**INVASIVE PLANTS IN METRO VANCOUVER:**

**RELATIONSHIPS BETWEEN SPECIES OCCURRENCES AND SOCIO-ECONOMIC FACTORS, GREENSPACE TYPE, AND THE PUBLIC'S RISK PERCEPTION**

by

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## Abstract

Effective management of invasive plants preserves biodiversity values, reduces economic costs, and minimizes negative impacts on human well-being. Prevention, the most cost-effective approach to invasive plant management, focuses on predicting species occurrences in high-risk areas and fosters the public's awareness of invasive plants. This study aims to contribute to the aforementioned prevention foci by (1) investigating the relationships between invasive plants occurrences and socio-economic, greenspace, topographic, and land use variables, and (2) assessing the public's levels of knowledge, risk perception, and support for invasive plant management in Metro Vancouver, British Columbia, Canada.

I utilized invasive plants inventory, land use, topographic, and socio-economic data to identify key drivers of species occurrences. The chances of invasive plants occurrences were higher in wealthier neighbourhoods. The relationships between species occurrences and the tested explanatory variables were different across municipalities. Greenspace type was a surrogate for median household income, gardening expenses, and greenspace area. The results can inform managers of key drivers of invasive plants occurrences in Metro Vancouver, which can ultimately aid in species occurrence prediction efforts.

An online survey in Metro Vancouver assessed the public's levels of knowledge, risk perception, and support for management activities. I found that the public's perception of invasive plants was ecologically oriented and positively correlated with age and income. The public highly supported community events or the planting of native species. Overall, the public's risk perception assessment provides managers with insights on which aspects of invasive plants are well-known and which management activities are preferred by the public.

## Lay Summary

Invasive plant invasions reduce biodiversity values, can cause human health problems, and are costly to control. Prevention is the most cost-effective invasive plants management strategy. To develop successful prevention strategies, managers and planners need to understand why and where invasive plants occur and to gain public support for management activities. This study aims to provide an understanding of invasive plants occurrences and the public's levels of invasive plants knowledge and risk perception in Metro Vancouver, British Columbia, Canada. Wealthier neighbourhoods experienced higher likelihoods of invasive plants occurrences. The public knew more about ecological than economic and human health impacts of invasive plants. Older people and high-income groups tended to have higher risk perception. The study results can help managers identify (1) why and where invasive plants are more likely to occur, and (2) what information and activities will most effectively target the public based on existing knowledge and risk perception.

## Preface

Chapter 2 of this thesis was initiated by Dr. Bianca Eskelson. I designed the research methods with input from Drs. Bianca Eskelson and Woongsoon Jang. The inventory data of invasive plants was provided by six municipalities in the Metro Vancouver region, Canada. Other datasets used in this chapter were retrieved by me from the open data catalogues of the six municipalities, Statistics Canada, and SimplyAnalytics. I performed data cleaning and exploration, analyses, and writing of the manuscript under the supervision of Dr. Bianca Eskelson.

Chapter 3 of this thesis was initiated by me, with advice from Drs. Bianca Eskelson and Michael Meitner. I was responsible for the research methods including the survey design, data compilation, analyses, and writing of the manuscript. During the survey design process, Dr. Bianca Eskelson, Dr. Michael Meitner, and Tasha Murray provided comments and edits. The survey information was distributed with support from Dr. Bianca Eskelson, the Invasive Species Council of Metro Vancouver, and the cities of Burnaby and North Vancouver. This work was funded by an NSERC ENGAGE Grant in collaboration with Diamond Head Consulting Ltd. The study was approved by The University of British Columbia's Behavioural Research Ethics Board (certificate number: H18-03449).

The thesis is original, unpublished work of the author Nguyet Anh Nguyen. All figures, tables, and writing are my own work. Edits and feedback for the thesis were provided by Dr. Bianca Eskelson, Dr. Michael Meitner, Dr. Sarah Gergel, and Tasha Murray. Chapters 2 and 3 of the thesis will be submitted for peer-reviewed publication upon the approval of the thesis.

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## Dedication

To my beloved family.

*Dành tặng gia đình yêu dấu của con.*

In memory of my grandfather.

*Trong sự thương nhớ tới ông Nội của con.*

# Chapter 1: Introduction

Plant invasions have a wide range of impacts on ecological, economic, and social values worldwide (Charles and Dukes, 2008). One-sixth of the global land surface, approximately 17%, is highly vulnerable to plant invasions (Early et al., 2016). Plant invasions are usually caused by humans as they introduce non-native plant species from one region to another region for different purposes (Gallardo & Aldridge, 2013). If non-native species establish and result in negative impacts on ecosystems (e.g., compete for resources with native species) and human well-being, they are considered invasive plants (García-Llorente et al., 2008). In Canada, 1,229 vascular plant species are non-native, accounting for 24% of all vascular plants. 486 out of those 1,229 non-native vascular plants are invasive plants (Canadian Food Inspection Agency, 2005). British Columbia (BC) ranks third among provinces in Canada by the number of invasive plants (Canadian Food Inspection Agency, 2005).

Although invasive plants can provide some positive ecosystem services such as increasing aesthetic and recreational benefits (Foster and Sandberg, 2010; Morgenroth et al., 2016), invasive plants also result in biodiversity reduction (Wilcove et al., 1998; Mollot et al., 2017), reduced ecosystem resilience to disturbances (Kumagai et al., 2015), and ecosystem degradation (Pyšek et al., 2010). Negative effects of invasive plants on environmental quality (e.g., reduced water quality, unpleasant looking landscape) and human well-being (e.g., allergies) were recorded as well (Branco et al., 2015; Jones, 2017). In addition to ecological and social impacts, invasive plants have high economic costs to human society (Pimentel et al., 2005; Pejchar et al., 2009). Invasive species generate environmental and economic costs up to approximately $120 billion US dollars (USD) per year in the United State (Pimentel et al., 2005) and range from $13.3 to $34.5 billion Canadian dollars (CAD) per year in Canada (Colautti et al., 2006). In BC, the invasive plant management expenditures were estimated to be approximately $7 million CAD in 2006 (Frid et al., 2009).The concern about the aforementioned negative impacts of invasive plants becomes more and more urgent because of the increasing population densities in cities (Gaertner et al., 2016). In Metro Vancouver—the largest regional district in BC, Canada, by population and population density (Statistics Canada, 2016)—local governments pay substantial attention to management activities of invasive plants in order to ensure healthy ecosystems in the region (ISCBC, 2017).

There is no single optimal strategy to manage invasive plants effectively. To date, governments at federal, territorial, provincial, and municipal levels have been applying prevention, early detection, control, and monitoring programs in order to effectively minimize impacts of invasive plants (Wittenberg and Cock, 2001; ISCBC, 2017). Among those invasive plants management efforts, prevention is considered to be the most cost-effective management strategy for future impact reduction (Wittenberg and Cock, 2001; Gallardo and Aldridge, 2013; Canadian Food Inspection Agency, 2005). In BC, prevention efforts have been made by both government and non-government organizations via early detection (e.g., surveying and mapping of invasive plants) and public awareness programs (e.g., behaviour-change programs, best management practices) (ISCBC, 2017).

Early detection activities focus on the occurrences of invasive plants (Wittenberg and Cock, 2001). Successful early detection not only records the occurrences but also provides an understanding of how and why an invasive plant occurs with regards to both ecological (e.g., favourite habitats), and social aspects (e.g., socio-economic characteristics of the neighborhood) (Gallardo and Aldridge, 2013). In many cities, including municipalities of Metro Vancouver, early detection activities have been implemented for candidate species.

The inventory data from municipalities have been entered into databases, which are available at municipal as well as provincial levels in BC (i.e., Invasive Alien Plant Program—IAPP). These databases can be used to understand invasive plants occurrences in Metro Vancouver with regards to socio-economic, greenspace, topographic, and land use variables. As a result, we can identify key drivers of species occurrences, which can be used to build predictive models (Peterson et al., 2003). Predictive models can assist managers in the process of identifying which areas are of high risk for plant invasions in the future (Jiménez-Valverde, 2011).

Besides an understanding of what drives invasive plants occurrences, public awareness programs are also an important part of prevention strategies, because they contribute to raising the public's awareness of invasive plants (Wittenberg and Cock, 2001). The public's knowledge and experience shape the way they perceive the risks of invasive plants (Hart and Larson, 2014). The public's perception has effects on their levels of willingness to support management programs (Shackleton and Shackleton, 2016). Therefore, understanding the public's perception of invasive plants has a primary role in motivating human behaviour changes (Stanto et al., 2015; Shackleton and Shackleton 2016). In Metro Vancouver, existing communication programs (ISCBC, 2017) demonstrate the efforts of governments in getting buy-in from the public in managing invasive plants. An assessment of how the public perceives the risks of invasive plants can help us understand diverse aspects of the public's perception regarding invasive plants (Potgieter et al., 2019). Once we have an understanding of the public perception (i.e., levels of knowledge, aspects used to define invasive plants, levels of management support), we can identify what kind of information and activities we should include in future outreach campaigns.

## 1.1 Research goals

This thesis aims to contribute to the understanding of invasive plants occurrences with regards to socio-economic, greenspace type, topographic, and land use variables in Metro Vancouver, BC, Canada. It further aims to provide an overview of the public's risk perception of invasive plants in the region.

Chapter 2 of this thesis focuses on developing statistical models in order to understand occurrences of invasive plants in relation to socio-economic, greenspace type, topographic, and land use variables. The findings of this chapter specifically address the following research questions: (1) What are the relationships between invasive plants occurrences and socio-economic factors and greenspace type? and (2) How can greenspace type be used in developing statistical models to understand the invasive plants occurrences in Metro Vancouver?

Chapter 3 of this thesis assesses the public's risk perception using rating scales and statistical tests for relationships between the public's risk perception and demographics—age, gender, ethnicity, education, and income. The results answered two specific questions: (1) How does the public perceive risks of invasive plants with regards to ecological, economic, and human health aspects? and (2) Are there any associations between the public's risk perception and demographics?

# Chapter 2: Relationships of invasive plants occurrences with socio-economic factors and greenspace type in urban greenspaces

## 2.1 Introduction

Urban ecosystems are one of the hotspots of biological invasions, especially urban greenspace (Gaertner et al., 2017). Invasive plants management in urban greenspace includes multiple approaches. However, prevention is considered to be the optimal approach of pro-active management (Pasquali et al., 2015). Prevention strategies are more cost-effective compared to manual control and chemical treatment when managers have an understanding of invasive plants occurrences (Coutts et al., 2011). Previous research has included climatic, habitat, topographic, and land use variables to build different types of species distribution models for invasive species (Bonamo, 2016). However, it has been suggested that explanatory variables beyond climatic, topographic, and ecological variables should be included in statistical models to provide a better understanding of invasive plants occurrences (Gaertner et al., 2017).

Recently, socio-economic factors have drawn substantial attention from scientists because there is evidence that socio-economic variables have effects on vegetation patterns in addition to environmental and ecological factors that are typically investigated (Lubbe et al., 2010). Occurrence and abundance of invasive plants are closely related with anthropogenic factors, as humans play a major role in species introduction and spread (Hobbs et al., 2006; Islands et al., 1997). Characteristics of human settlement such as housing, population, density of power lines and roads are associated with the distribution of invasive plants (Gavier-Pizarro et al., 2010; Akasaka et al., 2015; Lampinen et al., 2015). Hence, examining the relationship between socio-economic variables and the occurrences of invasive plants in urban areas provides managers with an understanding of where and why invasive plants occur. This will help managers to make better decisions (i.e., target areas of high risk) for invasive species management strategies (Graça et al., 2018).

Research has shown that the spatial distribution in urban areas of greenspace is positively associated with socio-economic characteristics (Graça et al., 2018; Nesbitt et al., 2019). For example, wealthier neighborhoods in some cities possess greater amounts of greenspace (Nesbitt et al. 2019). Therefore, we hypothesize that including socio-economic variables in statistical models will help us gain a better understanding of invasive plants occurrences in urban greenspaces.

In ecosystems other than forests, research has focused on explaining invasive species presence in models as a function of vegetation life form (e.g., trees, shrubs, grass) rather than a function of greenspace type (e.g., park, natural areas, or play grounds) (Graça et al., 2018). Meanwhile, Gaertner et al. (2017) emphasized that inclusion of urban greenspace type in the modelling process is crucial for understanding invasive plants occurrences. Variety of urban greenspace type has different effects on biodiversity and species richness of urban ecosystems (Burkman & Gardiner 2014; Nielsen et al., 2014), as well as the provision of urban ecosystem services (Graça et al., 2018). Therefore, it is possible to develop models for each greenspace type separately. We hypothesize that the relationships between invasive species occurrences and socio-economic factors are more refined within greenspace type across municipalities.

In this study, based on the aforementioned hypothesis, we aim to develop logistic regression models of invasive plant species occurrence for Metro Vancouver municipalities, which incorporate both greenspace type and socio-economic variables, as well as topographic and land use variables. The objectives are (1) to describe the relationship between invasive plants occurrences and both socio-economic factors and greenspace type after accounting for other explanatory variables; and (2) examine further how greenspace type can be used in developing statistical models to understand the invasive plants occurrences in Metro Vancouver, BC, Canada. The results provide managers with insights on which areas in terms of socio-economic characteristics and greenspace type are at high risk of plant invasions and should be targeted for spread prevention management and outreach programs. Moreover, the results of this study will enrich the current knowledge of relationships between socio-economic factors, greenspace type, and invasive plants occurrences in urban areas.

## 2.2 Methods

### 2.2.1 Study area

Metro Vancouver (MV) is a federation of 21 municipalities, one Electoral Area, and one Treaty First Nation in British Columbia (BC), Canada. It has a total area of 2,700 km$^2$ and a total population of 2.4 million. MV is the regional district with the greatest population density (855 persons per km$^2$) in BC and the third in population density among Canada's major metropolitan areas (Statistics Canada, 2016). 49% land use proportion of MV is occupied by small farms, which are less than 4 ha in size (Statistics Canada, 2016). Yet, despite ongoing pressure for urban development, farms in the region continue to thrive (Statistics Canada, 2016). This unique characteristic results in the development of horticulture and agriculture, which are key contributors to the introduction of invasive plants to the region (ISCBC, 2017). The demographics of MV reveal a multi-ethnic society in which people come from diverse cultural backgrounds and origins (Statistics Canada, 2016). Lastly, MV is located in the coastal region of the Pacific Northwest, which has suitable conditions for diverse types of ecosystems. According to the Sensitive Ecosystem Inventory from 2010 – 2012, greenspaces account for 25.4% (old forest: 10.5%; mature forest: 7.7%; young forest: 6.6%; and herbaceous: 0.6%) of the region (Metro Vancouver, 2014).

This study used invasive plants inventory data provided by six MV municipalities (hereafter the six municipalities): the cities of Burnaby, Coquitlam, Surrey, Delta, North Vancouver, and Richmond (Figure 2.1). The six municipalities have a wide range of characteristics (Table 2.1). Firstly, they are located from high to low elevation areas, with varied topographic features. Secondly, there is diversified landscape and socio-economic factors within these municipalities, which represent differences in population density, income, and land use proportion. For example, the cities of Delta, Surrey, and Richmond have large proportions of Agricultural Land Reserves, but the cities of Coquitlam, Burnaby, and North Vancouver have substantially lower proportions or no Agricultural Land Reserves (Statistics Canada, 2016). Finally, the six municipalities vary in size (Table 2.1), number of inventoried greenspaces (Table A.2.2, Appendix A.2), and invasive plant management approaches (Table A.1.3, Appendix A.1).

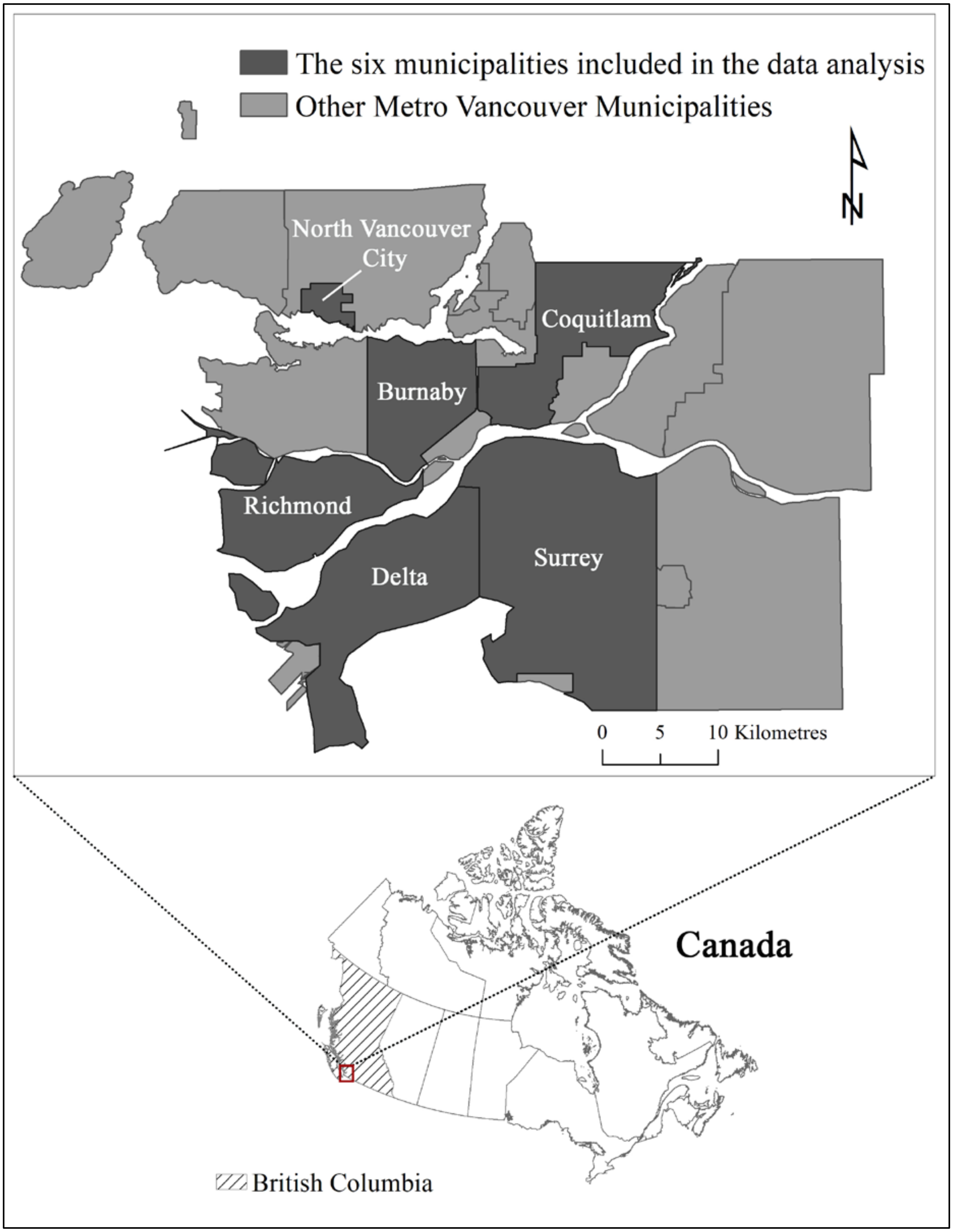



**Figure 2.1. Map of study area**

**Table 2.1. General characteristics of the six municipalities**

| Municipalities | Area ($km^2$) | Population | Land use classes (%) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Agricultural | Residential | Industrial | Recreation, open space and natural areas | Other* |
| Surrey | 316.4 | 517,885 | 25 | 33 | 3 | 15 | 24 |
| Burnaby | 98.6 | 232,755 | 2 | 27 | 10 | 25 | 38 |
| Richmond | 129.3 | 198,309 | 31 | 18 | 6 | 12 | 33 |
| Coquitlam | 122.3 | 139,285 | 2 | 21 | 2 | 51 | 24 |
| Delta | 180.1 | 102,240 | 43 | 11 | 4 | 22 | 20 |
| North Vancouver | 11.8 | 48,196 | 0 | 38 | 3 | 15 | 44 |

*Commercial and institutional areas, Port Metro Vancouver, rail, rapid transit, and other transportation, road rights-of-way, and undeveloped & unclassified land use areas

Agricultural, residential, industrial, and recreation, open space and natural areas (RONAs) are the four major land use classes of the six municipalities (Table 2.1). With 58% agricultural and residential areas, the city of Surrey has the largest proportion of agricultural and residential land use. It is the third largest city by area in the province (Statistics Canada, 2016). The city of Burnaby has the largest proportion of industrial areas, and the second largest proportion of residential areas and RONAs (Table 2.1). The city of Coquitlam has the highest proportion of RONAs among the six municipalities (Table 2.1). It is home to several large provincial and regional parks, and is located at higher elevation compared to the other municipalities. These characteristics lead to its lower proportion of industrial and agricultural areas (Table 2.1). The city of Delta has the lowest proportion of residential areas compared to the other municipalities, but agricultural areas cover most of the land base in this city among the four major land use classes (Table 2.1). The city of North Vancouver is the only city among the six municipalities that has no agricultural land, but it has the highest proportion of residential areas (Table 2.1). The city of Richmond has the lowest proportion of

RONAs, but in terms of the agricultural land use proportion it ranks second among the six municipalities (Table 2.1).

