bluegrass (*Poa compressa L.*), and Redtop (*Agrostis gigantea Roth*) (BC MoTI 2019). Typically, the grass seed mix along with fertilizer (18-18-18; $N$-$P_2O_5$-$K_2O$, percent by weight) and mulch, is applied to newly excavated or filled slopes by hydroseeding to prevent soil erosion, runoff, and invasive plant establishment (BC MoTI 2019). While there are instructions for the replacement of all plants found dead or failing during construction, there is no indication that trees are considered to be planted in the highway right-of-ways at the end of the construction period (BC MoTI 2016).

The total study area was gridded out using ArcMap with each grid being 20 by 20 m for tree sampling for a total of two polygons representing the North side (CNP) of the highway and the South side (CSP) of the highway (Figure 1). There were 14 total sites selected within these polygons, seven in the CNP and seven in the CSP, in proximity to randomly selected locations using a random number generator for ground truthing and direct tree measurements (Figure 4). A random number generator was used to choose sites randomly within each polygon (Taherdoost 2016). However, whenever the randomly selected site proved to be in a dangerous location (e.g. no access or steep grade) the location was changed to its nearest neighbor plot with safe access. If two sites were randomly selected too close together, for example within 40 m of each other, one of the sites was moved in order to have all the sites better represent the district as a whole. All of the sites that were randomly selected had to be altered in some way to achieve accessibility, safety, and representation of tree, shrub, and grass species.

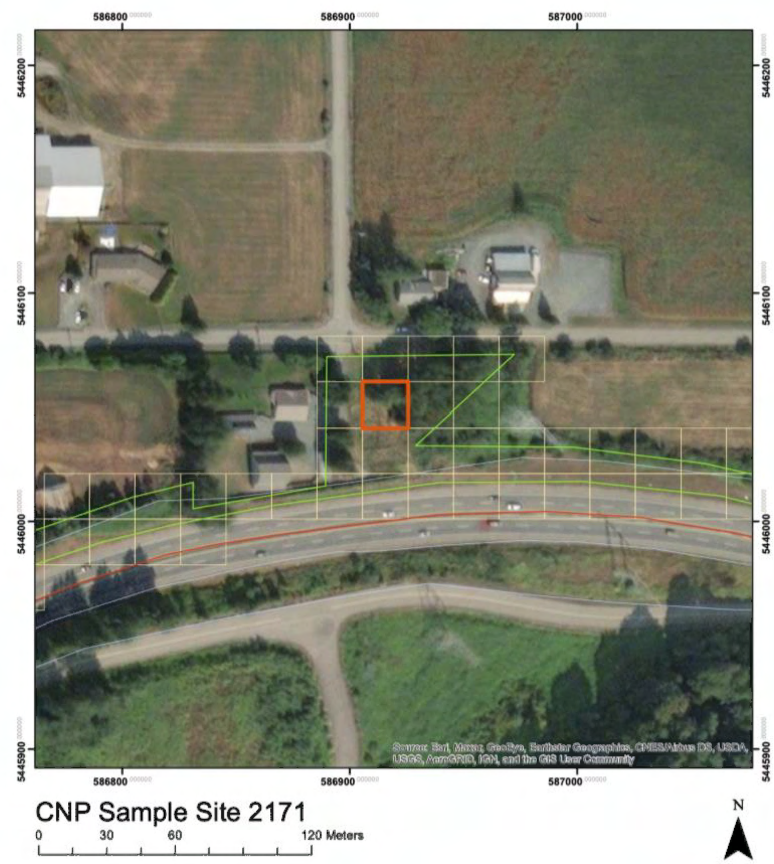


Figure 4. An example of a site selected showing the grid applied and border surrounding the MoTI owned land in the Chilliwack North Polygon (CNP) in BC.

## Modeling

The software program i-Tree Eco v6.0 (n.d.) was used to determine current carbon sequestration. The program i-Tree Eco used the tree measurements, such as tree height and diameter at breast height (DBH), and other data, such as land cover type, determined in the field to estimate ecosystem services and structural characteristics of the study area. This information was processed along with location specific hourly weather and air pollution concentration data, which was used to assess forest structure, health, threats, and ecosystem services and values for a tree population by i-Tree Eco v6.0 (n.d.). The model was used to estimate total carbon stored and net carbon annually sequestered in the Chilliwack area.

### Data Collection

Fieldwork for this study occurred in September and November of 2020 in the Chilliwack area. Tree and shrub surveys were conducted in the 14 sites in the Chilliwack area, in 20 by 20 m quadrats that were determined using grids in ArcMap. Tree and shrub percent cover was determined in the field and identified to species when possible or to genus if not. These percentages do not add up to 100% as each ground cover variable was measured within the space with respect to their plant layer and their total cover in each sample plot. Plant species or genus, tree diameter at breast height (DBH) and height, along with percent cover, was used to both characterize the study site and was entered into the i-Tree Eco software program to determine carbon storage and sequestration of the study site.

In each of the 14 sites selected, a 1 by 1 m quadrat was placed in an area most representative of the quadrant as a whole for soil and herbaceous vegetation sampling (i.e. a homogenous area that represents the majority of the vegetation in the plot). Grasses were identified on site to genus or species whenever possible, and their percent cover measured. Soil samples were also taken within the 1 by 1 m quadrat within the first 15 cm of the ground surface. The samples taken are anthroposols, which are soils that have been modified by humans where one or more natural soil horizons have been removed, replaced, added to, or modified in some way (Naeth et al. 2012). Therefore, sampling occurred within the first 15 cm to capture the conditions in the root zone for plant growth.  The soil samples taken were jar hand textured to assist with determining vegetation best suited to the study area (Oregon State University 2018).

### Highway Management Practices Review

The review consists of going over current management strategies and guidelines conducted by the Ministry of Transportation and Infrastructure such as the Design Build Standard Specifications for Highway Construction by the BC Ministry for Transpiration and Infrastructure (2018). Novel ideas outlined in peer-reviewed and other published sources about how to manage vegetation and increase carbon sequestration were reviewed along with identifying vegetation that will increase carbon sequestration that are best suited to the region. A vegetation selection framework was created to maximize carbon sequestration in the right-of-ways of the Trans-Canada highway within the Chilliwack area.

# Results

## Ecological Function: Site Characteristics

***Vegetation***

In terms of structure, there was a total of 3903 trees estimated to be within both the CNP and CSP stratum adding up to 11% total tree coverage. Shrubs covered the majority of both stratums (48.7%). Bare ground covered 44.3% and grasses covered 41.1% in both strata. Overall, 42.8% constituted plantable space in both strata with only 11% covered by trees (Table 1).