### 2.2.2 Target invasive plants

This research targets four invasive plants (hereafter target species; Table A.2.1, Appendix A.2): English Ivy (*Hedera helix*), Knotweed spp. (Japanese knotweed–*Fallopia japonica*, Bohemian knotweed–*F. x bohemica*, Giant knotweed–*F. sachalenensis*, Himalayan knotweed–*Polygonum polystachyum*), Himalayan blackberry (*Rubus armeniacus)*, and Yellow archangel (*Lamiastrum galeobdolon*). These four target species are priorities for all six municipalities, and the government of BC (ISCBC, 2017). The inventory data of target species were retrieved from the municipalities' databases and the BC Invasive Alien Plant Program (IAPP, 2017). Data are in form of Geographic Information System (GIS) layers, for each target species, which contain the species presence locations and the inventory time (2011 to 2018). All municipalities used Global Positioning System (GPS) units to collect the data. However, there are differences among municipalities in terms of survey protocols and number of greenspaces sampled (Table A.2.2, Appendix A.2).

Target species occurrence was defined as presence of each target species within each greenspace, the unit of analysis. The inventory data of the target species provided by the municipalities were presence-only data. For each target species, a 'presence' observation was identified if there was at least one inventory data point of one specific target species recorded within one greenspace. A 'pseudo-absence' was generated if there was no presence data point of a specific target species recorded within a given greenspace.

### 2.2.3 Explanatory variables

Three groups of continuous variables—(1) topographic and park, (2) land use, and (3) socio-economic variables (Table 2.2)—and one factor variable (i.e., greenspace type) were used as explanatory variables in this research. First, I hypothesized that topographic and park as well as land use variables are associated with species occurrences, because these two variable groups take into account favourite habitats and reproduction forms of the target species (Table A.3.2, Appendix A.3). Second, I hypothesized that socio-economic variables are positively associated with species occurrences due to the positive relationships between anthropogenic factors and invasive plant introduction found in existing literature (see Table A.3.2, Appendix A.3).

*Urban greenspace types*—there is a wide range of definitions of urban greenspaces. Beatley (2012) defined 'greenspace' as an expression that encompasses a broad variety of open spaces, both natural and semi-natural, many of which have an increasingly hybrid nature. Based on the management approaches prioritized by the six municipalities, as well as the characteristics of urban greenspaces in MV, this study focuses on three categories of urban greenspaces: (1) parks & recreation, (2) natural, semi-natural and feral areas (Natural areas), and (3) leisure or cultural civic facility grounds (LCCFGs). The three categories included in this study are a sub-group of six categories of urban greenspaces defined by Bell et al. (2007) and Branquilho et al. (2015) (Table A.3.1, Appendix A.3). We only included greenspaces that have a total area of 100 $m^2$ or larger in our data analysis because the six municipalities prioritized those greenspaces in their inventory data collection protocols.

Six *topographic and park variables* were extracted from GIS layers (Table 2.2), which were provided by the six municipalities. Topographic and park variables were selected based on favourite habitat characteristics of target species (Table A.2.1, Appendix A.2) and hypotheses about relationships between this group of variables and target species occurrences (Table A.3.2, Appendix A.3).

The four *land use variables* were the proportion of (1) agricultural areas, (2) residential areas, (3) industrial areas, and (4) recreation, open space, and natural areas (RONAs) within a 100-metre buffer from each greenspace polygon, the unit of analysis (Table 2.2). We included these four land use variables because they are the four major land use classes of the six municipalities (Table 2.1). Moreover, looking at the proportion of these four land use classes within a 100-metre buffer takes into account the relationship between target species occurrences and the characteristics of the surrounding land use of each greenspace (Table A.3.2, Appendix A.3).

*Socio-economic variables* were derived from the Simply Map database (SimplyAnalytics, 2018). All census data were compiled at the Dissemination Area level. This is the smallest standard geographic area for which all census data are available. In this research, five socio-economic variables (Table 2.2) were selected based on our hypotheses (Table A.3.2, Appendix A.3).

**Table 2.2. Explanatory variables**

| Explanatory variables | Sources | Description |
|---|---|---|
| **Topographic and park variables** | | |
| Elevation (m) | Digital Elevation Model | Average elevation of each greenspace |
| Slope | | Average slope of each greenspace |
| Greenspace area | Geographic Information System layers | Total area of each greenspace |
| Trail density ($km^{-2}$) | | Trail density of each greenspace |
| Distance to road (m) | | Linear distance between each greenspace polygon and the closest major road was measured using "near" tool in ArcMap 10.6.1. |
| Distance to water channel (m) | | Linear distance between each greenspace polygon and the closest open water channel was measured using "near" tool in ArcMap 10.6.1. If there is a water channel running through the greenspace, the distance is 0. |
| **Land use variables** | | |
| Agricultural<br>Residential<br>Industrial<br>Recreation, open space, and natural areas (RONAs) | 2011 Land Use Map of Metro Vancouver | A 100-metre buffer around each greenspace polygon was created. The proportion of each land use class was then calculated within the buffer. |
| **Socio-economic variables** | | |
| Median household income (CAD)<br>Population density ($km^{-2}$)<br>Single-detached house density ($km^{-2}$)<br>Mean household expenditure for gardening (CAD):<br>(1) Nursery (i.e., flowers, plants, seeds)<br>(2) Fertilizers, herbicides, insecticides, pesticides, soil | Statistics Canada, 2016<br>SimplyAnalytics, 2018 | Used "spatial join" tool to match each greenspace with dissemination areas. Each greenspace received the socio-economic values of the dissemination area in which it is located. If one greenspace straddled more than one dissemination area, a weighted average of each socio-economic variable was calculated for each greenspace. Weights were based on the proportion of greenspace falling into each dissemination area. |

### 2.2.4 Statistical analysis

Data exploration was used to support model building and variable selection steps. First, possible associations between variables within each and across explanatory variable groups were explored using scatterplots. Furthermore, the association between greenspace type and the continuous explanatory variables was examined using box plots.

Logistic regression models were used to test for relationships between target species occurrences and explanatory variables. The models were developed in two separate analyses: (1) models were fit for each municipality by species to understand differences in relationships across municipalities and to account for differences among municipalities, and (2) models were fit for each greenspace type by species across all six municipalities to understand differences in relationships across greenspace types. The Akaike Information Criterion (AIC) (Akaike, 1974) was used to assess model performance.

*Models fit for each municipality* included five main steps (Figure 2.2). First, univariable logistic regression models were fit for all explanatory variables in order to identify which variables were significantly related to species occurrences by themselves. Second, multivariable models within each group of explanatory variables (Table 2.2) were fit using the variables identified as significant by themselves in the previous step. Before the final model within each group was selected, variables that were not significant in the univariable model were added individually. If any of them improved the model performance—reduced the model AIC—these variables were kept in the final model of each explanatory variable group. In the third step, multivariable models were fit across variable groups combining all the variables included in the final model of each group. This step combined all variables that were significant within groups together, then variables that had been dropped in the previous step were added again to test if the model performance changed. If that was the case, the added variable was kept in the final model, otherwise it was dropped. Finally, greenspace type was added as a factor variable to the final model from the previous step. The variables that were not statistically significant at this step were dropped.

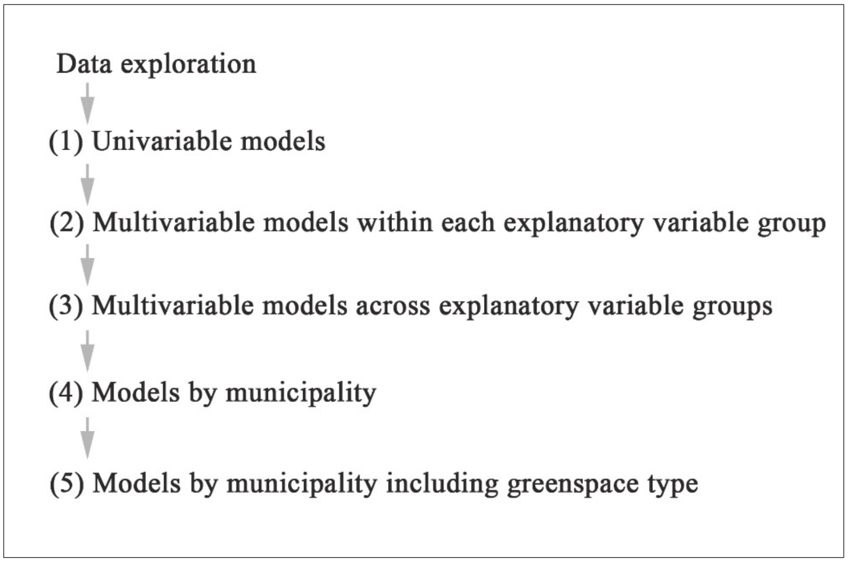



**Figure 2.2. Model development by municipality**

*Models were fit for each greenspace type* across the six municipalities in order to examine the relationship between target species occurrences and explanatory variables, especially the socio-economic variables, when we classified the data by greenspace type. The model selection process was done by greenspace type across municipalities rather than by municipality. However, the same model selection procedure was used (Figure 2.2) in order to build models by greenspace type. A random municipality effect was included in the model to account for correlations of observations within one municipality.

The *Hosmer-Lemeshow goodness-of-fit test* was used to assess the fit of the models. Pearson Chi-square statistics were obtained from the group (g) x 2 table of observed and expected frequencies (Hosmer et al., 2013; Hosmer and Lemeshow 1980). I used g = 10 groups to calculate the Hosmer-Lemeshow goodness of fit statistic, as suggested by Hosmer et al. (1988), in which the first group contained all greenspaces that had probability less than or equal to 0.1, while the tenth group contained those greenspaces that had estimated probability of species occurrences greater than 0.9. The model fit was assessed at an alpha of 0.05.

The *area under the Receiver Operating Characteristic (ROC) Curve* was calculated for each model in this study to measure the model performance. The ROC curve plots the probability of predicting true presences (sensitivity) and the false presences (1- specificity) of a target species for an entire range of possible cut-points—0.05 to 0.75 in increments of 0.05— (Hosmer et al., 2013). I followed the rule of thumb described by Hosmer et al. (2013) that a model with a ROC value between 0.7 and 0.8 provides satisfactory discrimination and a model with a ROC value greater than 0.8 provides excellent discrimination between presences and absences of each target species.

## 2.3 Results

### 2.3.1 Topographic, land use, and socio-economic characteristics of the six municipalities represent unique features of Metro Vancouver

*Topographic and park variables (Table A.4.1, Appendix A.4)*—The city of Coquitlam is located at the highest elevation among the six municipalities, followed by the cities of North Vancouver, Surrey, Burnaby, Delta, and Richmond. The variation in elevation and slope follows the same order. Regarding inventoried greenspaces, the cities of Surrey and Coquitlam have larger sample size compared to the other cities. The city of Delta has the lowest number of inventoried greenspaces, but it has the largest conservation area (2,947 $km^2$), which leads to the high variability in greenspace area within the city (Tale A.4.1, Appendix A.4). Lastly, the city of North Vancouver has smaller sized greenspaces, with the least variation in greenspace area overall.

*Land use variables (Table A.4.2, Appendix A.4)*— Residential areas dominated the land use within 100m buffers from each greenspace in all municipalities, followed by recreation, open space and natural areas (RONAs), agricultural, and industrial areas. The cities of Delta and Surrey had higher agricultural proportion within the 100m buffer around greenspaces compared to the other cities. The city of Coquitlam had the highest proportion of RONAs among the six municipalities.

*Socio-economic variables (Table A.4.3, Appendix A.4)*—The cities of Delta and Coquitlam exhibited the highest median household income values, followed by the cities of Surrey and North Vancouver. Based on scatterplots, the median household income had a positive association with expenditure for gardening including expenditure for nursery and fertilizer. Population density was higher in the cities of Burnaby and North Vancouver. However, the City of North Vancouver exhibited the lowest density of single detached houses among the six municipalities.

*Association between greenspace type and explanatory variables*—Data exploration suggested potential associations between greenspace type and some explanatory variables such as greenspace area, distance to water channel, and expenditure for gardening (Figure 2.3). For instance, natural areas tended to be larger (Figure 2.3a), and occurred within smaller distances to water channels compared to park & recreation and LCCFGs (Figure 2.3b). In addition, household gardening expenses seem to be higher within dissemination areas where natural areas are located compared to other two greenspace types (Figure 2.3c).

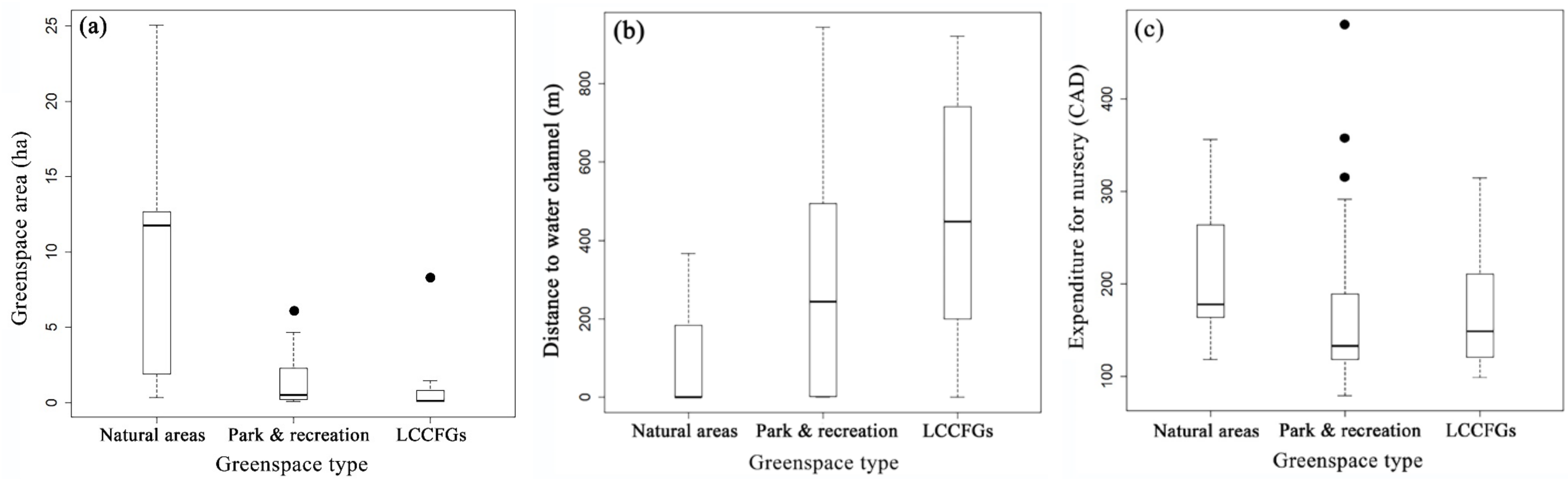



**Figure 2.3. Box plots showing associations between greenspace type (i.e., natural areas, park & recreation, and Leisure or Cultural Civic Facility Grounds--LCCFGs) and three explanatory variables a) greenspace area, b) distance to water channel, and c) expenditure for nursery.**

### 2.3.2 Significant relationships between socio-economic factors and target species occurrences varied by municipality

*Models by municipality*—Median household income (MHI), distance to water channel, greenspace area, trail density, and residential proportion were significant variables for two or more municipalities and two or more target species (Tables 2.3 – 2.6). For example, in the cities of Surrey and Coquitlam, greenspaces with larger size, shorter distance to water channel, and located within higher income dissemination areas had higher probabilities of having English ivy, Himalayan blackberry, and Knotweed species. In the cities of Delta and North Vancouver, the models of Yellow archangel suggested that greenspaces with steeper slopes, and located in dissemination areas that had higher gardening (i.e., nursery) expenses experienced higher probability of having invasive species occurrences (Table 2.6). However, there was no common relationships across the six municipalities and four target species. The models identified a list of five variables that were not significant in explaining target species occurrence in any of the municipalities including distance to road, topographic wetness index, single detached house density, and agricultural and industrial proportion within a 100m buffer.

*Models by municipality including greenspace type*—Adding greenspace type as a factor variable into the models (Tables 2.3 – 2.6) led to changes in the results described above. Topographic,park variables (e.g., greenspace areas, trail density) and socio-economic variables (e.g., MHI, expenditure for nursery, population density) were not significant in the final models with greenspace type.

*Goodness of fit*—Hosmer-Lemeshow tests for the models by municipality indicated a good fit of the models (p = 0.1). Furthermore, AUC values of the models ranged between 0.7 and 0.8, showing satisfactory discrimination of invasive plants occurrences.

**Table 2.3. Results by municipality for English ivy**

| **Models for English ivy*** | | | | |
|---|---|---|---|---|
| **Variable name** | **Coquitlam** | | **Surrey** | |
| | Estimate | p-value | Estimate | p-value** |
| Median household income | $2.73 \times 10^{-5}$ | 0.002 | $9.54 \times 10^{-6}$ | <0.001 |
| Expenditure for fertilizers | $-6.38 \times 10^{-3}$ | 0.008 | | |
| Population density | | | $1.15 \times 10^{-4}$ | 0.023 |
| Elevation | | | $1.17 \times 10^{-2}$ | 0.01 |
| Slope | | | $1.88 \times 10^{-2}$ | <0.001 |
| Area | $7.9 \times 10^{-2}$ | 0.03 | $4.99 \times 10^{-2}$ | 0.04 |
| Trail density | $-1.9 \times 10^{-3}$ | 0.007 | $-3.47 \times 10^{-3}$ | <0.001 |
| | **North Vancouver** | | **Delta** | |
| | Estimate | p-value | Estimate | p-value |
| Expenditure for fertilizers | | | 0.14 | 0.02 |
| Area | 2.52 | 0.03 | | |
| Slope | | | 0.39 | 0.05 |
| Residential proportion | 0.05 | 0.005 | 0.51 | 0.009 |
| | **Burnaby** | | **Richmond** | |
| | Estimate | p-value | | |
| Median household income | $3.02 \times 10^{-6}$ | 0.01 | No data | |
| Area | 0.18 | 0.005 | | |
| Residential proportion | $1.36 \times 10^{-2}$ | 0.04 | | |

* without greenspace type, variables that were not significant were left blank

**The p-value indicates if the variable is significant in explaining species occurrences, with the following thresholds: 0 ≤ convincing evidence < 0.01 ≤ moderate evidence < 0.05 ≤ suggestive, but inconclusive evidence ≤ 0.10 (Ramsey and Schafer, 2013)

**Table 2.4. Results by municipality for Himalayan blackberry**

| **Models for Himalayan blackberry*** | | | | |
|---|---|---|---|---|
| **Variable code** | **Coquitlam** | | **Surrey** | |
| | Estimate | p-value | Estimate | p-value** |
| Median household income | $2.45 \times 10^{-5}$ | 0.003 | $5.48 \times 10^{-6}$ | 0.02 |
| Expenditure for fertilizers | $-6.41 \times 10^{-3}$ | 0.007 | | |
| Population density | | | $1.34 \times 10^{-4}$ | 0.006 |
| Area | | | 0.141 | <0.001 |
| Trail density | | | $-2.84 \times 10^{-3}$ | <0.001 |
| Distance to water channel | $-1.3 \times 10^{-2}$ | 0.001 | $-1.61 \times 10^{-2}$ | 0.01 |
| Recreation, open space, and natural areas proportion | $3.1 \times 10^{-2}$ | 0.005 | | |
| | **North Vancouver** | | **Delta** | |
| | Estimate | p-value | Estimate | p-value |
| Expenditure for fertilizers | | | $1.7 \times 10^{-1}$ | 0.02 |
| Expenditure for nursery | $9.4 \times 10^{-2}$ | 0.08 | | |
| Area | 0.88 | 0.04 | | |
| Slope | | | 0.6 | 0.04 |
| Residential proportion | | | 0.35 | 0.01 |
| | **Burnaby** | | **Richmond** | |
| | Estimate | p-value | | |
| Median household income | $4.03 \times 10^{-5}$ | 0.009 | | |
| Expenditure for nursery | $1.69 \times 10^{-2}$ | 0.003 | No data | |
| Area | $5.86 \times 10^{-2}$ | 0.06 | | |
| Agricultural proportion | $-8.8 \times 10^{-2}$ | 0.02 | | |

* without greenspace type, variables that were not significant were left blank

**The p-value indicates if the variable is significant in explaining species occurrences, with the following thresholds: $0 \leq$ convincing evidence $< 0.01 \leq$ moderate evidence $< 0.05 \leq$ suggestive, but inconclusive evidence $\leq 0.10$ (Ramsey and Schafer, 2013)

**Table 2.5. Results by municipality for Knotweeds**

| **Models for Knotweeds*** | | | | |
|---|---|---|---|---|
| **Variable code** | **Coquitlam** | | **Surrey** | |
| | Estimate | p-value | Estimate | p-value** |
| Median household income | $2.6 \times 10^{-5}$ | 0.004 | $6.4 \times 10^{-6}$ | 0.003 |
| Expenditure for nursery | $2.06 \times 10^{-2}$ | 0.01 | | |
| Expenditure for fertilizers | $-1.51 \times 10^{-2}$ | <0.001 | | |
| Area | $4.9 \times 10^{-2}$ | 0.01 | | |
| Trail density | | | $-4.9 \times 10^{-3}$ | <0.001 |
| Slope | | | $1.27 \times 10^{-2}$ | 0.005 |
| Distance to water channel | $-2.58 \times 10^{-2}$ | 0.02 | $-5.44 \times 10^{-2}$ | <0.001 |
| Industrial proportion | $4.7 \times 10^{-2}$ | 0.007 | | |
| | **North Vancouver** | | **Delta** | |
| | Estimate | p-value | Estimate | p-value |
| Expenditure for nursery | 0.01 | 0.04 | | |
| Slope | | | -0.55 | 0.01 |
| Elevation | | | 0.43 | 0.04 |
| Distance to water channel | $-3.8 \times 10^{-2}$ | 0.01 | | |
| Recreation, open space, and natural areas proportion | | | 0.75 | 0.001 |
| | **Burnaby** | | **Richmond** | |
| | Estimate | p-value | Estimate | p-value |
| Median household income | $1.7 \times 10^{-5}$ | 0.04 | $1.86 \times 10^{-6}$ | <0.001 |
| Population density | | | $2.49 \times 10^{-4}$ | 0.003 |
| Area | $7.7 \times 10^{-2}$ | 0.006 | | |
| Elevation | $-7.8 \times 10^{-3}$ | 0.02 | | |
| Recreation, open space, and natural areas proportion | | | $6.92 \times 10^{-2}$ | 0.01 |

* without greenspace type, variables that were not significant were left blank
**The p-value indicates if the variable is significant in explaining species occurrences, with the following thresholds: $0 \leq$ convincing evidence $< 0.01 \leq$ moderate evidence $< 0.05 \leq$ suggestive, but inconclusive evidence $\leq 0.10$ (Ramsey and Schafer, 2013)

**Table 2.6. Results by municipality for Yellow archangel**

| **Models for Yellow archangel*** | | | | |
|---|---|---|---|---|
| **Variable code** | **Coquitlam** | | **Surrey** | |
| | Estimate | p-value | Estimate | p-value** |
| Median household income | | | $1.19 \times 10^{-5}$ | <0.001 |
| Expenditure for nursery | $8.7 \times 10^{-2}$ | <0.001 | | |
| Trail density | $-3.1 \times 10^{-2}$ | 0.002 | $-3.31 \times 10^{-3}$ | <0.001 |
| Slope | | | $2.20 \times 10^{-2}$ | <0.001 |
| Distance to water channel | | | $-4.21 \times 10^{-2}$ | <0.001 |
| Recreation, open space, and natural areas proportion | 0.33 | 0.008 | $1.24 \times 10^{-2}$ | 0.037 |
| Residential proportion | 0.27 | 0.005 | | |
| | **North Vancouver** | | **Delta** | |
| | Estimate | p-value | Estimate | p-value |
| Expenditure for fertilizers | | | $8.5 \times 10^{-2}$ | 0.04 |
| Area | 0.33 | 0.06 | | |
| Slope | 0.48 | 0.02 | 0.46 | 0.001 |
| Residential proportion | 0.47 | 0.01 | | |
| | **Burnaby** | | **Richmond** | |
| | Estimate | p-value | | |
| Expenditure for fertilizers | -0.03 | 0.006 | | |
| Expenditure for nursery | 0.01 | 0.003 | No data | |
| Area | 0.04 | 0.006 | | |
| Recreation, open space, and natural areas proportion | 0.02 | 0.09 | | |

* without greenspace type, variables that were not significant were left blank
**The p-value indicates if the variable is significant in explaining species occurrences, with the following thresholds: 0 ≤ convincing evidence < 0.01 ≤ moderate evidence < 0.05 ≤ suggestive, but inconclusive evidence ≤ 0.10 (Ramsey and Schafer, 2013)

**Table 2.7. Summary of models by municipality**

| | Models by municipalities | | | | | |
|---|---|---|---|---|---|---|
| | **Coquitlam** | **Surrey** | **North Vancouver** | **Delta** | **Burnaby** | **Richmond*** |
| Median household income | ↗ EI, HB, KW | ↗ EI, HB, KW, YA | NS | NS | ↗ EI, HB, KW | ↗ KW |
| Expenditure for fertilizers | ↘ EI, HB, KW | NS | NS | ↗ EI, HB, YA | ↘ YA | NS |
| Expenditure for nursery | ↗ KW, YA | NS | ↗ HB, KW | NS | ↗ HB, YA | NS |
| Population density | NS | ↗ EI, HB | NS | NS | NS | ↗ KW |
| Single-detached house density | NS | NS | NS | NS | NS | NS |
| Elevation | NS | NS | NS | ↗ KW | ↘ KW | NS |
| Slope | NS | ↗ EI, KW, YA | ↗ YA | ↗ EI, YA | NS | NS |
| Area | ↗ EI, KW | ↗ EI, HB | ↗ EI, HB, YA | NS | ↗ EI, HB, KW, YA | NS |
| Trail density | ↘ EI, YA | ↘ EI, HB, KW, YA | NS | NS | NS | NS |
| Distance to water channel | ↘ HB, KW | ↘ HB, KW, YA | ↘ KW | NS | NS | NS |
| Residential proportion | ↗ YA | NS | ↗ EI, YA | ↗ EI, HB | ↗ EI | NS |
| Agricultural proportion | NS | NS | NS | NS | ↘ HB | NS |
| Recreation, open space, and natural areas proportion | ↗ HB, YA | ↗ YA | NS | ↗ KW | ↗ YA | ↗ KW |
| Industrial proportion | ↗ KW | NS | NS | NS | NS | NS |

EI English ivy
HB Himalayan blackberry
KW Knotweeds
YA Yellow archangel
NS Not significant
↗ Increase in explanatory variable related to increase in probability of species occurrences
↘ Increase in explanatory variable related to decrease in probability of species occurrence
*Data is available for Knotweeds only

### 2.3.3 Greenspace type captures important information including topographic, land use, and socio-economic characteristics of the region

*Natural Areas*—Median household income (MHI) was associated with higher probability of target species occurrences. However, the odds of species occurrences were different for each target species. The odds of target species occurrence increased by 8.1% (English ivy), 12.7% (Himalayan blackberry), 7.1% (Knotweeds), and 8.5% (Yellow archangel) with every additional $10,000 in MHI. Whether the topographic and park and land use variables were significant in the model was species-dependent (Table 2.7). However, English ivy and Yellow archangel had the same set of significant variables in the models. For example, the odds of English ivy and Yellow archangel occurrences increased by 66.5%, and 59.9% respectively with each additional 100 metres linear distance from natural areas to a major road. Residential and agricultural proportion were significant in explaining the occurrences of English ivy, Yellow archangel, and Knotweeds, but not significant in the model of Himalayan blackberry.

*Park & recreation*—Population density and single detached house density were significantly associated with target species occurrences in park & recreation areas (Table 2.7). For instance, the odds of having Knotweed species increased by 3.1% and 8.9% as single detached house density increased by 1,000 houses per $km^2$. Greenspace area was positively associated with occurrences of English ivy ($p = 0.02$), Himalayan blackberry ($p < 0.001$), and Knotweeds ($p = 0.009$), while trail density was negatively associated with occurrences of Knotweeds ($p = 0.003$), and Yellow archangel ($p < 0.001$). Each additional hectare in park size was associated with an increase in the odds of English ivy (12.6%), Himalayan blackberry (43.7%), and Knotweed species (14.2%) occurrences. Land use variables were not significant across models of any of the target species.

*LCCFGs*—The model of LCCFGs did not have common relationships between species occurrences and socio-economic variables across species; but MHI, expenditure for nursery, and single detached house density were significant variables depending on species (Table 2.7). Elevation was significant for English ivy and Himalayan blackberry, but not for Knotweed species and Yellow archangel. Topographic and park variables were not significant for Knotweed species.

*Goodness of fit*—There is no evidence for lack of fit of the models by greenspace type according to the Hosmer-Lemeshow tests (p-values > 0.2). Models for natural areas and park & recreation groups had AUC values varying slightly from 0.73 to 0.76. However, the AUC values for the LCCFG group fluctuated from 0.69 to 0.93. The AUC value of 0.69 is close to a good discrimination (i.e., 0.70) while the 0.93 value demonstrates an excellent discrimination of invasive plants occurrences.

**Table 2.8. Results by greenspace type**

| Species | Variable code | Natural areas | | Park & recreation | | LCCFGs | |
|---|---|---|---|---|---|---|---|
| | | Estimate | p-value** | Estimate | p-value | Estimate | p-value |
| English ivy | Median household income | $7.8 \times 10^{-6}$ | <0.001 | | | $2.2 \times 10^{-5}$ | 0.05 |
| | Population density | | | $8.9 \times 10^{-5}$ | 0.007 | | |
| | Single-detached house density | | | 0.0003 | 0.01 | | |
| | Distance to road | 0.0051 | 0.001 | | | | |
| | Trail density | -0.0089 | 0.01 | | | | |
| | Park_area | | | 0.0010 | 0.02 | | |
| | Elevation | | | 0.1188 | 0.05 | 0.0260 | 0.02 |
| | Agricutural proportion | -0.025 | 0.02 | | | | |
| | Residential proportion | 0.0209 | <0.001 | | | | |
| AUC values | | | **0.73** | | **0.74** | | **0.69** |
| Himalayan blackberry | Median household income | $1.1 \times 10^{-5}$ | 0.002 | | | $2.9 \times 10^{-5}$ | 0.02 |
| | Expenditure for nursery | 0.0019 | 0.01 | | | | |
| | Population density | | | $1.2 \times 10^{-5}$ | 0.01 | | |
| | Park area | | | 0.3625 | <0.001 | | |
| | Distance to water channel | | | 0.0029 | 0.002 | | |
| | Elevation | | | | | 0.0255 | 0.01 |
| AUC values | | | **0.75** | | **0.73** | | **0.80** |
| Knotweeds | Expenditure for fertilizers | $6.9 \times 10^{-6}$ | 0.06 | | | | |
| | Expenditure for nursery | 0.0018 | <0.001 | | | 0.0102 | 0.03 |
| | Single-detached house density | | | $3.1 \times 10^{-5}$ | 0.03 | $3.7 \times 10^{-5}$ | 0.03 |
| | Park area | 0.0188 | 0.003 | 0.132 | 0.009 | | |
| | Elevation | -0.0050 | 0.006 | | | | |
| | Trail density | | | -0.0028 | 0.003 | | |
| | Agricutural proportion | -0.0368 | 0.004 | | | | |
| AUC values | | | **0.73** | | **0.70** | | **0.93** |
| Yellow archangel | Median household income | $8.2 \times 10^{-6}$ | <0.001 | $7.5 \times 10^{-6}$ | 0.006 | | |
| | Population density | | | $8.6 \times 10^{-6}$ | 0.03 | | |
| | Expenditure for furtilizers | | | | | 0.0105 | 0.06 |
| | Distance to road | 0.0047 | 0.002 | | | 0.2570 | 0.02 |
| | Trail density | | | -0.0026 | <0.001 | | |
| | Slope | | | 0.0039 | 0.02 | | |
| | Residential proportion | 0.0235 | <0.001 | | | | |
| AUC values | | | **0.76** | | **0.72** | | **0.89** |

**The p-value indicates if the variable is significant in explaining species occurrences, with the following thresholds:
$0 \leq$ convincing evidence $< 0.01 \leq$ moderate evidence $< 0.05 \leq$ suggestive, but inconclusive evidence $\leq 0.10$ (Ramsey and Schafer, 2013)

**Table 2.9. Summary of models by greenspace type**

| | Models by greenspace type | | |
|---|---|---|---|
| | Natural areas | Park & recreation | LCCFGs |
| Median household income | ↗ EI, HB, YA | ↗ YA | ↗ EI, HB |
| Expenditure for fertilizers | ↗ KW | NS | ↗ YA |
| Expenditure for nursery | ↗ HB, KW | NS | ↗ KW |
| Population density | NS | ↗ HB, YA | NS |
| Single-detached house density | NS | ↗ EI, KW | ↗ KW |
| Elevation | ↗ KW | ↗ HB | ↗ EI, HB |
| Slope | NS | ↗ YA | NS |
| Area | ↘ KW | ↗ EI, HB, KW | NS |
| Trail density | ↘ EI | ↘ KW, YA | NS |
| Distance to water channel | NS | ↘ HB | NS |
| Residential proportion | ↗ EI, YA | NS | NS |

EI English ivy
HB Himalayan blackberry
KW Knotweeds
YA Yellow archangel
NS Not significant
↗ Increase in explanatory variable related to increase in probability of species occurrences
↘ Increase in explanatory variable related to decrease in probability of species occurrences

## 2.4 Discussion

This study aims to test for relationships between the target species occurrences and socio-economic factors as well as greenspace type. In addition, the study examines how greenspace type should be used in the model development process. Our analyses demonstrated that median household income, expenditure for gardening, and population density were positively associated with target species occurrences after accounting for the other explanatory variables. The differences among management and inventory approaches across the six municipalities are the key reasons for different sets of significant variables by municipality. Moreover, greenspace type captures important information of other explanatory variables when explaining invasive plants occurrences. Lastly, fitting models by greenspace type provided a more refined understanding of the invasive plant occurrences across the six municipalities in Metro Vancouver.