Within both woody stratums, Red Alders (*Alnus rubra*) comprised 51.6% of the trees identified, with Western Hemlock (*Tsuga heterophylla*) and Big Leaf Maple (*Acer macrophyllum*) both comprising 18.1%. Himalayan blackberry (*Rubrus discolour*) made up the majority of the shrub population in both stratums at 62.5% in the CNP and 17% in the CSP. The coverage over both strata for Himalayan blackberry is 39.75%. The only other invasive plant recorded within the study area was English Holly (*Iiles aquifolium*) covering 0.33% total. The species to cover the next largest percent in the study area is Western Serviceberry (*Amelanchier* alnifolia) with 0.833 %. Grasses were visually identified to those that were expected to be in these locations as those that part of the Vancouver Island/Coastal Grass Mix applied to the right of ways during highway construction. Soil samples were collected from each site. These samples were hand and jar textured and determined to be of sandy-loam consistency across all sample sites (Table 2)

Of the two strata, the CNP encompassed the majority of trees (16%) and shrubs (61.1%), while the CSP had a greater percentage of space available for planting (70.7%). Out of the total estimate number of trees, the CNP was estimated to have 3777 trees while the CSP had 126. All trees identified in the CSP were Red Alder (*Alnus rubra*) whereas five tree species were identified in the CNP. The most numerous tree species in the CNP was Red Alder (*Alnus rubra*) with an estimation of 1888 trees, followed by Big Leaf Maple (*Acer macrophyllum*) and Western Hemlock (*Tsuga heterophylla*), both estimated at 708 trees, and finally Paper birch (*Betula papyrifera*) and Black Cottonwood (*Populus trichocarpa*), both estimated to have 236 trees. The CNP had a tree density of 56.6 trees/ha while the CSP had a tree density of 3.5 trees/ha (Table 3).

Table 1. Percent cover within each stratum and of the whole study area.

| *Stratum* | *Tree* | | *Shrub* | | *Herbs* | | *Grass* | | *Water* | | *Rock* | | *Bare Soil* | | *Plantable Space* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | SE | % | SE | % | SE | % | SE | % | SE | % | SE | % | SE | % | SE |
| CNP | 16.0 | 10.7 | 61.1 | 14.4 | 14.3 | 10.2 | 25.7 | 16.6 | 4.3 | 4.0 | 1.4 | 1.3 | 54.3 | 14.1 | 27.9 | 14.4 |
| CSP | 1.6 | 1.1 | 25.6 | 14.4 | 0.7 | 0.7 | 73.9 | 30.6 | 3.6 | 1.7 | 0.0 | 0.0 | 25.7 | 14.7 | 70.7 | 14.5 |
| Study Area | 11.0 | 7.0 | 48.7 | 10.6 | 9.6 | 6.7 | 41.1 | 15.4 | 4.0 | 2.6 | 0.9 | 0.9 | 44.3 | 10.5 | 42.8 | 10.7 |

Table 2. Shrub species cover percentage per stratum and of the whole study area.

| *Stratum* | *Species* | *Cover (%)* | *SE* |
|---|---|---|---|
| CNP | *Rubrus discolor* | 62.5 | 18.428 |
| | *Rubus parviflorus* | 1 | 1 |
| | *Iiles aquifolium* | 0.67 | 0.667 |
| | *Amelanchier alnifolia* | 1.667 | 1 |
| CSP | *Rubrus discolor* | 17 | 12.741 |
| Study Area | *Rubrus discolor* | 39.75 | 12.693 |
| | *Rubus parviflorus* | 0.5 | 0.5 |
| | *Iiles aquifolium* | 0.33 | 0.333 |
| | *Amelanchier alnifolia* | 0.833 | 1 |

Table 3. Estimated tree number, leaf area, leaf biomass, tree dry weight, and average condition of each tree species identified in each stratum and the whole study area.

| *Stratum* | *Species* | *Trees* | | *Leaf Area* | | *Leaf Biomass* | | *Tree Dry Weight Biomass* | | *Average Condition* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | # | SE | (ha) | SE | (t) | SE | (t) | SE | % |
| CNP | *Acer macrophyllum* | 708 | 333 | 36.1 | 23.3 | 20.3 | 13.1 | 7,080.2 | 4,528.8 | 75.5 |
| | *Alnus rubra* | 1,888 | 1,413 | 57.9 | 41.7 | 42.2 | 30.4 | 2,202.6 | 2,143.5 | 87.0 |
| | *Betula papyrifera* | 236 | 236 | 0.1 | 0.1 | 0.0 | 0.0 | 39.3 | 39.2 | 37.5 |
| | *Populus trichophylla* | 236 | 236 | 3.7 | 3.6 | 2.6 | 2.6 | 3,540.7 | 3,533.2 | 62.5 |
| | *Tsuga heterophylla* | 708 | 490 | 23.2 | 15.0 | 12.8 | 8.2 | 2,307.2 | 2,208.4 | 83.8 |
| | Total | 3,777 | 1,638 | 121.1 | 63.0 | 78.1 | 41.6 | 15,170.1 | 9,967.9 | 79.6 |
| CSP | *Alnus Rubra* | 126 | 126 | 11.51 | 11.5 | 8.4 | 8.4 | 211.3 | 210.4 | 94.5 |

### *Temperature and Precipitation*

Temperature data was analyzed using ANOVA and then a Tukey's HSD post-hoc analysis from Environment Canada from the weather station AGASSIZ CDA (Climate ID 1100120) from 2015 to 2018 to see if there was any difference in temperature over this four-year period. Data from 2019 and 2020 was not used as there was too much missing information. From 2015 to 2018, average yearly temperatures ranged between 11ºC and 13ºC, with the lowest yearly average being in 2017 with an average of 11.32ºC. The year with the highest average was 2018 with 13.06ºC (Table 4). A significant difference between yearly temperatures was found between 4 different pairings of years. 2017 was significantly cooler than 2015, 2016 and 2018 while 2016 was significantly cooler than 2018. There was no significant difference between 2015 and 2016 as well as between 2015 and 2018 (Table 5).