### 2.4.1 Wealthier neighbourhoods experienced higher invasive plants occurrences

*Positive relationships between target species occurrences and median household income, expenditure for gardening, and population density*—Wealthy neighbourhoods tend to experience more intense landscaping and invasive species introduction (Hope et al. 2003). This is supported by our findings that higher median household income neighbourhoods spend more money on gardening. The higher chance of target species occurrences in wealthier neighbourhoods that I found aligns with Zhai et al.'s (2018) findings of higher invasive tree species presence in wealthier counties in Missisippi, USA. Expenditure for gardening positively explained occurrences of English ivy and Yellow archangel because these species are two popular ornamental plants that can easily escape from residential gardens to nearby greenspaces to form infestations (Bigirimana et al., 2012; Cubino et al., 2015). Purchases of these two species may be a part of the gardening expenses, and therefore, the more the residents spend on gardening expenses, the more likely it is that nearby greenspaces may experience English ivy and Yellow archangel occurrences. Population density was positively associated with target species occurrences in Surrey because increases in population density lead to the increase of human activities, which play a major role in introduction and spreading of invasive plants (McNeely 2001; Hobbs et al., 2006). This positive relationship confirmed the same association between human population and invasive species occurrences found by previous studies (Williamson and Fitter 1996; Gallardo and Aldridge 2013).

*Larger greenspace area and shorter distance to water channel were associated with higher target species occurrences*—This finding is consistent with previous research that tested effects of park size on invasive species distribution (Gormley et al., 2011), abundance (Ehrlén et al., 2015), and diversity (McKinney 2002). Similar relationships were found in two or more municipalities for distance to water channel and greenspace area due to the associations between greenspace type and topographic and park variables. For example, natural areas tended to have larger sizes and shorter distance to water channels compared to the other two greenspace types (Figure 2.3). Meanwhile, each municipality experiences its own topographic conditions, and therefore, the relationships between invasive plants occurrences and other topographic variables—elevation and slope—rather than distance to water channel varied accordingly.

*Land use variables*—Invasive plants are typically found in greenspaces, and plant invasions can spread if greenspaces are located next to each other (Borgmann & Rodewald, 2005). Residential areas create roadside habitat, which has been reported to have a positive relationship with invasive plants distributions (Vilà & Pujadas, 2001). Therefore, both RONAs and residential areas were positively correlated with target species occurrences due to the habitat characteristics of the targeted invasive plants species. Furthermore, we expected that distance to road would be significant in the models by municipality because this variable represents access to greenspace and a pathway for species distribution, yet it was not. The reason could be the significance of residential proportion, which may act as a better proxy for access to greenspace and pathway for spreading species than distance to major roads. Meanwhile, agricultural and industrial proportions were not significant in the models because the four target species in MV do not favour these habitats (ISCBC, 2017).

Greenspace type was confounded with topographic and park and socio-economic variables which were not significant in the model. Each greenspace type has different topographic characteristics (e.g., elevation, total area), and is located within dissemination areas that have their own socio-economic factors (Table A.1, Appendix A). Therefore, the changes in relationships between species occurrences and the explanatory variables suggested that greenspace type can act as a proxy for socio-economic factors and other explanatory variables (Figure 2.3; Branquilho et al., 2015).

### 2.4.2 Fitting models by greenspace type reveals refined relationships between species occurrences and explanatory variables across the six municipalities

Characteristics of each greenspace type can be used to explain the relationships between target species occurrences and significant explanatory variables in models by greenspace type. Firstly, natural areas tend to be located near wealthier neighbourhoods, which experience a higher chance of having invasive plants (Bell et al. 2007; Gavier-Pizarro et al., 2010). However, each species has it owns preferences in terms of topographic features (Bellard et al., 2016). For instance, Knotweeds tend to occur in natural areas that have lower elevation. This is why elevation was significant for Knotweeds, but not for others.

Secondly, park & recreation greenspaces are located in areas of higher population density compared to natural areas. This characteristic explained our finding of positive associations between target species occurrences and population density as well as single-detached house density. Due to the smaller greenspace size and higher population density surrounding park & recreation greenspaces (Bell et al., 2007), we can see that land use variables were not significant across target species. Moreover, the information of land use variables may already be explained by population density and single-detached house density, which were significant in the models.

Lastly, leisure or culatural civic and facility grounds (LCCFGs) were inventoried mainly because target species occurrences were reported by the public. Therefore, the occurrence is not significantly related to socio-economic characteristics of the surrounding dissemination areas. These characteristics of LCCFGs explained the changes in relationships between species occurrences and socio-economic variables in the final models. In addition, LCCFGs are frequently managed and manicured for recreational activities such as camping (Braquiho et al., 2015), which may have effects on target species occurrences.

### 2.4.3 Applications and significance of findings and suggestions for further research

*Models by municipality* suggested a set of significant variables that can be used to support the early detection and risk assessment at the local government scale in MV. This finding also explains recent research focus on relationships between socio-economic variables and invasive species occurrences (Stantos et al., 2011; Akasaka et al., 2015; Staudhammer et al., 2015). Our results suggest that the tested socio-economic variables should be incorporated into invasive plant detection processes. For example, detection approaches that rely solely on the use of moderate to high spatial resolution imagery such as multispectral data and hyperspectral data (Chance et al., 2016) could possibly be improved upon by additional incorporation of socio-economic predictors.

*Models by greenspace type* confirmed our hypothesis that it is important to develop models for each greenspace type in order to understand invasive plants occurrences, because greenspace type captures important information including socio-economic characteristics of the region. Our findings are in line with other recent studies, which highlighted the significance of incorporating greenspace type information in invasive species research (Gaertner et al., 2017; Graça et al., 2018). Therefore, better performance of statistical models will be achieved by including greenspace type after accounting for socio-economic variables, and other explanatory variable groups. Fitting models by greenspace type can inform managers about the type of greenspace and its surrounding socio-economic, topographic, as well as land use features where plant invasions have higher chances of occurrences. Therefore, managers can identify which areas should be targeted for pro-active management. One of the future research directions is to examine whether there is any relationship between equity of urban greenspace and invasive plants occurrences because recent research on greenspace equity in urban areas described a positive relationship between access to urban greenspace and higher income (Nesbitt et al., 2019).

We acknowledge that the model performance in this study could possibly be improved if we could avoid differences in survey protocols among municipalities. Municipalities in MV each have their own way of implementing survey protocols. For example, some municipalities applied survey protocols based on site-specific methods (i.e., inventoried sites that have high biodiversity values), while others used species-specific methods (i.e., inventoried invasive plants that have the highest impacts on local ecosystems). The differences in survey protocols were reflected by our modelling results, as we did not find common relationship between species occurrences and explanatory variables across municipalities. Moreover, priorities for data collection depends on available funding from local governments. Those priorities lead to the issues of differences in number of inventoried greenspaces. Some large municipalities only collect invasive plants inventory data along major roads and trails or in certain areas within a short distance to major roads (e.g., within 100 – 300 metres from a major road), while a small city such as the city of North Vancouver performs a city-wide inventory. Hence, we suggest municipalities in MV follow a protocol that is identical throughout the metropolitan area. Different levels of implementation could be adapted based on available funding in each municipality. To apply explanatory models to a larger scale—regional, provincial, or national—and to examine changes in invasive plants occurrences over time, Vittoz and Guisan (2007) suggested that local governments should apply permanent sample plots to collect presence-absence data.

## 2.5 Conclusion

This study demonstrates that there was a significant relationship between invasive plants occurrences and socio-economic variables including median household income, expenditure for gardening, and population density. Therefore, these significant socio-economic variables should be included in the modelling process of explaining invasive plants occurrences in the region both by municipality and greenspace type. I suggest that in order to understand regional trends a standard survey protocol for the region should be adopted because I found varied sets of significant variables in models by municipality. A base survey protocol may improve model performance, which leads to a higher ability in implementing predictive models of invasive plants occurrences across MV. Lastly, I conclude that greenspace type is one of the key drivers of invasive plants occurrences besides socio-economic, topographic, and land use variables.

# Chapter 3: How does the public perceive the risk of invasive plants in Metro Vancouver?

## 3.1 Introduction

Humans introduce non-native plant species in most urban areas (Gallardo & Aldridge, 2013) for different purposes (e.g., horticultural, ornamental plants). A non-native plant becomes an invasive plant when it dominates an ecosystem and has negative impacts on native species and human well-being (García-Llorente et al., 2008). Therefore, invasive plants are problematic to urban ecosystems, residents, and governments in terms of ecology, economy, and human health (Shackleton et al., 2016). In the Metro Vancouver (MV) region of British Columbia (BC), Canada, regional and provincial governments identify invasive plants as one of the top environmental problems (ISCBC, 2017). In many regions, including MV, the most popular methods of invasive plants management are prevention, control, restoration, and monitoring programs (Bonamo, 2016). Among those methods, prevention is highlighted as the most cost-effective management method, which includes early detection, communication, and education (Kemp et al., 2017; ISCBC, 2017). The invasive species strategy for BC (ISCBC, 2017) also emphasizes the important role of promoting positive behaviour-change of the public via communication and education programs. Recent studies confirmed the importance of engaging the public for invasive plants management (e.g., Olszańska et al., 2016; Hart and Larson 2014; Verbrugge et al., 2013). Communication and education programs help engage the public to get buy-in for management approaches (Hart & Larson, 2014). Moreover, those programs can achieve the public’s support in preventing new species introductions, thus minimizing the spread of existing invasive plants (ISCBC, 2017).

In order to carry out successful communication and education programs about invasive plants, it is necessary to understand the public's perception (Potgieter et al., 2019). The public's perception is defined as the public's knowledge and experience with invasive plants (Estévez et al., 2015). The perception can fall into one of the following three groups: (1) positive perception (e.g., aesthetic values), (2) negative perception (e.g., ecological, economic, or human health impacts), and (3) aggregate perception, including both positive and negative perception or neutral perception (Rotherham and Lambert, 2012). Based on the levels of knowledge and experience of each individual, the risk perception of invasive plants is formed (Santo et al., 2015). For example, if a person only perceives invasive plants negatively, the risk perception of the person is high. Due to the differences in levels of knowledge and personal experiences with invasive plants, the public's risk perception varies by social groups (Novoa et al., 2017). Hence, an assessment of the public's risk perception will enable urban planners to tailor communication and education programs, which fit well with the levels of the public's risk perception (Novoa et al., 2017). In addition, the understanding of differences by social groups based on demographic information can help decision-makers to allocate appropriate funding or utilize effective techniques to target groups and communities (Potgieter et al., 2019).

Verbrugge et al. (2013) assessed the relationships between the lay public's vision of nature and their perception of non-native species, which highlighted how important the assessment of the public's risk perception is for invasive species management. Despite the aforementioned importance, a majority of studies focused on building theoretical frameworks rather than using quantitative analyses to assess the public's risk perception (Shackleton & Shackleton, 2016). Recently, Potgieter et al. (2019) found significant relationships between demographics (e.g., age, education, and ethnicity) and the public's perception of the impacts of invasive plants. The study used the concept of ecosystem services (i.e., positive impacts) and ecosystem disservices (i.e., negative impacts) in order to assess the public's perception of impacts. However, the study used open-ended questions instead of a rating scale. This resulted in economic and human health impacts being mentioned less frequently by the public compared to ecological impacts (Potgieter et al., 2019). Meanwhile, Shackleton et al. (2019) points out the importance of having a quantitative assessment for each component of risk perception in order to understand the public's risk perception.

In MV, local governments have incorporated public communication and education campaigns and have worked closely with non-profit organizations as well as stewardship groups to raise the public's awareness of invasive plants (ISCBC, 2017). An understanding of current levels of the public's risk perception will help managers to determine future directions of outreach and educational programs in the region. Therefore, this research aims to (1) assess the public's risk perception of invasive plants in MV using rating scales for three risk components: ecological, economic, and human health risks, (2) test for associations between the public's risk perception and demographics—age, gender, ethnicity, education, income, and professional or recreational membership, and (3) assess the public's levels of support for current management strategies. The results can be used to inform managers and decision-makers about which groups of people, based on demographic information, should be targeted by outreach activities and relevant management activities. The assessment will also provide local governments with insights into the public's level of awareness and willingness to support current management strategies. Lastly, the outcomes of this research will add to the body of knowledge of assessing the public's risk perception using quantitative methods and scales.

## 3.2 Methods

### 3.2.1 Study area and target invasive plants

The study site is MV, a metropolitan area in BC, Canada (as described in section 2.2.1). According to Environment Canada (2017), MV is classified into five regions based on common topographic features (Figure 3.1).

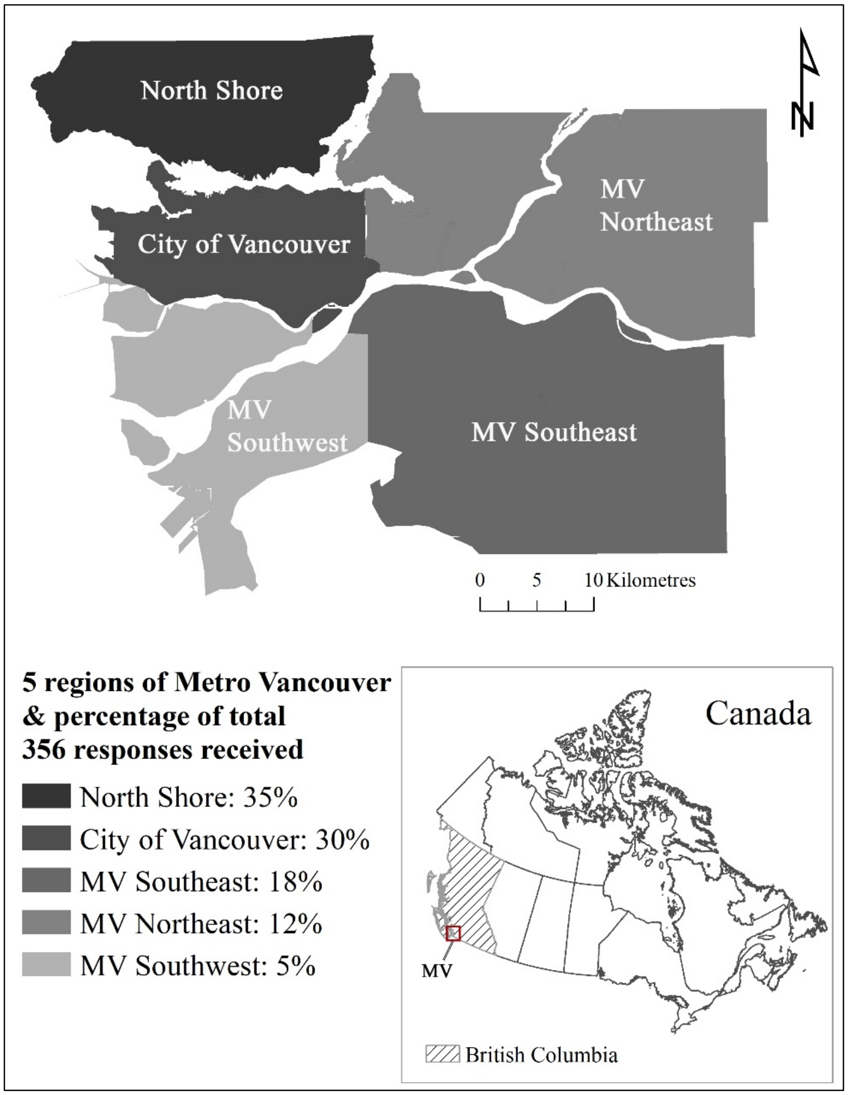



**Figure 3.1. Map of the study area and percentage of total 356 responses received by region across Metro Vancouver (North Shore: Cities of West Vancouver and North Vancouver, District of North Vancouver; City of Vancouver: Cities of Vancouver, Burnaby, and New Westminster; MV Southeast: Cites of Surrey and Langley; MV Northeast: Cities of Coquitlam and Maple Ridge; MV Southwest: Richmond and Delta).**

*Target invasive plants*—We assessed the public's risk perception in terms of ecology, economy, and human health for five invasive plants in this study. In addition to the four target species described in section 2.2.2, we also included Giant hogweed (*Heracleum mantegazzianum* Sommier & Levier). Human health problems such as burns, blisters, and scarring can be caused by Giant hogweed if humans touch the plant (ISCBC, 2017).

### 3.2.2 Data collection

*Survey design*—an online survey was conducted using the Qualtrics survey tool (https://ubc.qualtrics.com). It was open to residents of MV (age 19 or older) during a period of three months starting mid-March 2019. The survey had been approved by the University of British Columbia Behavioural Research Ethics Board before it became available online. The survey consisted of four main parts (Appendix B.1).

The first part of the survey used multiple-choice and two open-ended questions to test the public's general knowledge of invasive plants. The first open-ended question identified the most frequent factors that the public used to define invasive plants. The second open-ended question assessed which impacts were perceived by the public at the highest frequency, which were then identified as high priority impacts. In addition, participants were asked to rate their levels of knowledge about each target species at the end of the first part of the survey.

The second part of the survey assessed the public's risk perception of invasive plants using a 10-point rating scale. Participants were able to rate their overall risk perception of invasive plant problems before rating the ecological, economic, and human health risks separately. We used a 10-point risk-rating scale in order to assess quantitatively how the public perceives risks resulting from invasive plants. Moreover, it allowed us to quantify the difference in the public's risk perception of each target species, among the five sub-regions of MV.

The third part of the survey assessed the levels of willingness to support different management strategies using a 9-point rating scale. The mid-point (5) of the scale indicated the status quo of the funding support for each invasive plant's management strategy. I listed the most current and common management strategies used in MV so that the public could express their management preferences for each invasive plant. I included two follow-up questions for participants who did not support herbicide treatments for Knotweeds and Giant hogweed. The follow-up questions provided the participants with the option to reverse their opinion after reading a provided rationale for herbicide use as best practice for these two species in the region.

The last part of the survey included demographic questions about age, gender, ethnicity, education, annual gross income, environmental experience, and memberships with recreational or professional groups. All demographic questions used in this survey match the questions used in the census surveys of Statistics Canada (Statistics Canada, 2016). The demographic information was collected in order to understand the relationships between the public's risk perception of invasive plants and demographics.

*Recruitment methods*—the survey information was distributed in two phases, each phase included both online and offline distribution methods. In the first phase, we used posters (Appendix B.2) to distribute the information offline at 40 public libraries and community/recreation centres across the MV region. Our selection of libraries and community/recreation centres was limited to our capacity to travel to the locations as well as the local policies of posting research-related information. The online distribution was carried out on websites, social media platforms, and e-newsletters of the Invasive Species Council of Metro Vancouver (ISCMV), and the Cities of Burnaby, and North Vancouver.