Table 4. An ANOVA of temperature data from Environment and Climate Change Canada for years 2015 to 2018.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 2015 | 345 | 4,437.2 | 12.8 | 39.4 |
| 2016 | 324 | 3,984.2 | 12.2 | 36.4 |
| 2017 | 307 | 3,476.2 | 11.3 | 45.1 |
| 2018 | 224 | 2,926.6 | 13.1 | 48.7 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 529.4 | 3 | 176.4 | 4.22 | 0.005 | 2.61 |
| Within Groups | 50019.7 | 1,196 | 41.8 | | | |
| Total | 5,0549.1 | 1,199 | | | | |

Table 5. A post-hoc Tukey HSD analysis of the temperature data from Environment and Climate Change Canada for years 2015 to 2018

| *Pooled Variance* | *Q value* | *k* | *n* | *df* |
|---|---|---|---|---|
| 42.4 | 3.64 | 4 | 10,956 | 1,091 |

| *Comparison* | *Abs. Mean Diff* | *Q crit* | *Significant?* |
|---|---|---|---|
| 2015 v. 2016 | 0.56 | 0.71 | No |
| 2016 v. 2017 | 0.97 | 0.71 | Yes |
| 2017 v. 2018 | 1.74 | 0.71 | Yes |
| 2015 v. 2018 | 0.20 | 0.71 | No |
| 2016 v. 2018 | 0.76 | 0.71 | Yes |
| 2015 v. 2017 | 1.53 | 0.71 | Yes |

Precipitation data was also analyzed using ANOVA from Environment Canada from 2015 to 2018. Data from 2019 and 2020 was also not used due to missing information. From 2015 to 2018, the average precipitation amount ranged from 4.5 mm in 2016 to 5.5 mm in 2018. There was no significant difference in precipitation amount between years (Table 6).

Table 6. An ANOVA of precipitation data from Environment and Climate Change Canada for years 2015 to 2018.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| 2015 | 358 | 1,720.5 | 4.8 | 90.9 |
| 2016 | 353 | 1,604.9 | 4.5 | 61.2 |
| 2017 | 336 | 1,594.9 | 4.7 | 90.3 |
| 2018 | 337 | 1,858.9 | 5.5 | 88.9 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 183.1 | 3 | 61.0 | 0.74 | 0.529 | 2.61 |
| Within Groups | 11,4192.8 | 1,380 | 82.7 | | | |
| Total | 11,4375.8 | 1,383 | | | | |

## Ecological Function: Carbon Sequestration and Storage

### *Carbon Sequestration (Leaf Biomass)*

The annual carbon sequestration of trees by stratum was determined by tree measurement data collected in September 2020 in i-Tree Eco. The Chilliwack North Polygon (CNP) had a gross carbon sequestration density of 670.19 kg $y^{-1}$ $ha^{-1}$ while the Chilliwack South Polygon had a gross carbon sequestration density of 53.82 kg $y^{-1}$ $ha^{-1}$. The CNP had a net carbon sequestration density of - 739.81 kg $y^{-1}$ $ha^{-1}$ while the CSP had 42.61 kg $y^{-1}$ $ha^{-1}$ (Table 7). The total leaf biomass for CNP was 4,715.8 kg/ha while the CSP had 1645.7 kg/ha. The majority of the leaf biomass in the CNP was made up of Himalayan Blackberry (*Rubus discolor*) with 3307.3 kg/ha, followed by Red Alder (*Alnus rubra*) with 701.4 kg/ha and Bigleaf Maple (*Acer macrophyllum*) with 321.1 kg/ha. The majority of the leaf biomass in the CSP was also made up of Himalayan Blackberry (*Rubus discolor*) with 1,409.5 kg/ha while the only other plant species recorded in the area was Red Alder (*Alnus rubra*) with 236.2 (Table 8).

Table 7. Gross v. Net Carbon Sequestration for each stratum and for the whole study area.

| *Stratum* | *Gross Carbon Sequestration Density* kg $y^{-1}$ $ha^{-1}$ | *Gross $CO^2$ Equivalent* kg $y^{-1}$ $ha^{-1}$ | *Net Carbon Sequestration* kg $y^{-1}$ $ha^{-1}$ | *Net $CO_2$ Equivalent* kg $y^{-1}$ $ha^{-1}$ |
|---|---|---|---|---|
| CNP | 670.19 | 2457.6 | -739.81 | -2,712.89 |
| CSP | 53.82 | 197.35 | 42.61 | 156.25 |
| Study Area | 455.43 | 1,670.05 | -467.19 | -1,713.18 |

Table 8. Leaf area and biomass density and total for the tree and shrub species in each polygon and the whole study area. N = 14.

| | | *Density* | | | | *Total* | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Stratum* | *Species* | *Leaf Area ($m^2$/ha)* | *SE* | *Leaf Biomass (kg/ha)* | *SE* | *Leaf Area (ha)* | *SE* | *Leaf Biomass (t)* | *SE* |
| CNP | *Acer macrophyllum* | 5,704.5 | 3668 | 321.1 | 206.5 | 38.1 | 24.5 | 21.5 | 13.8 |
| | *Alnus rubra* | 9,620.8 | 6,535.3 | 701.4 | 476.5 | 64.3 | 43.7 | 46.9 | 31.9 |
| | *Amelanchier alnifolia* | 773.6 | 615.3 | 77.4 | 61.5 | 5.2 | 4.1 | 5.2 | 4.1 |
| | *Betula papyrifera* | 7.9 | 7.9 | 0.6 | 0.6 | 0.1 | 0.1 | 0 | 0 |
| | *Ilex aquifolium* | 22.5 | 22.4 | 3 | 3 | 0.2 | 0.2 | 0.2 | 0.2 |
| | *Populus trichocarpa* | 554.1 | 553 | 40 | 39.9 | 3.7 | 3.7 | 2.7 | 2.7 |
| | *Rubus discolor* | 88,631.8 | 31,737.2 | 3,307.3 | 1,184.3 | 592.7 | 212.2 | 221.2 | 79.2 |
| | *Rubus parviflorus* | 144 | 143.7 | 5.4 | 5.4 | 1 | 1 | 0.4 | 0.4 |
| | *Rubus spectabilis* | 1,818.1 | 1,814.2 | 67.8 | 67.7 | 12.2 | 12.1 | 4.5 | 4.5 |
| | *Tsuga heterophylla* | 3,472.3 | 2,245.1 | 191.8 | 124 | 23.2 | 15 | 12.8 | 8.3 |
| | Total | 110,749.7 | 37,859 | 4,715.8 | 1,648.8 | 740.6 | 253.2 | 315.3 | 110.3 |
| CSP | *Alnus rubra* | 3,239.2 | 3,226.4 | 236.2 | 235.2 | 11.6 | 11.5 | 8.4 | 8.4 |
| | *Rubus discolor* | 37,,774.5 | 24,459.7 | 1,409.5 | 912.7 | 135.1 | 87.5 | 50.4 | 32.6 |
| | Total | 41013.7 | 25,448.1 | 1,645.7 | 997.1 | 146.7 | 91 | 58.9 | 35.7 |
| Study Area | | 86,451.2 | 26,212.8 | 3646 | 1,129.1 | 887.2 | 269 | 374.2 | 115.9 |

### *Carbon Storage (Woody Biomass)*

The carbon storage of trees by polygon per unit area was determined using tree measurement data in September 2020 in i-Tree Eco. The CNP had a total carbon storage of 113,429.7 kg/ha while the CSP had 2,954.9 kg/ha. Both areas combined totaled 74,936.3 kg/ha (Table 10). In the whole of the study area, Bigleaf Maple (*Acer macrophyllum*) had the most carbon storage with 3540.1 t, followed by Black Cottonwood (*Populus trichocarpa*) with 1,770.4 t and Red Alder (*Alnus rubra*) with 1,207.0 t. In the CNP, the tree with the most storage capacity was a Bigleaf Maple (*Acer macrophyllum*) with a woody biomass of 16.97 $m^3$ (Table 9). However, Red alders (*Alnus rubra*) made up the majority of the tree species with 6 individuals measured and all together had a woody biomass of 32.14 $m^3$. In total, the CNP had a woody biomass of 49.16 $m^3$ while the CSP had a woody biomass of 5.75 $m^3$. The study area had a woody biomass of 54.92 $m^3$. The tallest tree measured was a Red Alder at 15.58 m (Table 11).

Table 9. Carbon Storage of Trees by Species in the study area, Chilliwack B.C.

| *Species* | *Carbon Storage (t)* | *Carbon Storage (%)* | *CO2 Equivalent (t)* |
|---|---|---|---|
| *Acer macrophyllum* | 3,540.1 | 46 | 12,981.6 |
| *Alnus rubra* | 1,207.0 | 15.7 | 4,426 |
| *Betula papyrifera* | 19.7 | 0.3 | 72.1 |
| *Populus trichocarpa* | 1,770.4 | 23 | 6,491.9 |
| *Tsuga heterophylla* | 1,153.6 | 15 | 4,230.3 |
| Total | 7,690.7 | 100 | 28,201.8 |

Table 10. Carbon Storage of Trees by polygon in the study area, Chilliwack B.C.

| *Stratum* | *Carbon Storage (kg/ha)* | *CO2 Equivalent (kg/ha)* |
|---|---|---|
| CNP | 113,429.7 | 415,946.9 |
| CSP | 2,954.9 | 10,835.6 |
| Study Area | 74,936.3 | 274,791.5 |

Table 11. Diameter at Breast Height (DBH), tree height, basal area, and woody biomass of each tree in each stratum and the whole study area. Woody biomass was determine using the equation $v = 0.42 \times g \times h$, where $v$ is the woody biomass, $g$ is the basal area, $h$ is the tree height, and the constant 0.42 is used as an approximation of tree shape determined by Kershaw et al. (2008). Used to determine carbon storage equivalent (woody biomass).

| *Stratum* | *Species* | *DBH (cm)* | *Tree Height (m)* | *Basal Area ($m^2$)* | *Woody Biomass ($m^3$)* |
|---|---|---|---|---|---|
| *CNP* | *Alnus rubra* | 81.5 | 9.54 | 0.52 | 2.09 |
| | *Alnus rubra* | 155.5 | 14.09 | 1.89 | 11.24 |
| | *Alnus rubra* | 126.5 | 15.55 | 1.25 | 8.20 |
| | *Alnus rubra* | 98.5 | 15.56 | 0.76 | 4.97 |
| | *Alnus rubra* | 73.5 | 15.57 | 0.42 | 2.77 |
| | *Alnus rubra* | 74.5 | 15.58 | 0.43 | 2.85 |
| | *Acer macrophyllum* | 187.5 | 14.63 | 2.76 | 16.96 |
| | *Betula papyrifera* | 20.32 | 4.00 | 0.03 | 0.05 |
| | *Acer macrophyllum* | 20.32 | 4.00 | 0.03 | 0.05 |
| | *Tsuga heterophylla* | 45 | 4.94 | 0.15 | 0.33 |
| | *Populus trichocarpa* | 242.5 | 16.80 | 4.61 | 32.60 |
| | *Acer macrophyllum* | 142.5 | 15.13 | 1.59 | 10.13 |
| | *Tsuga heterophylla* | 282.5 | 11.05 | 6.26 | 29.09 |
| | | | | Total | 121.38 |
| *CSP* | *Alnus rubra* | 124.5 | 11.26 | 1.22 | 5.76 |
| | | | | Total | 5.76 |
| *Study Area* | | | | Total | 127.15 |

## Social Function: Highway Management Practices

The Trans-Canada Highway is a trans-continental federal-provincial highway system: the federal government oversees the maintenance of the portions of the highway that run through national parks while the provincial governments are responsible for the rest (Blog of Lists 2012). In the 2018 Design Building Standards for Highway Construction (BC MoTI 2018), section 754 specifically refers to the work that is necessary for the supply and planting of trees, shrubs, and ground covers, including seeded and sodded areas. This section specifically references the Canadian Nursery Stock Standard 9th edition, the BC Weed Control Act and Regulations (2011), the Canada Seeds Act, and the British Columbia Standard for Turfgrass Sod (1999). All planting material and quality control is managed by the contractor of the project who notifies the ministry representative of the sources of plant materials for the project two weeks prior to commencing work. This indicates there are clear protocols and responsibilities that must be adhered to. Subsection 754.71 refers to the maintenance of the planted vegetation from installation to construction completion date. This section specifies - among specifications determined by the project contractor - water application, implementation of the Integrated Pest Management Plan, mowing, insect and disease control, pruning and maintenance of trees. This section highlights both requirements to maintain plant health and aesthetic appeal of landscaped areas.

Section 757 refers to the work done for the application of seed, fertilizer, mulch, tackifier, and other materials used for revegetating disturbed areas not covered by section 754. This section references the Canada Seeds Act and Regulations. The grass seed mix designated for along the Trans-Canada Highway in Chilliwack BC is the Vancouver Island/Coast Mix, which is comprised of Perennial Ryegrass, Creeping Red Fescue, Alsike Clover, Hard Fescue, White Clover, Timothy, Canada Bluegrass, and Redtop. The fertilization ratio is 16-32-6 unless otherwise stated.

The B.C. Ministry of Transportation Maintenance Specification Chapter on Roadside Vegetation Control (4-350) ensures the visibility surrounding highways remains unobstructed for the road user, control noxious weeds, facilitate adequate drainage, and reduce potential fire hazards. The project contractor must remove vegetation that causes Sight Distance obstructions on curves or intersections of Highways and at accesses, as well as at Railway Crossings or Railway Crossing Approaches. Signs must be visible along with delineators, animal reflectors and other Roadside features for Highway Users as well as remove noxious weeds or any vegetation that impedes drainage. The distance from the shoulder in which vegetation must be controlled is dependent on the Summer Highway Classification ranging from medians and interchanges with vegetation control from 1.5 m to 15 m from the shoulder to Class 7 highways with vegetation control from 0 m to 1.8 m from the shoulder. The Trans-Canada Highway is classified as a Class 1 Highway averaging greater than 10,000 vehicles per day traveling through Chilliwack BC (10 Year Annual Summary Traffic Data 2020 – Vedder Rd). The vegetation along this portion of the Trans-Canada Highway must be maintained from 0 to 7 meters from the shoulder and must be kept within 0.5 m to 3 m in height. Management practices can greatly affect the productivity and function of plants (USDA 2012). Understanding what is currently done will help determine approaches better suited too carbon sequestration and storage along the Trans-Canada Highway. This information was used to inform the type of planting approach that could be adopted.