In the second phase, we distributed the information via a postal mail and digital ads campaign to 3,000 randomly selected households in the City of North Vancouver. We targeted low housing density areas where single-detached houses and low-rise apartments are located. The main reason for this selection was that these groups of residents may have gardens or greater access to nearby greenspaces than residents living in areas of high housing density (Bigirimana et al., 2012; Cubino et al., 2015). To select 3,000 households, areas of low housing density in the city of North Vancouver (retrieved from Open Data Catalogue of Metro Vancouver, http://www.metrovancouver.org/data) were overlaid with dissemination areas (i.e., areas with a total population of 400 to 700 residents; Statistics Canada, 2016). Dissemination areas were then randomly selected until the total number of households reached 3,000 (Figure 3.2). Postcards (Appendix B.2) were mailed out to the random sample of 3,000 households every two weeks until three postcards in total were sent to each household. In addition to the postal mail, we also included digital ads provided by Canada Post (https://snapadmail.canadapost.ca/Digital-Ads). The information about the survey appeared as online advertising on websites to the same areas of households and lasted for the same period as the postal mail campaign.

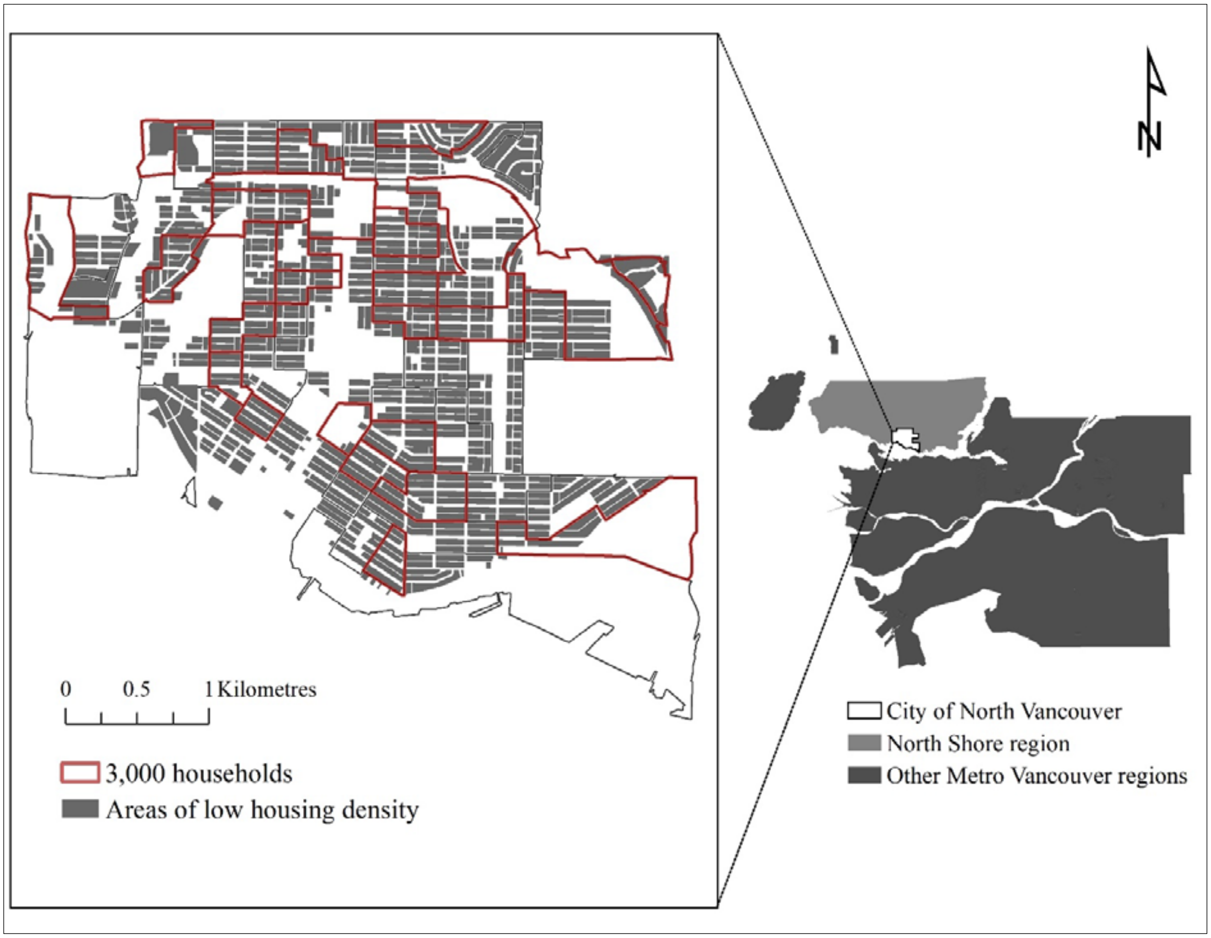



**Figure 3.2. Map of areas where the mail out and digital ads campaign was carried out**

### 3.2.3 Data analysis

Levels of knowledge about invasive plants were determined by responses received to the two open-ended questions about definitions and impacts of invasive plants. For each definition and list of impacts mentioned by participants, different aspects were identified and grouped into topics using NVivo 12.0. In order to assess the public's knowledge, a standard definition and impacts of invasive plants were chosen based on the work of Richardson et al. (2000) and Weber (2017). We compared each participant's response to the standard definition and list of impacts and a level of accuracy was assigned to each. The levels of accuracy included 0: do not know, 1: only one aspect of standard definition/impacts was mentioned, 2: two aspects of standard definition/impacts were mentioned, 3:

three aspects of standard definition/impacts were mentioned, and 4: all aspects of definition/impacts were mentioned, which is the highest level of accuracy. Lastly, each level of accuracy was reported as percentage of total responses received.

Levels of the public's risk perception of each target species were visualized by plotting the mean and standard deviation of each risk component. The summary statistics of the public's risk perception were obtained for each region of MV as well as across the entire region of MV. Linear mixed-effects models were fit using the nlme package (Pinheiro and Bates, R Core Team, 2018) in R (R Core Team, 2018) to test for relationships between the public's risk perception of target species, expressed as ecological, economic, and human health risk rating, and demographics of participants (Table 3.1). Fixed effects were age, gender, education, ethnicity, membership, and income (Table 3.1). A random effect for region was included in the models. The model assumptions (i.e., linearity, equal variance, normality, and independence) were checked using diagnostic plots. Likelihood ratio tests (Ripley, 2002) were performed to test for the significance of the categorical variables and the random region effect.

**Table 3.1. Variables included in linear mixed-effects models**

| Variables | Measurement type | Levels of categorical variables |
|---|---|---|
| **Response variables** | | |
| Ecological risks | Continuous | Not applicable |
| Economic risks | Continuous | |
| Human health risks | Continuous | |
| **Explanatory variables** | | Not applicable |
| Age (actual age) | Continuous | |
| Gender | Categorical | Male<br>Female |
| Education | Categorical | Bachelor's degree or higher<br>Below Bachelor's degree |
| Ethnicity | Categorical | European origins<br>Others |
| Membership | Categorical | No affiliations<br>Professional/recreational groups |
| Income (CAD) | Categorical | 24,000 – 50,000<br>50,000 – 100,000<br>More than 100,000 |

Levels of willingness to support invasive plants management strategies were sorted into one of the following three categories (1) lower funding, (2) same funding, and (3) more funding. The percentages of each category of support for each species were reported. The four management strategies mentioned in the survey were classified into active and passive management from the community's point of view. Active management included "community pulls invasive plants" and "community plants native species". Passive management included "printed materials" and "removal by city crews". In addition, the level of support for herbicide treatment was assessed for the group of participants who did not support herbicide treatment in the initial question. This group was divided into two sub-groups based on their response after they read the provided explanation and decided to 1) reverse their opinion, or 2) still vote against herbicide treatment. The differences between the two sub-groups with regards to levels of knowledge, risk perception levels, and their demographics were tested with t-tests (Student, 1908; Kalpić et al., 2011) or contingency tables (Pearson, 1904; Van Belle et al., 2004) in conjunction with Pearson's Chi-square test (Pearson, 1900) depending on the measurement type of the variable tested (see Table 3.2).

**Table 3.2. Variables and tests used for herbicide treatment questions**

| Variables | Measurement type | Test used |
|---|---|---|
| Levels of species knowledge<br>Levels of three risk components<br>Age | Continuous | t-test |
| Gender<br>Ethnicity<br>Education<br>Income | Categorical | Pearson's Chi-squared test<br>(a contingency table was constructed for each categorical variable) |

## 3.3 Results

### 3.3.1 Participants are diverse in terms of demographics across Metro Vancouver

The risk perception survey received 356 responses across MV. The responses received on the North Shore, in the City of Vancouver, and in Southeast MV accounted for 83% of the total responses received (Figure 3.1). Northeast and Southwest MV had the lowest number of responses, which accounted for 17% (Figure 3.1).

Participants were between the ages of 19 and 83, with 82% of them aged between 25 and 65 (Table B.3.1, Appendix B.3). Females accounted for 59% of the participants, followed by male and others (Table B.3.2, Appendix B.3). More than half of the total participants had European origins while Asian, North America Aboriginal origins, and other North American origins accounted for only one-third of the total responses received (Table B.3.3, Appendix B.3). 39% of participants had higher income levels compared to the median household income of MV ($72,662; Statistics Canada 2016) and the City of North Vancouver ($67,119; Statistics Canada 2016); and 41% of participants had an annual household income between 50,000 – 100,000 CAD (Table B.3.4, Appendix B.3). The number of participants who had a bachelor's degree or higher levels of education (57%) was higher than that of MV (30.6%; Statistics Canada 2016) and the city of North Vancouver (43%; Statistics Canada 2016). Lastly, roughly one-third of the total participants reported professional and/or recreational memberships, in which 9% of the participants had both professional and recreational affiliations (Table B.3.5, Appendix B.3).

### 3.3.2 The public tends to pay attention to ecological aspects while underestimating the economic and human health aspects of invasive plants

Invasive plants were defined as follows: “An invasive species is a species that is not native to a specific location, and that has a tendency to spread to a degree believed to cause damage to the environment, human economy or human health” (Richardson et al., 2000; Weber, 2017). Four aspects were included in this standard definition: (1) non-native species, (2) ecological impacts, (3) ecological characteristics, and (4) other negative impacts such as economic and human health impacts.

The survey results showed that all four aspects of the standard definition were mentioned by the public in their definition of invasive plants (Figure 3.3a). However, the public emphasized ecological aspects including ecological impacts (i.e., reduces native ecosystem values), ecological characteristics (i.e., aggressive growth), and non-native species. Less attention was given to the economic and human health aspects of invasive plants (Figure 3.3a). A similar tendency was found when we compared the public’s definition of invasive plants with the standard definition, with a strong focus on ecological characteristics and impacts of invasive plants (Figure 3.3.b). 72% of the total participants used one aspect or two aspects in their definition of invasive plants (Figure 3.3b). Accuracy level 1 was either “non-native” or “negative impacts on native species”, and accuracy level 2 included both. Only 21 of the survey participants (6%) reached the highest level of accuracy, with all four aspects of the standard definition mentioned. 15 out of those 21 participants had either professional or recreational group memberships.

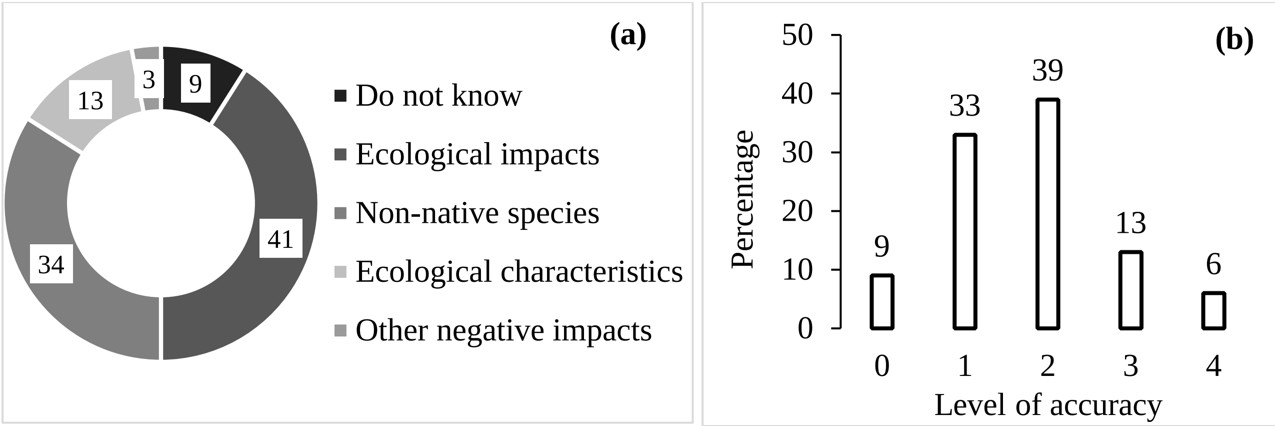



**Figure 3.3. Percentage of (a) topics mentioned by the public in their definitions, and (b) accuracy levels of responses compared to the standard definition**

Impacts of invasive plants provided in existing literature include both positive (e.g., aesthetic values; food values) and negative impacts (e.g., ecological, economic, and human health impacts) (Richardson et al., 2000; Weber, 2017). Based on the standard list of impacts, this study used four groups of impacts as follows: (1) negative ecological, (2) economic, (3) human health, and (4) positive impacts.

The list of impacts reported by the public was relevant to aspects that they used to define invasive plants at the beginning of the survey. 63% of the responses only reported negative ecological impacts of invasive plants on native ecosystems (Figure 3.4a). Economic and human health impacts were mentioned by only 13% (Figure 3.4a). Positive impacts were mentioned by the public more frequently than both economic and human health impacts combined (Figure 3.4a). Roughly, one-third of the participants mentioned two out of four impacts in the standard list (Figure 3.4b). The second-largest group of participants (i.e., 27%) only listed one impact, which was either an ecological or economic impact. In contrast, the percentages of participants who listed three or four impacts were low with 15% and 13%, respectively.

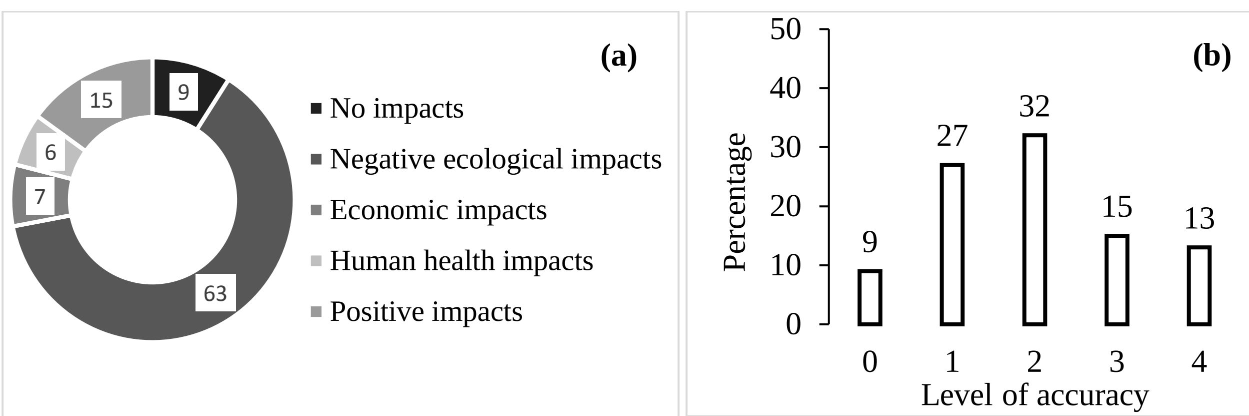



**Figure 3.4. Percentage of (a) impacts mentioned by the public in their impact lists, and (b) accuracy levels of the public's responses compared to the standard impact list**

### 3.3.3 The public's self-reported levels of knowledge about target species vary across Metro Vancouver

Participants across MV self-reported their levels of knowledge about target species from 1 to 10 out of the 10-point rating scale, except for Knotweeds, which had the lowest self-reported level of 0. Overall, participants rated themselves at higher levels of knowledge with regards to English ivy and Himalayan blackberry compared to other target species across MV (Figure 3.5). Meanwhile, Yellow archangel and Giant hogweed were the ones least recognized by the public among the five target species (Figure 3.5). Regarding the public's levels of knowledge in each region of MV, participants from the City of Vancouver and the Northeast region tended to rate themselves at higher levels of knowledge compared to the other regions. Participants from the North Shore and Southeast regions rated themselves at lower levels compared to the other three regions (Appendix B.4).

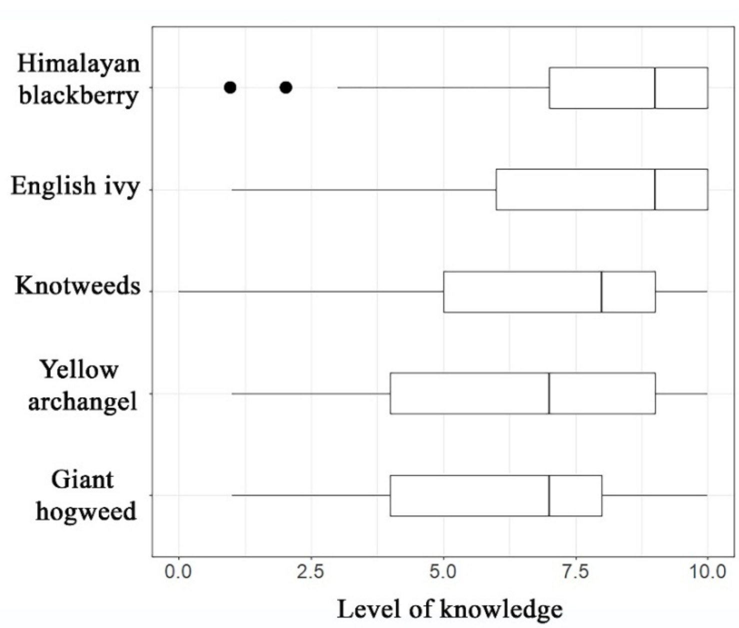



**Figure 3.5. The public's self-reported levels of knowledge about five target species across Metro Vancouver**

### 3.3.4 The risks perceived by the public are equal or above the average level of the 10-point rating scale and positively associated with age and income

The public rated overall risk caused by invasive plants around 7 out of the 10-point rating scale across MV. However, the Northeast region had a slightly higher average rating for overall risk compared to the average values of the other regions as well as across MV (Figure 3.6). The Southwest region had higher variability for the overall risk compared to the rest of the regions.