# Discussion

## Ecological Function: Site Characteristics

### *Vegetation*

Due to the number of individual trees, Red Alders (*Alnus rubra*) was the most populous tree in the CNP, and the only tree surveyed in the CSP. Red Alders range in distribution across the Pacific Northwest from California to southeast Alaska (Cortini et al. 2012). These trees prefer humid climate, preferring moist and well drained alluvial soils and low winter temperatures. A short growing season and lack of precipitation are the main variables limiting the range of Red Alders (Cortini et al. 2012). This species is usually found in areas that have experienced disturbances such as clearcutting or flooding. The presence of Red Alders along the Trans-Canada Highway in Chilliwack in the Study Area is not surprising. The majority of the Red Alder population are found in the CNP, which is not only due to the proximity of the Fraser River and the sandy-loam texture of the soils, but also due to agriculture activities that take place on the south side of the Trans-Canada Highway in the CSP, which have most likely been cleared for such activities.

The frequency at which Red Alders appear in the coastal regions of British Columbia is also predicted to increase as temperatures rise (Hamann and Wang, 2006). While this species enjoys a humid climate and is limited by lack of precipitation, increasing levels of $CO_2$ has been shown to also increase Red Alder productivity (Hibbs et al. 1995). The results presented previously concerning temperature indicate that temperatures are increasing while precipitation has remained relatively the same from 2015 to 2018. Climate projections for the Fraser Valley were generated from 2020 to 2050 and have indicated that the annual average will warm by 1ºC by 2020 and by 1.8ºC by 2050 while the growing degree-days have increased by 184 by 2020 (Climate Action Initiative 2015). Unless precipitation decreases significantly, it can be expected that Red Alders will remain in the Study Area until and beyond the 2050s (Cortini et al. 2012).

Bigleaf Maple (*Acer macrophyllum*) was the next most abundant tree found in the CNP. They are primarily found on the west coast of North America ranging from southern Alaska to San Diego, California. Their northern distribution is limited by cold climates while their southern limit is limited by drought (Fryer 2011). This species is found in similar habitats as Red Alders, preferring a mild climate and moist alluvial soils. However, they are less tolerant of poor drainage or long-term flooding events when compared to Red Alders (Green and Klinka 1994). Even so, Case and Lawler (2015) determined that out of 11 tree species in western North American, Bigleaf Maple was determined to be the least vulnerable to climate change. They indicated that this is largely due to its' adaptive capacity, ability to reproduce quickly after disturbances, and its seeds can disperse long distances.

As with the Red Alders in the study area, Bigleaf Maple has the potential to continue to thrive and expand their distribution in the area. However, proximity to paved roads and increasing temperatures may hamper their productivity. Betzen (2018) found that higher temperatures, vapour pressure deficits, decreased precipitation, high levels of anthropogenic activity, and proximity to paved roads were all positively associated with a decline in Bigleaf Maple. While both species have similar rapid juvenile growth rates, Red Alders are able to produce seeds by 6 years of age while Bigleaf Maples produce seeds by 10 years (DeBell and Giordano 1994, Niemiec et al. 1995). Even so, Red Alders seldom survive past 100 years while Bigleaf Maples have been known to reach 300 years of age (Niemiec et al. 1995).

Western hemlock (*Tsuga heterophylla*) had the same number of estimate trees in the CNP as Bigleaf Maple. This species thrives in humid environments on the west coast of the Pacific North West, where there is frequent precipitation and resides in well drained soils. Western hemlocks can live to be 400 years old with the oldest recorded being older than 700 years old (Packee 1990). Western hemlock is typically found with the other tree species listed in this study and can be found from southern Oregon into British Columbia (Anderson and Palik 2011). A tree vulnerability assessment was conducted by the USDA (Devine et al. 2012) which concluded that Western hemlock had a low vulnerability concerning climate change, however this was conducted in areas under active management by foresters removing dead and dying trees. This information was further backed up by DellaSala et al. (2015) who modelled the potential distribution of focal conifers considered to be important to land managers in order to predict potential future distributions of focal species given climate change. They found that western hemlock showed marked persistence in mostly northern portions of their range, growing by 55 – 82% in distribution by 2080. However, the southern British Columbia coastline was marked as an unstable area due to the expected expansion of Red Alders, Bigleaf Maples, and other temperate deciduous broadleaf tree species (DellaSala et al. 2015). Also, with the expected increases in temperature and decreased precipitation, there is potential for western hemlock looper (*Lambdina fiscellaria lugubrosa* Hulst) outbreaks to increase in the Study Area, limiting the expansion of western hemlock (McCloskey and Daniels 2009).

The Black Cottonwood (*Populous trichophylla*) population in the study area was estimated to be 236 individuals, same as the Paper Birch (*Betula papyrifera*). Black Cottonwoods are a large deciduous tree that are one of the tallest and fastest-growing hardwoods on the west coast. They are typically found along rivers and streams in the Pacific northwest from northern California to Kodiak Island in Alaska, across the southern half of British Columbia and as far east as the Rocky Mountains in Montana (Niemiec et al. 1995). These trees mature by 60 years old at the earliest and can live to at least 200 years old. Depending on the landscape, Black Cottonwoods crowns can develop into narrow, cylindrical shapes in forest stands while the crowns can develop larger branches along a single massive stem in more open areas (Niemiec et al. 1995). They are typically found in more open areas as they are a shade-intolerant species and are commonly found in areas associated with and dominate areas that are disturbed by floodwaters. Without disturbance, Black Cottonwoods are replaced with other species from upland sites (Niemiec et al. 1995). Black Cottonwoods can grow in climates that range from humid to arid, ranging further inland in humid locations while remaining close to riverbanks in arid locations.

This information indicates that Black Cottonwood is another typical species of the Study Area, residing in the CNP as that is the area closest to the Fraser River. With the predicted rising temperatures while precipitation remains the same, it would be appropriate to say that Black Cottonwood would remain a typical species to be found in the Study Area despite climate change (Climate Action Initiative 2015). Nitschke (et al. 2012) found that Black Cottonwood populations were modeled to decline in all sites within the Bulkley Valley in northwest British Columbia but will most likely be restricted exclusively to riparian areas with wet moisture regimes.