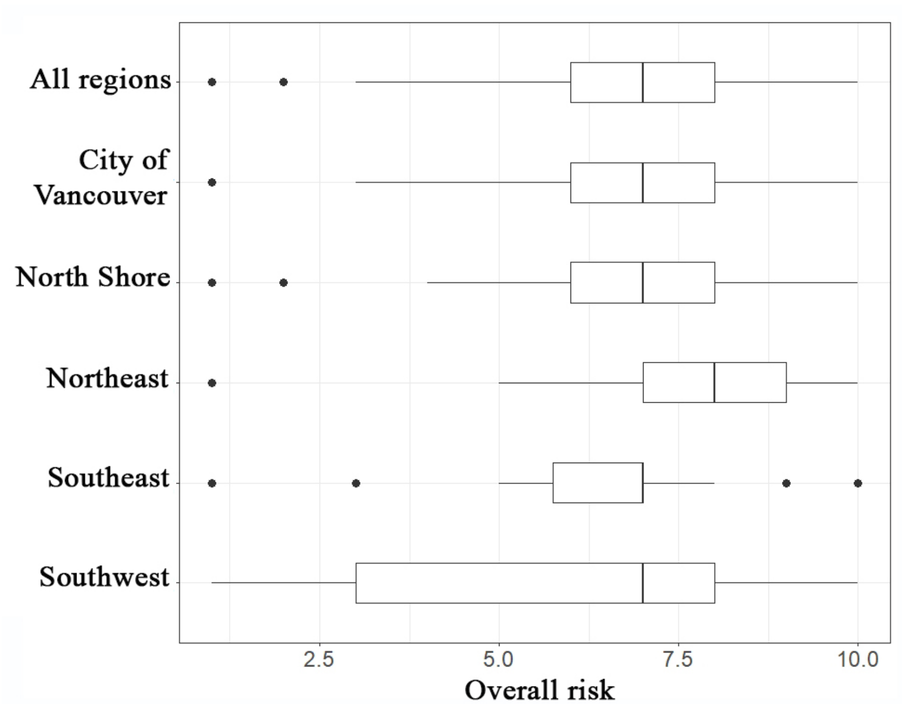



**Figure 3.6. Levels of overall risk considering invasive plants rated by participants**

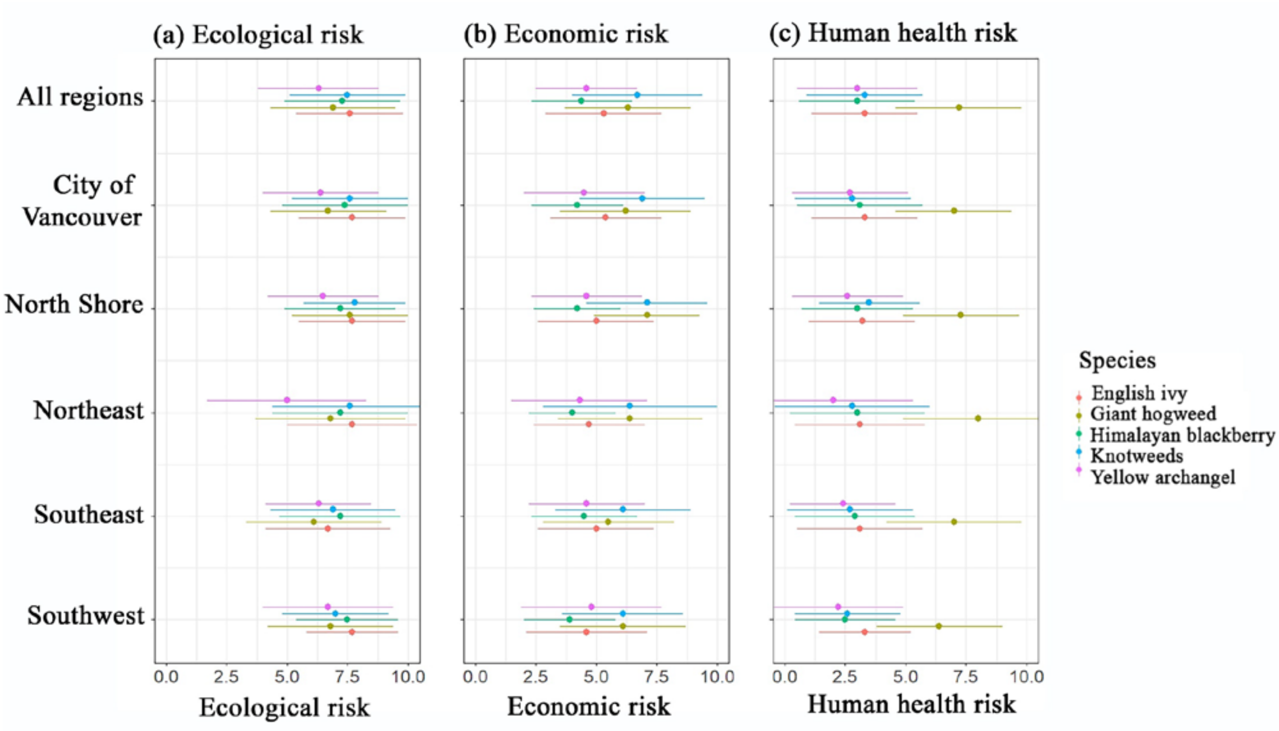



**Figure 3.7. Three risk components rated by the public for each invasive plant: (a) ecological, (b) economic, and (c) human health risks**

*Ecological risks (Figure 3.7a)*—English ivy and Knotweeds were rated at high ecological risk while Yellow archangel was rated at the lowest ecological risk compared to the other target species across MV. Giant hogweed and Himalayan blackberry were perceived to have similar levels of ecological risks.

*Economic risks (Figure 3.7b)*—The public considered Knotweeds and Giant hogweed as the two species of high priority in terms of economic risks compared to the other target species. In contrast, Himalayan blackberry and Yellow archangel were perceived to have the least economic risks compared to the other species across MV. English ivy was perceived to have higher economic risks compared to Himalayan blackberry and Yellow archangel.

*Human health risks (Figure 3.7c)*—Giant hogweed was rated as the human health concern with the highest priority by the public while the other four target species were rated at substantially lower levels of human health risks (Figure 3.7c). Yellow archangel was the one species with the least concern in terms of human health across MV, especially in the Northeast region.

*The association between the public's risk perception and age, income, and professional or recreational membership*—Older participants perceived ecological, economic, and human health risks at higher levels ($p < 0.05$). Also, among participants of the same age, the three risk components were perceived at higher levels by participants who had income levels higher than $50,000 annually ($p < 0.005$). However, only ecological risk models had both age ($p < 0.001$ for English ivy, and $p < 0.04$ for the other species) and income ($p < 0.05$) as significant variables for all target species. In the models of economic risk, age ($p = 0.03$ for Knotweeds; and $p = 0.04$ for Giant hogweed) and income ($p = 0.01$ for Knotweed; and $p = 0.05$ for Giant hogweed) were significant in the models for Knotweed and Giant hogweed only. Participants who had professional and/or recreational group memberships perceived higher economic risks for Giant hogweed compared to participants without memberships ($p = 0.03$). Regarding human health risk, age ($p = 0.03$) and income ($p = 0.01$) were significantly associated with risk perception of Giant hogweed, but not with any of the other target species.

### 3.3.5 Active management strategies are highly supported by the public

*Active management strategies (i.e., community takes part in the activities directly)*—The public gave higher levels of support to community events (e.g., community invasive pulls; Figure 3.8a) and they wanted to plant native plant species (Figure 3.8b). The number of participants who rated "more funding" for active management strategies was higher than that of other levels of support across all target species. According to the responses received, the participants particularly mentioned that they expected local governments to ban some invasive ornamental plants from local nurseries and plant stores. However, the public indicated that they wanted to reduce funding for the community pulls of Himalayan blackberry and Yellow archangel rather than keeping the same amount of funding.

*Passive management strategies (i.e., community does not take part in activities directly)*—Printed materials were not preferred by the public (Figure 3.8c). However, the removal by city crews was highly supported (i.e., English ivy), except for Himalayan blackberry with the lowest levels of support (Figure 3.8d).

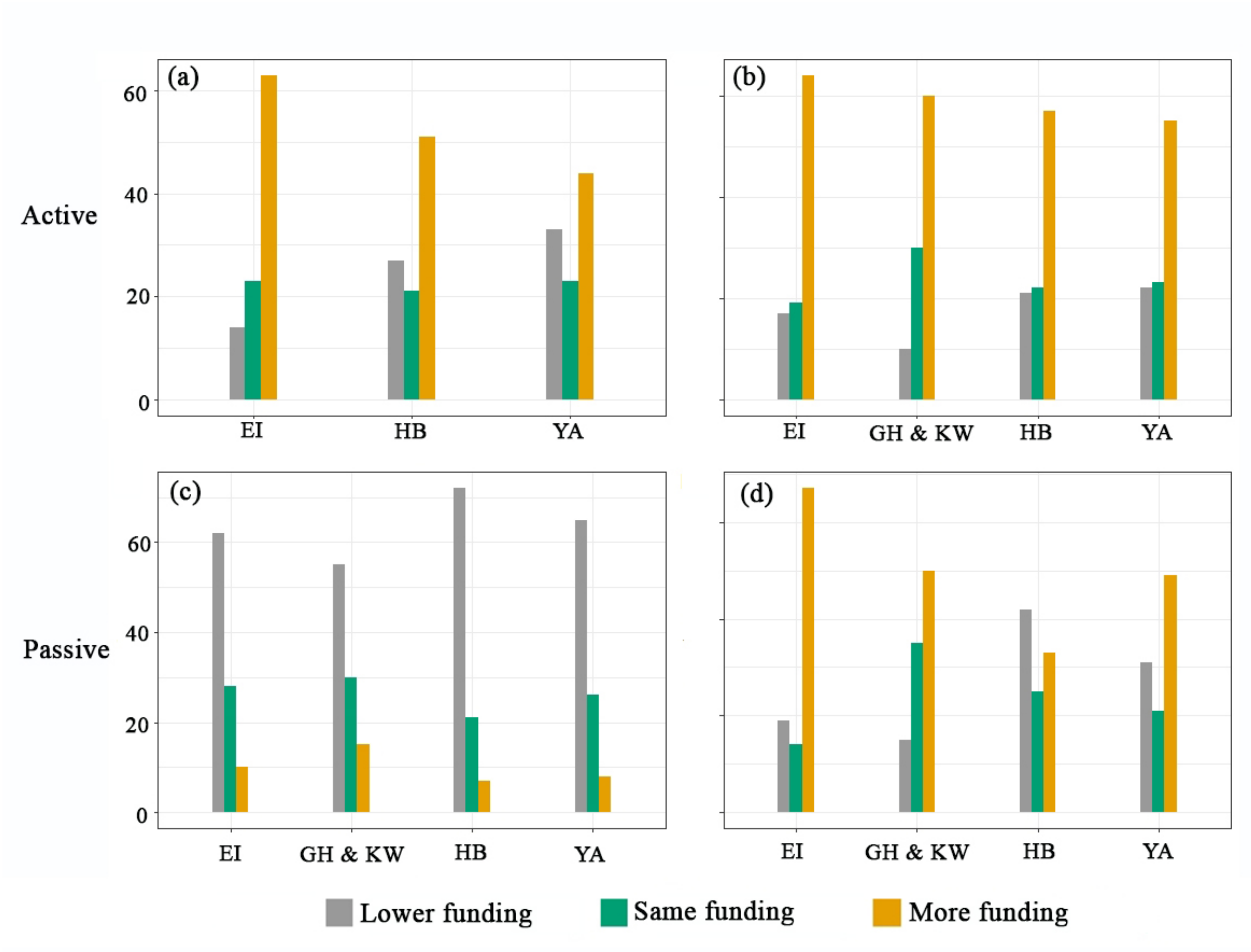



**Figure 3.8. Percentage of levels of willingness to support management approaches for the five target species: EI = English ivy; GH = Giant hogweed; KW = Knotweeds; HB = Himalayan blackberry; YA = Yellow archangel; (a) Community pulls invasive plants, (b) community plants native species, (c) printed materials, and (d) removals by city crews**

### 3.3.6 Almost half of the opposing participants reversed their opinions to support herbicide treatments after reading the provided rationale

*Giant hogweed*—38 participants did not support using herbicide treatments for Giant hogweed. The average level of knowledge of this group was low (4.5/10). They also tended to rate the three risk components at levels ranging from 5.1 to 6.2. None of the 38 participants had professional or recreational affiliations. 27 out of the 38 participants (71%) had below bachelor education level. Regarding income, 30 out of the 38 participants (79%) had income levels of $50,000

– $100,000 or higher. After reading an explanation providing the rationale for using herbicide treatments**,** 22 out of the 38 participants reversed their opinions to support herbicide treatments for Giant hogweed, while the response of the other 16 participants remained unchanged. The results of the t-test for human health risk ($p = 0.048$) and Pearson's Chi-squared test for education ($p = 0.035$) suggested that the group who reversed their opinion had significantly higher levels of human health risk perception and education compared to the group that did not change their opinion about herbicide use.

*Knotweeds*—42 participants did not support using herbicide treatments for Knotweeds. 36 out of these 42 participants neither supported herbicide treatment for Giant hogweed at first. The level of knowledge about Knotweeds was on average 5.9 out of 10. Ecological and economic risks ranged from 5.8 to 6.7 out of 10, which was lower compared to the whole population mean (7.6/10). Human health risks were rated at a substantially lower average (3.6/10) by these 42 participants. None of the 42 participants had professional or recreational affiliations. 27 out of the 42 participants (64%) had education below bachelor level. However, a majority of them (67%) had average or high levels of income. After reading the provided reasons for using herbicide treatment, 20 out of 42 participants reversed their opinions to support herbicide treatment while the responses of the other 22 remained unchanged. The 20 participants were the same people out of 22 participants who reversed their opinion to support herbicide treatment for Giant hogweed. The t-test showed that participants who reversed their opinion were older (p-value = 0.038) and had significantly higher levels of self-reported knowledge about Knotweeds (p-value = 0.019). However, no significant difference in the demographics (e.g., gender, education, ethnicity, and income) of the two groups was found (p-values > 0.2).

## 3.4 Discussion

This chapter aims to assess the public's risk perception of invasive plants in MV. Our findings showed that the public was well informed about ecological aspects and risks of invasive plants on native ecosystems. However, the public tended to underestimate or not know much about the economic and human health risks of invasive plants. Among demographic variables, age and income had positive relationships with the public's risk perception of two or more target species. Active management strategies were highly supported by the public compared to passive management strategies. Herbicide treatment was not supported by a group of participants who had low levels (e.g., less than 5 out of 10-point rating scale) of knowledge and risk perception about invasive plants. However, an explanation of herbicide treatment as best management practice showed positive effects on receiving support for implementing management activities from the public.

### 3.4.1 Survey participants represent a highly educated population in Metro Vancouver

The survey participants of this study were mostly highly educated residents of MV, which is suggested by the fact that the demographics of our survey participants are not representative of the demographics of the general lay public in MV and the city of North Vancouver (Section 3.3.1). Therefore, the reported risk perception may not be representative of the risk perception of the general lay public, especially the groups with lower levels of income and education. The main reasons for receiving survey responses from a highly educated group of MV citizens may be due to our recruitment strategies. First, the participants had access to our survey via email or websites of local organizations for which they had memberships or affiliations, and therefore, most of the participants were already informed about invasive plants. Second, our selection of low housing density in the City of North Vancouver targeted residents who have higher income levels compared to the median household income of the city (Statistics Canada, 2016). However, our recruitment strategies were based on the rationale that we assessed the risk perception of groups who had experiences with gardens and parks more than others; and therefore, more likely to have experiences with invasive plants (Zhai et al., 2018). As a result, the scope of inference for this study is limited to highly educated groups of the public who already have certain levels of knowledge and experiences with invasive plants in MV.

### 3.4.2 The public's self-reported knowledge is ecologically-oriented and higher than their actual knowledge

The public associates both positive and negative aspects with invasive plants. Therefore, the concept of invasive plants is dynamic to the public because it depends on personal knowledge and experiences (Lindemann-Matthies, 2016). However, the perceived negative aspects of invasive plants are mainly ecological because ecological characteristics of invasive plants (e.g., aggressive growth, no natural competitors) are the most obvious traits (Andreu et al., 2009). Our findings of the most frequent aspects—negative ecological impacts—mentioned by the public agree with the findings of Andreu et al. (2009), Lindemann-Matthies (2016) and Potgieter et al. (2019) that invasive plants are mostly known by their impacts on native species and ecosystems due to their ecological characteristics. Meanwhile, economic and human health aspects were found to be perceived least important by the public (Bardsley and Edwards-Jones, 2007) because these impacts come later to the process of invasions and can be less noticed by the public (Bremner et al., 2007).

The public ranked their knowledge at high levels because they have good understanding of ecological aspects of invasive plants (Rotherham and Lambert, 2011). Yet, they were not knowledgeable about economic and human health impacts, which resulted in low accuracy levels of their definition and impact list. Besides the personal education and experiences, the knowledge gap between the public's self-rated knowledge and the actual accuracy levels might be a result of management strategies that are strongly focused on ecological impacts (Selge et al., 2011; Verbrugge et al., 2013). For example, outreach campaigns emphasize the importance of protecting native species by preventing invasive plants, while economic and human health risks are mentioned but not supported by specific examples (ISCBC, 2017). In addition, the knowledge gap between the public perception and the actual risks caused by invasive plants has been reported as consequence of the media focusing on ecological-oriented impacts of invasive plants (Gozlan et al., 2013).

### 3.4.3 Age, income, and membership are three significant indicators of the public's risk perception

The public's awareness, values, and beliefs reflect their perception of the surrounding environment in general (Taylor et al., 1987) and perception of invasive plants in particular (Estévez et al., 2014). Moreover, personal experiences with the natural environment partly shape the environmental perception of individuals (Taylor et al., 1987). Therefore, age is a significant indicator of the public's risk perception of invasive plants because older people may have had greater exposure to invasive plants compared to younger people. This finding is in line with Bremner and Park (2007) and Potgieter et al. (2019), who also found a positive relationship between the public's perception of negative impacts and the age of survey participants. Older people may be more interested in gardening activities compared to young people (Wang and MacMillan, 2013), and young people may have opportunity to garden or less capacity to afford housing that has gardens (Teixeira, 2009). The interest in gardening activities can lead to extensive experiences with invasive plants among the group of older people (Cubino et al., 2015). Higher levels of income explained higher levels of risk perception because income may be confounded with levels of education and types of environmental experiences (e.g., larger garden, easier access to natural areas) (Nesbitt et al., 2019). In the previous chapter, we also found that wealthier neighbourhoods in MV are more likely to experience invasive plants occurrences. Hence, this can be a good indicator of why the group of higher income levels tends to perceive higher levels of risks caused by invasive plants.