With the Fraser River being a large river dominated by a hydrological regime of snow accumulation and melting processes, receiving water from many tributaries, it is expected that climate change will lead to an intensification of water regime (increased storm activity leading to higher precipitation events), influencing freshwater quantity and quality by increasing turbidity (Climate Action Initiative 2015). Climate change has already have had an impact in the region (Stewart 2009). Barnett (et al. 2005) found changes in precipitation affected the maximum snow accumulation and runoff volume while temperature changes affected runoff timing. In the Fraser River Basin, warmer cold season temperatures are reducing snow accumulation while increasing the amount of precipitation occurring as rain. Warmer spring temperatures are increasing the rate which snow is melting, causing earlier runoff times, and reducing summer and fall river flows (Stewart 2009). This shift will result in higher winter and spring runoff rates which in turn will cause and increased risk of winter and spring floods (Stewart 2009). Knowing the interplay between temperature, precipitation, and the hydrological regime of the Fraser River, it can be inferred that there will be an increase in flooding events in the lower Fraser River causing disturbances along the riverbank close to the highway in these locations. This will create opportunities for more Black Cottonwoods to establish in the region, increasing their population in the area.

Paper Birch (*Batula papyrifera*) was estimated to have a similar number of individuals as Black Cottonwoods in the Study Area. Paper birch is widespread throughout British Columbia, usually mixed among conifers (Comeau et al. 1998). This tree is typically found on rolling upland terrain and floodplain sites but can grow in a variety of soils and can be found on open slopes, disturbed sites, swamps and in bogs (Parish 1948). Paper Birch are able to produce seeds as early as 15 years of age and matures around 70 years of age (Safford et al. 1990). Few trees live longer than 200 years. Paper Birch resides in cool temperate climate, appearing infrequently in warmer climates.  This fast-growing birch may contribute to increasing biodiversity, accelerate nutrient cycling and can increase conifer yield when mixed throughout and typical conifer stand (Comeau et al. 1998). Stands ranging from 1200-1600 stems/ha of paper birch seem to leave enough light passing through the canopy to allow other tree species to grow unaffected. Seeds or seedlings of Paper Birch are usually present soon after a disturbance – within 20 years – and dominates an area in various combinations of early seral conifers (Simard 1996). This species is particularly successful at forming a pure seral stand post fire disturbance due to its ability to sprout from buried advantageous buds and the ability of their seeds to disperse over long distances. The tree itself can also survive fire due to low foliar flammability (Simard 1996). As the early seral conifers start to die and the canopy opens again, the area will be late dominated by species such as western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*).

Paper Birch trees don't grow well in shade and therefore will die back as western redcedar and western hemlock start to take over (Parish 1948). As with sites associated with Black Cottonwoods, the Study Area can be expected to experience flooding disturbance events in general that will allow Paper Birch to establish quickly in the area following the disturbance (Climate Action Initiative 2015). That being said, with temperatures rising and with infrequent precipitation events, there may not be enough water in the area to allow large stands of Paper Birch to establish. The decline of Paper Birch has been documented throughout southern BC and appears to be caused by several factors, with changing environmental factors and insect-pathogen complexes being the main causes (Woods et al. 2010). With changing environmental facts expected to increase over time and thereby exacerbating insect-pathogen complexes, Paper Birch is expected to be pushed beyond its adaptive limits causing a large-scale dieback throughout its current range (Woods et al. 2010).

Himalayan blackberry (*Rubus discolor*) is the dominant shrub species present in the Study Area. While this species is seen by some as an accessible food source, Himalayan blackberry is more recently recognized as an invasive species (Metro Vancouver 2019). This shrub grows on a variety of soil types, most typically taking advantage of disturbed, barren, infertile soils with a wide range of soil pH and textures, although it prefers well drained soils. Himalayan blackberry can tolerate period flooding of either brackish or fresh water (Metro Vancouver 2019). This invasive plant is somewhat shade intolerant, surviving in varied light conditions, but can grow fast and become widespread in areas with lots of sun exposure. Therefore, Himalayan blackberry is typically found along stream edges and disturbed sites like transportation and utility corridors, parks, tails, backyards and abandoned properties (Metro Vancouver 2019).

Sensitive areas along streams and rivers such as riparian areas and freshwater wetlands typically are taken over by Himalayan blackberry, outcompeting native vegetation and increasing soil erosion. While some argue that the berries offer food and the shrub itself offers nesting habitat and wildlife cover, research has shown that the decreased plant biodiversity caused by Himalayan blackberry leads to a significant reduction in bird species richness and evenness (Bennett 2006). As for pollinators, though Himalayan blackberry flowers provide nectar and pollen, the bloom period does not cover the majority of pollinators' foraging times (Wray and Elle 2015). Currently, this species is one of the most widespread invasive plants according to Metro Vancouver (2019) and the Invasive Species Council of Metro Vancouver (ISCMV) in the south coast. The likelihood of increased flooding events along the Fraser River will most likely lead to an increase in infested areas along the river before, during, and after restoration if significant efforts are not put in to manage this species (Hays 2012). Currently, the management of Himalayan blackberry is dependent on the combination of mechanical and chemical control measures. According to a report published by the Institute for Applied Ecology (2013) the distribution for Himalayan blackberry is likely to increase by 2050, though it's range may shift. Taking this into account, it is highly likely that Himalayan blackberry will thrive and increase its cover over the Study Area if it is not managed. Noting the increased possibility of flooding disturbances clearing the areas along the river will only exacerbate the increase in distribution of this species along the Fraser River, decreasing diversity and productivity. While this may increase carbon sequestration, carbon storage will not change as Himalayan blackberry does not have any woody biomass to store carbon.

## Ecological Function: Carbon Sequestration and Storage

### *Carbon Sequestration (Leaf Biomass)*

Carbon sequestration refers to the processes in which carbon dioxide ($CO_2$) is either removed from the atmosphere or diverted from carbon sources and is then stored in the ocean, the land, or in geological formations (Crosby et al. 2010). For the purposes of this project, carbon sequestration is referred to the specific process in which $CO^2$ is absorbed from the atmosphere through photosynthesis, which would then be eventually stored in woody biomass (Crosby et al. 2012). As carbon sequestration is dependent on photosynthesis, the amount of leafy biomass in an area, and the specific area of a leaf, is directly related to the carbon sequestration capabilities of the vegetation in an area. The CNP had the greatest amount of gross carbon sequestration density of 670.19 kg $y^{-1}$ $ha^{-1}$ compared to the CSP with 53.82 kg $y^{-1}$ $ha^{-1}$. This is confirmed by the amount of tree and shrub species in each stratum where the CNP had more tree and shrub species compared to the CSP. However, this is not reflected in the net carbon sequestration values. The CNP had a net carbon sequestration amount of -739.81 kg $y^{-1}$ $ha^{-1}$ while the CSP had a net carbon sequestration amount of 42.61 kg $y^{-1}$ $ha^{-1}$. This indicates that the CNP is emitting more $CO_2$ than it is sequestering. According to Nowak et al. (2013), carbon sequestration becomes negative when a forest is declining or when carbon emission from dead trees exceeds the carbon uptake by live trees. While Red Alders are numerous in both areas, the minimum diameter at breast height (DBH) of all alders measured was greater than 73 cm. This indicates that all the Red Alders in the area have matured, and their growth has decreased (Niemiec et al. 1995). The western hemlocks and black cottonwoods seem to be in a similar situation, while bigleaf maples and paper birches have positive net carbon sequestration indicating they are continuing to grow (Nowak et al. 2013). One of the main factors limiting the physiological processes affecting tree growth and survival is water (Sands and Mulligan 1990).

Water transport in plants occurs along a negative pressure gradient through xylem (water transport cells). Water moves from the roots, up the xylem, and transpires out the stomata where $CO_2$ then enters (Koch et al. 2004). The water is able to travel up the xylem against gravity through adhesion to cell walls and surface tension. However, it was found that as a tree becomes taller, there is increasing leaf water stress due to gravity. Increasing the length for water to travel also increases resistance against the water. This ultimately limits leaf growth and photosynthesis (Koch et al. 2004). Trees also reduce stomatal conductance in leaves when there is reduced hydraulic input. In both situations, photosynthesis is reduced and therefore, carbon sequestration is reduced.

Knowing that the Red Alders as well as the Hemlocks and Black Cottonwoods in the area have reached their maturity based on their DBH, it can be assumed that these trees have reached maturity and are no longer growing. However, the tallest tree measured was a Red Alder at less than 16 m whereas Red Alders have been documented to grow up to 24 m tall (Parish 1948). This indicates that rather than being old, these trees are potentially water stressed. This could explain why there is a positive gross carbon sequestration amount but a negative net carbon sequestration amount. Considering temperatures are predicted to increase while precipitation doesn't change, more drought resistant species would be more successful and productive within the study area (Climate Action Initiative 2015). Since carbon sequestration is largely based on the photosynthetic capabilities within the leaves, the plant with the greatest amount of leaf area should have the highest carbon sequestration capabilities. Himalayan blackberry was found to cover more than 60% of the area within the CNP and was the only shrub found in the CSP covering 17% of that area. Overall, Himalayan blackberry covered almost 40% of the Study Area. The leaf area of Himalayan blackberry covers 80% of the CNP while covering 92% in the CSP. For i-Tree Eco (v6.0), DBH is necessary for calculating carbon sequestration, therefore information concerning Himalayan blackberry was not included in the estimation of carbon sequestration.

### *Carbon Storage (Woody Biomass)*

While carbon sequestration refers to the process in which carbon is removed from the atmosphere through photosynthesis, carbon storage refers to the amount of carbon that is contained in non-atmospheric stores such as plants, soils, and oceans. For this project, carbon sequestration refers to the process of storing carbon in forest biomass (Crosby et al. 2010). The majority of carbon stored in a forest resides in the woody biomass (roots, trucks, and branches). This store eventually ends up as organic matter on the forest floor and in soils (U.S. EPA, 2018). As the CNP has the most tree species, the CNP also has the most carbon storage of 113,429.7 kg/ha while the CSP only has about 2,954.9 kg/ha. As for tree species, Bigleaf maple accounts for almost half (46%) of the total carbon storage within the Study Area while only representing 18% of the estimate tree population. While Red Alders represent 48% of the estimate number of trees, they only account for 15.7% of the total carbon storage in the Study Area. Since i-Tree Eco (v6.0) needs DBH to determine carbon storage, only tree species were used in this estimation.

## Social Function: Highway Management Proposals

The 2018 Design Building Standards for Highway Construction seems detailed in the concern for plant health and longevity within construction sites as well as concern against the establishment of invasive plant species (BC MoTI 2018). As mentioned previously, there are many procedures and steps in place to make sure the vegetation planted in a disturbed area as well as the currently residing vegetation remain uncompromised. That being said, there is a difference in efforts for the establishment of grass species compared to tree and shrub species. The BC MoTI (2018) has gone to great lengths to establish a grass seed matrix for specific areas throughout BC indicating which seed mix would be best to apply along the highways in specific areas based on hydrological regime and hardiness zones. However, tree and shrub species are left up to the discretion of the project contractor to decide on for the particular area the project is occurring in, and therefore there is no decision chart or readily available list of species specific for establishment along highways (BC MoTI 2018). In this next section I will explore the possibility of creating a tree species list that takes into account local species ranges, their temperature and hydrological regimes, carbon sequestration and storage capabilities, and the potential for their ability to continue to thrive within the Study Area during the next few decades considering climate change.

BC MoTI (2018) has been using the Standard Grass Seed Mixes for Revegetation of British Columbia Highway Roadsides in order to determine the grass seed mix and fertilizer to be used in each provincial region. This matrix has also been expanded upon to include a generalized seed mix per region, as well as mixes intended for forestland and dryland areas, plus optional “other” mixes (BC MoTI 2018). It would be useful to develop a similar compendium of standard tree species for the BC MoTI that would include species following a selection framework that included climate change resiliency.

Metro Vancouver has a climate adaption framework for urban forest planting that uses a selection framework that may be adapted for use by BC MoTI in order to create such a compendium of tree species (Diamond Head Consulting Ltd. 2016a). The framework suggested by Diamond Head Consulting in figure 5 for selecting species that will be well-adapted to the current and future climate of Metro Vancouver has three steps prior to selecting a tree species:

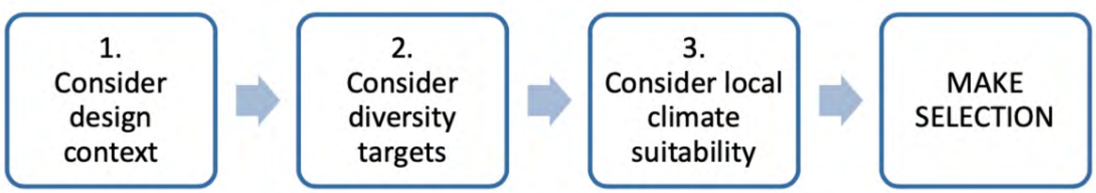


Figure 5. Urban Forest Climate Adaptation Framework for Metro Vancouver (Diamond Head Consulting Ltd. 2016a)

The design context refers to the site design of the project being conducted. Metro Vancouver also has a Design Guidebook that provides context for selecting appropriate species for particular project sites (Diamond Head Consulting Ltd. 2016b). Of the 12 project locations considered in the guidebook, Highways, Infrastructure Corridor, and Landscape Buffer are the three described projects that would be most similar to the construction projects conducted by the BC MoTI (Diamond Head Consulting Ltd. 2016b).