Interestingly, the relationships between age and income and the public's risk perception found in ecological risk models are also true for Knotweeds and Giant hogweed in terms of economic and human health risks. The differences in perception among individuals at species-level is a key reason for this (Rotherham and Lambert, 2011; Shackleton and Shackleton, 2016). For example, a person can know one invasive plant very well, but has no idea about the other invasive plant. In the case of MV, Knotweed and Giant hogweed are well known because of their economic and human health impacts, respectively (ISCBC, 2017). Therefore, Giant hogweed is perceived at higher economic risks by participants who are affiliated with professional or recreational groups. Meanwhile, other participants without memberships tend to have little knowledge about economic costs caused by this species. This finding aligns with previous research on higher levels of awareness and risk perception of people who are associated with either environmental or recreational organizations (Eiswerth et al., 2011; Gaertner 2017). The group of participants with membership tends to have prior experience with conservation knowledge or activities, and therefore, they may have expert levels of knowledge, which cannot be found in the perception of the lay public (Taylor et al., 1987; Bremner and Park, 2007; Cottet et al., 2015). It may also be due to the fact that we received responses from highly educated participants who have higher levels of knowledge about invasive plants.

### 3.4.4 Levels of willingness to support active management strategies exceed support of passive management strategies

Active management strategies (e.g., community plants native species) are highly supported because the public considers this to be the simplest way to be involved (Wittenberg and Cock, 2001; McCarthy et al., 2007). Another reason is that active management strategies make the public feel engaged (McCarthy et al., 2007), and community events, where volunteers manually pull invasive plants, have positive effects on the awareness of the locals (Crall et al., 2015). Lastly, the participants represent highly educated groups of the public (Section 3.3.1; Statistics Canada, 2016). Therefore, they may be more interested in activities they can directly be involved in.

In contrast, hard-copied materials were not preferred by the public in this study, who preferred information about invasive plants via websites. This is in line with previous findings that printed materials are one of the least effective communication strategies (Wittenberd and Cock's 2001). Due to the fact that most of participants were highly educated, they may have more access to technologies and computers than the general public on average (Anderson, 2015). Therefore, the participants preferred web-based information over printed materials. However, printed materials might work well with groups of lower income and education levels (Palmer, 2002; Anderson, 2015).

When it comes to the manual removal by city crews for Himalayan blackberry, it is not surprising that the public gave low levels of support for removing this species. The public wants to keep Himalayan blackberry because they value the fruits of this species (Weber, 2017), and therefore this value can affect the public preferences of management strategies (Slimak and Dietz, 2006). Lindemann-Matthies (2016) found a similar tendency in the public's levels of support for manual removal of Summer lilac in Switzerland: the willingness to remove Summer lilac decreased with an increase in its perceived values of beauty.

An explanation of management approaches has been confirmed to have positive effects on the public's support in management activities (Gobster, 2011). In our case of Giant hogweed and Knotweeds, the provided short explanations resulted in changes in the participants' opinions with regards to herbicide treatment, which aligns with previously reported positive impacts of education materials on the lay public's management preferences (Sharp et al., 2011; Schreck Reis et al., 2010). The participants who reversed their opinion had high prior self-reported knowledge, and therefore, they were willing to learn from provided education materials (Dickinson et al., 2012; Novoa et al., 2017). This may explain why this group of participants reversed their opinion while other participants still voted against herbicide treatment.

## 3.5 Conclusion

Firstly, the public’s knowledge and risk perception of invasive plants in MV are ecologically oriented. Therefore, I conclude that it is necessary to increase the emphasis of the economic and human health impacts of invasive plants in future outreach campaigns. This can be accomplished by tailoring outreach materials in a way that informs the public about economic and human health impacts caused by invasive plants in addition to ecological risks, which the public is already well informed about. Secondly, our finding of positive relationships between age, income, and professional or recreational membership implies that future outreach programs should target demographic groups who currently perceive invasive plants at lower risks: low-income groups, young people (e.g., 19-25 years old), and people without professional or recreational memberships. I also conclude that managers may get high levels of support for future outreach programs from the public if they continue to implement active management strategies (e.g., community events of native species planting and pulls). Therefore, managers can choose to focus on this type of management approach to engage and get buy-in from highly educated groups of the public. Moreover, special management approaches such as herbicide treatment should be well explained to the public in order to get higher levels of support. Lastly, I acknowledge that participants of this study represent highly educated groups of the MV public. Hence, it is necessary to take this into account before making any further inference to the population of the general public in MV.

# Chapter 4: Conclusion

## 4.1 Overall conclusion

This thesis contributes to a nuanced understanding of species occurrences and the public's risk perception of invasive plants in Metro Vancouver (MV), British Columbia (BC), Canada. In chapter 2, I found that socio-economic variables (i.e., median household income, gardening expenses, single-detached house density, and population density) are drivers of species occurrences, but the sets of significant variables varied by municipality. Moreover, greenspace type was found to be a surrogate for some socio-economic as well as other variables (i.e., total area of greenspace, distance to water channel). Overall, I conclude that the relationships between species occurrences and tested socio-economic variables as well as greenspace type identify key drivers of species occurrences. As a result, the key drivers can be used to develop predictive models of invasive plants occurrences in urban greenspaces of MV. The predictive models can provide managers with information of where to target future prevention efforts of invasive plants.

In chapter 3, I found that ecological aspects of invasive plants dominate the public's risk perception and levels of knowledge. Economic and human health risks are perceived at higher levels by people who have either professional or recreational memberships. Older and high-income groups perceived higher ecological risks. I also found that the public's management preferences are given to active management activities that community can get involved over passive management activities such as printed materials. The understanding of the public's levels of knowledge, risk perception, and willingness to support management activities can help managers to identify what levels and types of outreach programs fit with the public's current knowledge of invasive plants and management preferences.

## 4.2 A regional base protocol for pro-active management of invasive plants

The difference in the selection of greenspace and survey protocols used by municipalities (e.g., site-specific versus species-specific surveys) was one of the challenges to this study in terms of finding sets of significant variables across the region for predicting species occurrences. Hence, I suggest municipalities in MV follow a regional survey protocol that is identical throughout the metropolitan area. The criteria to select which greenspace areas to survey, time of the year, and data collection protocol should be similar across the region. However, different levels of implementation could be available so that it can be adapted based on available funding in each municipality. In order to apply explanatory models to a larger scale (e.g., regional, provincial or national scale) and to look at changes over time, it is recommended that municipalities should apply permanent sample plots to collect presence-absence data (Vittoz and Guisan, 2007). Implementing a base survey protocol with permanent sample plots across the region could improve the data quality and aid the process of developing explanatory models to identify key drivers of invasive plants occurrences (e.g., socio-economic factors). Based on the understanding of key drivers from explanatory models, we can develop predictive models for mapping invasive plants in the region, in addition to remote sensing data, to achieve a better prediction outcome (Jiménez-Valverde, 2006; Gallardo and Aldridge, 2013; Rocchini et al., 2015).

The tested relationships between species occurrences and socio-economic variables demonstrate that it is promising to use existing socio-economic data in explanatory models for invasive plants in many urban areas. Besides socio-economic variables, greenspace type is also an important factor that needs to be included in explanatory models because it incorporate socio-economic as well as topographic information. Managers can use key drivers of invasive plants occurrences found in this study (e.g., median household income, gardening expenses, and greenspace type) to gain insights on which areas are of high risk for plant invasions with regards to socio-economic characteristics and type of greenspace. As a result, the insights may aid managers in determining where they should target spread prevention management and outreach programs.

### 4.3 The understanding of the public's risk perception aids future outreach programs

The process of developing and implementing outreach programs is affected by the current understanding of planners about the public's awareness and preferences related to invasive plants (Wittenberg and Cock, 2001). Therefore, the findings on the public's ecologically-oriented knowledge and risk perception of invasive plants can provide planners with a subtle understanding of what aspects of impacts resulted from invasive plants they should emphasize in future outreach programs. Knowing that the public prefers active management strategies will aid planners in selecting the type of outreach activities that align with the public's preferences (Wittenberg and Cock, 2002; Palmer, 2002). One challenge in this study is that the understanding of the public's risk perception found in chapter 3 is based only on highly educated participants of the general MV public. Therefore, the inference is restricted to the public with similar demographic characteristics only. In the future, the recruitment method could be improved by distributing survey information on public transits (e.g., buses, sky trains) to reach out to more representative participants from the general lay public (e.g., including groups of lower-income, and education levels).

Lastly, the relationships found between the public's risk perception and demographics—age, income, and professional and/or recreational memberships—were in line with in the results from chapter 2 that wealthy, educated groups had more experience with invasive plants. In chapter 2, wealthier neighbourhoods experience higher chances of species occurrences (Section 2.3.2). In chapter 3, wealthy educated groups knew more and also perceived invasive plants at higher risks (Section 3.3.4). Based on the aforementioned findings, I conclude that managers and planners can receive buy-in for future outreach campaigns from wealthy, educated groups, because these groups have prior awareness of problems caused by invasive plants. However, future outreach campaigns need to provide detailed enough information (e.g., see our example of herbicide treatment questions) on the rationale of each management activity so that the public not only knows about it but is also willing to take action and support management activities. Furthermore, a spatial link between the public's risk perception and species occurrences is needed to achieve a better understanding of where to spatially target public outreach and education campaigns across Metro Vancouver.

## Bibliography

Akaike H. (1974). A New Look at the Statistical Model Identification. In: Parzen E., Tanabe K., Kitagawa G. (eds) Selected Papers of Hirotugu Akaike. Springer Series in Statistics (Perspectives in Statistics). Springer, New York, NY

Akasaka, M., Osawa, T., & Ikegami, M. (2015). The role of roads and urban area in occurrence of an ornamental invasive weed: a case of Rudbeckia laciniata L. Urban Ecosystems, 1021–1030.

Anderson, N. (2015). Digital technologies and equity: gender, digital divide and rurality. Teaching and digital technologies: Big issues and critical questions, 46

Andreu, J., Vila, M., & Hulme, P. E. (2009). An assessment of stakeholder perceptions and management of noxious alien plants in Spain. Environmental Management. 43(6), 1244.

Bardsley, D. K., & Edwards-Jones, G. (2007). Invasive species policy and climate change: social perceptions of environmental change in the Mediterranean. Environmental Science & Policy, 10(3), 230-242.

Beatley, T. (2012). Green urbanism: Learning from European cities. Island Press.

Bell, S., Montarzino, A., & Travlou, P. (2007). Mapping research priorities for green and public urban space in the UK. Urban Forestry and Urban Greening, 6(2), 103–115.

Bellard, C., Cassey, P., & Blackburn, T. M. (2016). Alien species as a driver of recent extinctions. Biology letters, 12(2), 20150623.

Bigirimana, J., Bogaert, J., De Cannière, C., Bigendako, M. J., & Parmentier, I. (2012). Domestic garden plant diversity in Bujumbura, Burundi: role of the socio-economical status of the neighborhood and alien species invasion risk. Landscape and Urban Planning, 107(2), 118-126.

Bonanno, G. (2016). Alien species: To remove or not to remove? That is the question. Environmental Science and Policy, 59, 67–73.

Borgmann, K.L. and Rodewald, A.D. (2005). Forest restoration in urbanizing landscapes: interactions between land uses and exotic shrubs. Restoration Ecology, 13(2), pp.334-340.

Branco S, Videira N, Branco M, Paiva MR. (2015). A review of invasive alien species impacts on eucalypt stands and citrus orchards ecosystem services: Towards an integrated management approach. J Environ Manage. 149, 17-26.

Braquinho, C., Cvejić, R., Eler, K., Gonzales, P., Haase, D., Hansen, R., … Železnikar, Š. (2015). A typology of urban green spaces, ecosystem services provisioning services and demand, 7, 68.

Bremner, A., & Park, K. (2007). Public attitudes to the management of invasive non-native species in Scotland. Biological conservation, 139(3-4), 306-314.

Burkman, C.E. and Gardiner, M.M. (2014). Urban greenspace composition and landscape context influence natural enemy community composition and function. Biological control, 75, 58-67.

Canadian Food Inspection Agency.(2005). Invasive Alien Plants in Canada. Technical Report.

Chance Curtis M., Coops Nicholas C., Plowright Andrew A., Tooke Thoreau R., Christen Andreas, Aven Neal. (2016). Invasive Shrub Mapping in an Urban Environment from Hyperspectral and LiDAR-Derived Attributes. Frontiers in Plant Science, 7, 15-28.

Charles H., Dukes J.S. (2008). Impacts of Invasive Species on Ecosystem Services. In: Nentwig W. (eds) Biological Invasions. Ecological Studies (Analysis and Synthesis), vol 193. Springer, Berlin, Heidelberg.

Colautti RI, Bailey SA, van Overdijk CDA, Amundsen K, MacIsaac HJ. (2006). Characterised and Projected Costs of Nonindigenous Species in Canada. Biol Invasions. 8(1), 45-59.

Coutts, S. R., van Klinken, R. D., Yokomizo, H., & Buckley, Y. M. (2011). What are the key drivers of spread in invasive plants: dispersal, demography or landscape and how can we use this knowledge to aid management?. Biological invasions, 13(7), 1649-1661.

Cottet, M., Piola, F., Le Lay, Y. F., Rouifed, S., & Riviere-Honegger, A. (2015). How environmental managers perceive and approach the issue of invasive species: the case of Japanese knotweed s. l.(Rhône River, France). Biological invasions, 17(12), 3433-3453.

Cubino, J.P., Subirós, J.V. Lozano, C.B. (2015). Propagule pressure from invasive plant species in gardens in low-density suburban areas of the Costa Brava (Spain). Urban Forestry & Urban Greening, 14, 941-951.

Crall, A. W., Jarnevich, C. S., Young, N. E., Panke, B. J., Renz, M., & Stohlgren, T. J. (2015). Citizen science contributes to our knowledge of invasive plant species distributions. Biological invasions, 17(8), 2415-2427.

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., ... & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment, 10(6), 291-297.

Early R, Bradley BA, Dukes JS, et al. (2016). Global threats from invasive alien species in the twenty-first century and national response capacities. Nat Commun. 7, 12485.

Ehrlén, J., & Morris, W. F. (2015). Predicting changes in the distribution and abundance of species under environmental change. Ecology Letters, 18(3), 303-314.

Eiswerth, M. E., Yen, S. T., & van Kooten, G. C. (2011). Factors determining awareness and knowledge of aquatic invasive species. Ecological economics, 70(9), 1672-1679.

Environment Canada. (2017). Important changes to British Columbia weather forecast regions. Metro Vancouver.

Estévez, R. A., Anderson, C. B., Pizarro, J. C., & Burgman, M. A. (2015). Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. Conservation Biology, 29(1), 19–30.

Frid, L., Knowler, D., Murray, C., Myers, J., & Scott, L. (2009). Economic Impacts of Invasive Plants in British Columbia. Williams Lake, BC.

Foster J, Sandberg LA. (2010). Friends or foe? Invasive species and public green space in Toronto. Geogr Rev. 94(2), 178-198.

García-Llorente, M., Martín-López, B., González, J. A., Alcorlo, P., & Montes, C. (2008). Social perceptions of the impacts and benefits of invasive alien species: implications for management. Biological Conservation, 141(12), 2969-2983.

Graça, M., Alves, P., Gonçalves, J., Nowak, D.J., Hoehn, R., Farinha-Marques, P. and Cunha, M. (2018). Assessing how green space types affect ecosystem services delivery in Porto, Portugal. Landscape and Urban Planning, 170, 195-208.

Gaertner, M., Larson, B. M., Irlich, U. M., Holmes, P. M., Stafford, L., van Wilgen, B. W., & Richardson, D. M. (2016). Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape and Urban Planning, 151, 1-9.

Gaertner, M., Wilson, J.R., Cadotte, M.W., MacIvor, J.S., Zenni, R.D. and Richardson, D.M.. (2017). Non-native species in urban environments: patterns, processes, impacts and challenges. Biological invasions, 19 (12), 3461-3469.

Gallardo B, Aldridge DC. The “dirty dozen”: socio-economic factors amplify the invasion potential of 12 high-risk aquatic invasive species in Great Britain and Ireland. (2013). Frid C, ed. J Appl Ecol. 50(3), 757-766.

Gavier-Pizarro, A.G.I., Radeloff, V.C., Stewart, S.I., Cynthia, D., Keuler, N.S. (2010). Housing is positively associated with invasive exotic plant species richness in New England, USA. Ecological Applications 20, 1913-1925.

Gobster, P. H. (2011). Factors affecting people’s responses to invasive species management. Invasive and introduced plants and animals: Human perceptions, attitudes and approaches to management, 249-263.

Gormley, A. M., Forsyth, D. M., Griffioen, P., Lindeman, M., Ramsey, D. S., Scroggie, M. P., & Woodford, L. (2011). Using presence-only and presence–absence data to estimate the current and potential distributions of established invasive species. Journal of Applied Ecology, 48(1), 25-34.

Gozlan, R. E., Burnard, D., Andreou, D., & Britton, J. R. (2013). Understanding the threats posed by non-native species: public vs. conservation managers. PloS one, 8(1), e53200.

Hart, S. P., & Larson, B. M. H. (2014). Communicating About Invasive Species: How “Driver” and “Passenger” Models Influence Public Willingness to Take Action. Conservation Letters, 7(6), 545–552.

Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., … Zobel, M. (2006). Novel ecosystems: Theoretical and management aspects of the new ecological world order. Global Ecology and Biogeography, 15(1), 1–7.

Hope, D., Gries, C., Zhu, W., Fagan, W.F., Redman, C.L., Grimm, N.B., Nelson, A.L., Martin, C. Kinzig, A. (2003). Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Sciences 100, 8788-8792.

Hosmer, David W., et al. (2013). Applied Logistic Regression, John Wiley & Sons, Incorporated. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/ubc/detail.action?docID=1138225

Hosmer, D.W. and Lemesbow, S. (1980). Goodness of fit tests for the multiple logistic regression model. Communications in statistics-Theory and Methods, 9(10), 1043-1069.