Diversity targets refers to a selection of multiple species that would represent a resilient tree stock to optimize desired ecosystem services (Diamond Head Consulting Ltd. 2016a). The majority of the diversity targets mentioned are population percentages, climate considerations, age class, seed and clonal stocks, and diversity spacing.

Climate suitability refers to ensuring that the trees selected are suitable for the present and future climate for the particular region the project is being conducted in. A climate suitability decision tree is used in order to help filter out suitable trees focusing on cold tolerance (US Department of Agriculture plant hardiness zones), heat tolerance (American Horticultural Society heat zones), and drought tolerance (fig. 6). The last filter assumes the areas of Metro Vancouver that currently experience low soil moisture will decrease further and intensify.

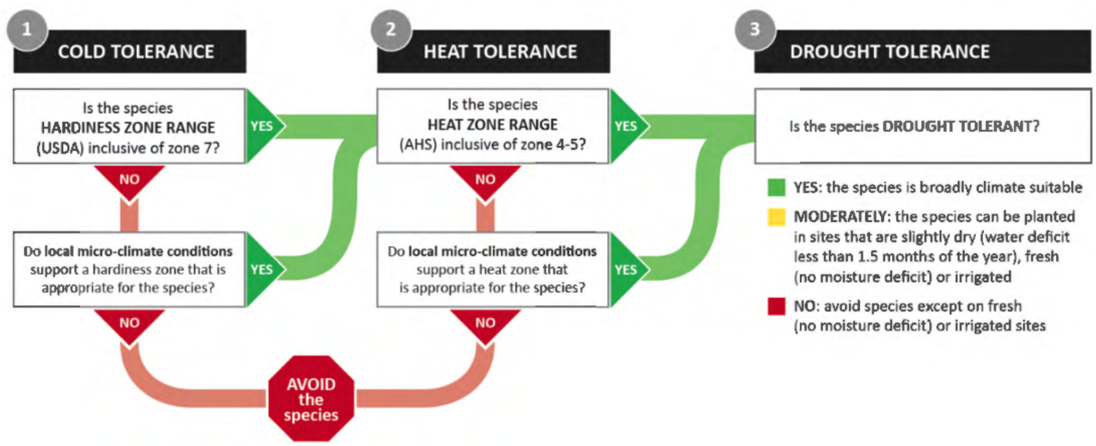


Figure 6. Climate suitability decision tree for Metro Vancouver (Diamond Head Consulting Ltd. 2016a)

Going through this process, Diamond Head Consulting Ltd. (2016a) has come up with 144 tree species that fit into either Broadly Suitable (acceptable for current and future climates), Slightly Dry Sites (suitable for sites except for the driest sites), or Fresh Sites (only suitable for sites that remain moist/sites suitable are expected to become restricted in the future)

To adapt this species selection framework for BC MoTI, I would suggest adding a fourth step before reaching a selection. This step would be added between steps two and three and would consist of carbon storage targets that would cover the amount of carbon emitted in the area (fig. 7). Tree species would them be selected to meet this target.

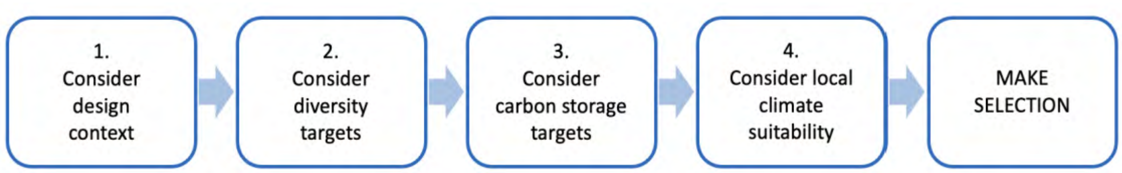


Figure 7. Modified Urban Forest Climate Adaptation Framework for Metro Vancouver (Diamond Head Consulting Ltd. 2016a)

Next, I would suggest adding an additional step in the climate suitability decision tree after determine drought tolerance that would include whether the project site in question will remain within the range of a supposed tree species considering the Representative Concentration Pathway (RCP) 8.5 climate modeling for years 2041 to 2070 (fig. 8).

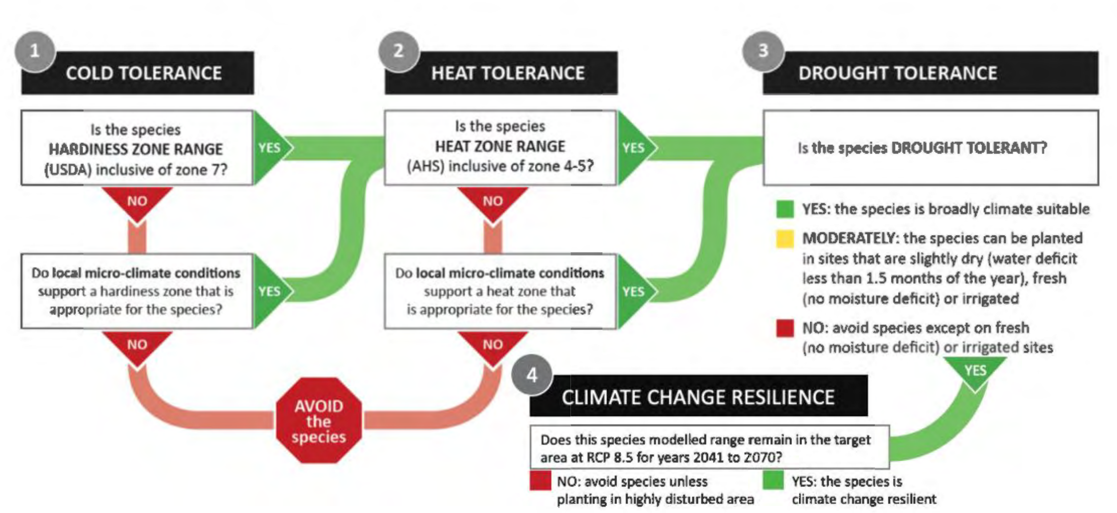


Figure 8. Modified Figure 6. Climate suitability decision tree for Metro Vancouver (Diamond Head Consulting Ltd. 2016a)

RCP 8.5 was chosen in order to plan for the worst-case climate change scenario, allowing the right-of-way landscapes to be more robust to climate change given a less severe RCP scenario. Natural Resources Canada has species climatic distributions based on future climate scenarios for multiple geneses and species that can visually show range changes from 2011 to 2100 (Natural Resources Canada 2021). With these additions, BC MoTI will be able to select tree species ideal for their project that includes carbon storage targets and will be resilient to climate change in the Trans-Canada Highway right-of-ways.

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