Hosmer, D.W., Lemeshow, S. and Klar, J. (1988). Goodness-of-fit testing for the logistic regression model when the estimated probabilities are small. Biometrical Journal, 30(8), 911-924.

Invasive Species Council of British Columbia (ISCBC). (2017). Invasive Species Strategy for British Columbia. Retrive from: https://bcinvasives.ca/about/invasive-species-strategy-for-bc.

Islands, P., National, H., Field, P., Program, N. W., Health, P., & Service, I. (1997). Vitousek 1997 Introduced species, 21, 1–16.

Jiménez-Valverde, A., Peterson, A. T., Soberón, J., Overton, J. M., Aragón, P., & Lobo, J. M. (2011). Use of niche models in invasive species risk assessments. Biological invasions, 13(12), 2785-2797.

Jones BA. (2017). Invasive Species Impacts on Human Well-being Using the Life Satisfaction Index. Ecol Econ. 134:250-257.

Kalpić D., Hlupić N., Lovrić M. (2011). Student's t-Tests. In: Lovric M. (eds) International Encyclopedia of Statistical Science. Springer, Berlin, Heidelberg.

Kemp, C., van Riper, C. J., BouFajreldin, L., P. Stewart, W., Scheunemann, J., & van den Born, R. J. G. (2017). Connecting human–nature relationships to environmental behaviors that minimize the spread of aquatic invasive species. Biological Invasions, 19(7), 2059–2074.

Kumagai Y, Gibson RB, Filion P. (2015). Evaluating long-term urban resilience through an examination of the history of green spaces in Tokyo. Local Environ. 20(9):1018-1039.

Lampinen, J., Ruokolainen, K., and Huhta, A.-P. (2015). Urban power line corridors as novel habitats for grassland and alien plant species in South- Western Finland. PLoS ONE 10, e0142236.

Lindemann-Matthies, P. (2016). Beasts or beauties? Laypersons' perception of invasive alien plant species in Switzerland and attitudes towards their management. NeoBiota, 29, 15.

Lubbe, C. S., Siebert, S. J., & Cilliers, S. S. (2010). Political legacy of South Africa affects the plant diversity patterns of urban domestic gardens along a socio-economic gradient. Scientific Research and Essays, 5(19), 2900–2910.

Metro Vancouver. (2014). Sensitive Ecosystem Inventory for Metro Vancouver & Abbotford 2010 – 2012. Technical Report. Retrieved from: http://www.metrovancouver.org.

McCarthy, M. A., & Possingham, H. P. (2007). Active adaptive management for conservation. Conservation Biology, 21(4), 956-963.

McKinney, M. L. (2002). Urbanization, Biodiversity, and ConservationThe impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. Bioscience, 52(10), 883-890.

McNeely, J. A. (Ed.). (2001). Global strategy on invasive alien species. IUCN.

Mollot G, Pantel JH, Romanuk TN. (2017). The Effects of Invasive Species on the Decline in Species Richness: A Global Meta-Analysis. Vol 56. 1st ed. Elsevier Ltd.

Morgenroth J, Östberg J, Konijnendijk van den Bosch C, et al. (2016). Urban Tree diversity—Taking Stock and Looking Ahead. Vol 15.

Nesbitt, L., Meitner, M.J., Girling, C., Sheppard, S.R. and Lu, Y. (2019). Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. Landscape and urban planning, 181, 51-79.

Nielsen, A. B., Van Den Bosch, M., Maruthaveeran, S., & van den Bosch, C. K. (2014). Species richness in urban parks and its drivers: a review of empirical evidence. Urban ecosystems, 17(1), 305-327.

Novoa, A., Dehnen-Schmutz, K., Fried, J., & Vimercati, G. (2017). Does public awareness increase support for invasive species management? Promising evidence across taxa and landscape types. Biological invasions, 19(12), 3691-3705.

Olszańska, A., Solarz, W., & Najberek, K. (2016). To kill or not to kill-Practitioners' opinions on invasive alien species management as a step towards enhancing control of biological invasions. Environmental Science and Policy, 58, 107–116.

Palmer, J. A. (2002). Environmental education in the 21st century: Theory, practice, progress and promise. Routledge.

Pasquali, S., Gilioli, G., Janssen, D. and Winter, S. (2015). Optimal strategies for interception, detection, and eradication in plant biosecurity. Risk Analysis, 35(9), pp.1663-1673.

Pearson, K. (1900). X. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 50(302), 157-175.

Pearson, K. (1904). On the theory of contingency and its relation to association and normal correlation; On the general theory of skew correlation and non-linear regression. Cambridge University Press.

Pyšek P, Richardson DM. (2010). Invasive Species, Environmental Change and Management, and Health. Annu Rev Environ Resour. 35(1), 25-55.

Pimentel D, Lach L, Zuniga R, Morrison D. (1999). Environmental and economic costs of nonindigenous species in the United States. Bioscience. 50(1), 53-65.

Pejchar L, Mooney HA. (2009). Invasive species, ecosystem services and human well-being. Trends Ecol Evol. 24(9),497-504.

Peterson, A. T., Papes, M., & Kluza, D. A. (2003). Predicting the potential invasive distributions of four alien plant species in North America. Weed Science, 51(6), 863-868.

Pimentel D, Zuniga R, Morrison D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol Econ. 52(3 SPEC. ISS.), 273-288.

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team .(2018). _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-137. https://CRAN.R-project.org/package=nlme.

Potgieter, L. J., Gaertner, M., O'Farrell, P. J., & Richardson, D. M. (2019). Perceptions of impact: Invasive alien plants in the urban environment. Journal of environmental management, 229, 76-87.

Ramsey, F., & Schafer, D. (2013). The statistical sleuth: a course in methods of data analysis. Cengage Learning.

R Core Team .(2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org.

Richardson, D. M., Pyšek, P., Rejmánek, M., Barbour, M. G., Panetta, F. D., & West, C. J. (2000). Naturalization and invasion of alien plants: concepts and definitions. Diversity and distributions, 6(2), 93-107.

Ripley, B. D. (2002). Modern applied statistics with S.

Rocchini, D., Andreo, V., Förster, M., Garzon-Lopez, C. X., Gutierrez, A. P., Gillespie, T. W., ... & Marcantonio, M. (2015). Potential of remote sensing to predict species invasions: A modelling perspective. Progress in Physical Geography, 39(3), 283-309.

Rotherham, I. D., & Lambert, R. A. (Eds.). (2012). Invasive and introduced plants and animals: human perceptions, attitudes and approaches to management. Routledge.

Santo, Anna R. et al. (2015). “A Human-Centered Approach to Designing Invasive Species Eradication Programs on Human-Inhabited Islands.” Global Environmental Change 35: 289–98.

Santos, M., Freitas, R., Crespí, A. L., Hughes, S. J., & Cabral, J. A. (2011). Predicting trends of invasive plants richness using local socio-economic data: An application in North Portugal. Environmental Research, 111(7), 960–966.

Schreck Reis, C., Marchante, H., Freitas, H., & Marchante, E. (2013). Public Perception of Invasive Plant Species: Assessing the impact of workshop activities to promote young students' awareness. International Journal of Science Education, 35(4), 690-712.

Selge, S., Fischer, A., & van der Wal, R. (2011). Public and professional views on invasive non-native species–A qualitative social scientific investigation. Biological Conservation, 144(12), 3089-3097.

Shackleton, C. M., Ruwanza, S., Sanni, G. S., Bennett, S., De Lacy, P., Modipa, R., ... & Thondhlana, G. (2016). Unpacking Pandora’s box: understanding and categorising ecosystem disservices for environmental management and human wellbeing. Ecosystems, 19(4), 587-600.

Shackleton, C. M., & Shackleton, R. T. (2016). Knowledge, perceptions and willingness to control designated invasive tree species in urban household gardens in South Africa. Biological Invasions, 18(6), 1599–1609.

Shackleton, R. T., Richardson, D. M., Shackleton, C. M., Bennett, B., Crowley, S. L., Dehnen-Schmutz, K., ... & Marchante, E. (2019). Explaining people's perceptions of invasive alien species: A conceptual framework. Journal of environmental management, 229, 10-26.

Sharp, R. L., Larson, L. R., & Green, G. T. (2011). Factors influencing public preferences for invasive alien species management. Biological Conservation, 144(8), 2097-2104.

Slimak, M. W., & Dietz, T. (2006). Personal values, beliefs, and ecological risk perception. Risk analysis, 26(6), 1689-1705.

Statistics Canda. (2016). 2016 Cencus of Agriculture. https://www.statcan.gc.ca/eng/ca2016

Statistics Canada. (2016). Vancouver [Census metropolitan area], British Columbia and British Columbia [Province] (table). Census Profile. 2016 Census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa.

Staudhammer, C. L., Escobedo, F. J., Holt, N., Young, L. J., Brandeis, T. J., & Zipperer, W. (2015). Predictors, spatial distribution, and occurrence of woody invasive plants in subtropical urban ecosystems. Journal of environmental management, 155, 97-105.

Student. (1908). The probable error of a Mean. Biometrika (Vol. 6, Issue 1), 1-25.

Taylor, J.G., Zube, E.H., & Sell, J.L. (1987). Landscape assessment and perception research methods. In Methods in environmental and behavioral research, R. B. Bechtel, & R. W. Marans, (Eds); Nostrand Reinhold. New York, 361-393.

Teixeira, C. (2009). New immigrant settlement in a mid-sized city: a case study of housing barriers and coping strategies in Kelowna, British Columbia. The Canadian Geographer, 53(3), 323-339.

Van Belle, G., Fisher, L. D., Heagerty, P. J., & Lumley, T. (2004). Biostatistics: a methodology for the health sciences (Vol. 519). John Wiley & Sons.

Verbrugge, L. N. H., den Born, R. J. G., & Lenders, H. J. R. (2013). Exploring Public Perception of Non-native Species from a Visions of Nature Perspective. Environmental Management, 52(6), 1562–1573.

Vilà, M., & Pujadas, J. (2001). Land-use and socio-economic correlates of plant invasions in European and North African countries. Biological conservation, 100(3), 397-401.

Vittoz, P., Guisan, A. (2007). How reliable is the monitoring of permanent vegetation plots? A test with multiple observers. Journal of Vegetation Science, 18(3), 413-422.

Wang, D., & MacMillan, T. (2013). The benefits of gardening for older adults: a systematic review of the literature. Activities, Adaptation & Aging, 37(2), 153-181.

Weber, E. (2017). Invasive plant species of the world: a reference guide to environmental weeds.

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. (1998). Quantifying Threats to Imperiled Species in the United States. Bioscience. 48(8), 607-615.

Williamson, M. H., & Fitter, A. (1996). The characters of successful invaders. Biological conservation, 78(1-2), 163-170.

Wittenberg, R., Cock, M.J.W. (eds). (2001). Invasive Alien Species: A Toolkit of Best Prevention and Management Practices. CAD International, Wallingford, Oxon, UK, xvii – 228.

Zhai, J., Grebner, D., Grala, R., Fan, Z., & Munn, I. (2018). Contribution of Ecological and Socioeconomic Factors to the Presence and Abundance of Invasive Tree Species in Mississippi, USA. Forests, 9(1), 38.

# Appendices

## Appendix A

### A.1 Summary of greenspaces and management approaches for the six municipalities

**Table A.1.1. Summary statistics of greenspace size (ha) by municipality**

| Municipality | Total greenspaces | | | Inventoried greenspaces | | |
|---|---|---|---|---|---|---|
| | Mean | Median | Max | Mean | Median | Max |
| Coquitlam | 188.5 | 0.5 | 75,208.5 | 4.5 | 0.8 | 179.0 |
| Surrey | 5.1 | 0.5 | 367.8 | 2.5 | 0.5 | 161.8 |
| City of North Vancouver | 0.9 | 0.1 | 27.2 | 2.9 | 0.6 | 25.0 |
| Burnaby | 6.8 | 0.4 | 579.4 | 64.3 | 11.9 | 579.4 |
| Delta | 14.1 | 0.2 | 2,947.4 | 93.5 | 5.3 | 2,947.5 |
| Richmond | 4.6 | 0.3 | 396.3 | 22.3 | 1.9 | 396.3 |

**Table A.1.2. Number of greenspaces by municipality (Leisure Cultural Civic and Facility Grounds—LCCFGs, Natural Areas—NAs, and Park and recreation—PRs)**

| Municipality | Total Greenspaces | | | | Inventoried Greenspaces | | | |
|---|---|---|---|---|---|---|---|---|
| | LCCFGs | NAs | PRs | Total | LCCFGs | NAs | PRs | Total |
| Coquitlam | 23 | 193 | 380 | 596 | 9 | 132 | 214 | 214 |
| Surrey | 275 | 350 | 621 | 1,246 | 2 | 196 | 450 | 648 |
| City of North Vancouver | 28 | 271 | 52 | 351 | 7 | 13 | 36 | 56 |
| Burnaby | 130 | 224 | 265 | 619 | 9 | 14 | 20 | 43 |
| Delta | 391 | 19 | 76 | 486 | 22 | 12 | 38 | 72 |
| Richmond | 429 | 39 | 145 | 613 | 3 | 12 | 35 | 50 |

**Table A.1.3. Management approaches of the six municipalities (information retrieved from websites of the six municipalities)**

| Management strategies | **Coquitlam** | **Surrey** | **CNV[1]** | **Burnaby** | **Delta** | **Richmond** |
|---|---|---|---|---|---|---|
| **Control** | | | | | | |
| Manual control | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Herbicide treatment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Assessment and Inventory** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Education and Outreach** | | | | | | |
| **Passive:** Printed materials or information on websites | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Actives:** Community activities, door to door communication campaigns, information booths at parks | × | ✓ | × | × | ✓ | × |
| **Partnership with NGOs and universities** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

[1]The city of North Vancouver
✓ On going
× Finished, but with the possibility to be continued in the future

## A.2 Summary of habitat and survey protocols of target species

**Table A.2.1. Habitat description of target species including ecological characteristics (ISCBC, 2017)**

| Invasive plant species | Habitat description |
|---|---|
| **English ivy**<br>*Hedera helix* (Linnaeus) | The favorite habitats have warm conditions from lowland to high mountain sites, but especially in sub-montane to temperate regions. It is more abundant on moist fertile or very fertile soils and less abundant on poor and well-drained sandy soils. |
| **Himalayan blackberry**<br>*Rubus armeniacus* (Focke) | Popular habitats include pastures, disturbed sites, and areas along roadsides and water bodies. A single berry can contain up to 80 seeds that can be spread by mammals, birds, and water. Stem fragmentation and seedling are also means of reproduction. Preferring rich, well-drained soils, HB can grow well in a variety of barren, infertile soils, and is tolerant of periodic flooding or shade. |
| **Knotweed spp.**<br>*Fallopia japonica* (Houtt)<br>*F. x bohemica* (J. Chrtek & A. Chrtková) J. P. Bailey<br>*F. sachalenensis* (F.Schmidt) Nakai<br>*Polygonum polystachyum* (Wall. ex Meisn.) | Knotweeds thrive in roadside ditches, low-lying areas, irrigation canals, and other water drainage systems. They are also found in areas with high soil moisture. Knotweeds are dispersed by human activities or water to downstream areas. Knotweeds are easy to spread because they can regenerate from small piece of stem or root. Plants emerge in early spring. Infestations can dominate stream banks and reduce sight lines along roads, fences, and rights-of-way. |
| **Yellow archangel**<br>*Lamiastrum galeobdolon* (Linnaeus) Crantz | YA is used as ornamental plant in many gardens. It easily escapes from gardens and residential properties to establish in nearby natural vegetation areas. It has several forms of reproduction including seed dispersal, fragmentation, and nodes on their stem. |

**Table A.2.2. Summary of survey protocols for the six municipalities**

| | Surrey | Burnaby | Coquitlam | Delta | CNV[1] | Richmond |
|---|---|---|---|---|---|---|
| **Number of surveyed greenspaces[2]** | 632 | 395 | 214 | 72 | 56 | 50 |
| **Selection of greenspace** | | | | | | |
| Type of survey | Site specific[3] (Natural areas and parks) Species specific[4] (all other city land) | Site specific | Site specific | Site specific | Site specific | Species specific |
| Was it a city-wide survey? | No | Yes | No | No | Yes | No |
| **Survey methods** | | | | | | |
| Which areas were selected within surveyed greenspaces? | Forest edge, edge of water bodies, grassland and meadows | Trails and edge of water bodies | Trails, park perimeters, forest/meadow interfaces, edge of water bodies | Trails and walking paths | Trails and edge of water bodies | Trails and walking paths |
| How were areas surveyed? | Field crew walked along selected paths and ran transects in grassland meadows | Field crews walked along water bodies and trails | Field crew walked along selected paths and ran transects for natural areas only | Field crew walked along selected paths, no transects applied | Field crew walked along water bodies and trails | Field crew walked along selected paths and made visual estimation |
| What information of species presence was recorded? | Location and size of impacted areas | Location and size of impacted areas | Location and size of impacted areas | Location and size of impacted areas (IAPP, 2010) | Location and size of impacted areas | Location and size of impacted areas (IAPP, 2010) |
| When was this done? | Spring – Summer, 2016 | Summer, 2018 | Summer – Fall, 2016 | Summer, 2015 – 2016 | Summer – Fall, 2010 – 2015 | Summer, 2016 |

[1] The city of North Vancouver

[2]Greenspaces included in the analysis of this study only.

[3]Site specific: Key sites were selected based on criteria (i.e., biodiversity values, areas of high risk, sensitive ecosystem map) defined by the municipalities.

[4]Species specific: Based on list of high priority species in high priority natural areas and parks or other areas of city land.

### A.3 Urban greenspace types and hypothesis table

**Table A.3.1. Typology of urban greenspaces (Bell et al., 2017; Branquilho et al., 2015)**

| Category | Greenspace elements |
|---|---|
| **Park and recreation** | Large urban park; botanical/zoological garden; neighbourhood greenspaces |
| **Natural, semi-natural and feral areas** | Urban forest—managed forest, mixed forms; shrub-land |
| **Leisure or cultural civic and facility grounds (LCCFGs)** | Green sport facilities and camping areas |
| Agricultural land | Grassland; tree meadow; biofuel production; horticulture |
| Private, commercial, industrial, institutional greenspaces | Bioswale; tree alley and street tree; house garden; school ground |
| Building greens | Balcony green; ground based green wall; green roof |

**Table A.3.2. List of hypotheses of associations between target species occurrences and explanatory variables**

| Variables | Scale | Hypotheses | | | | | Explanation | Relevant literature |
|---|---|---|---|---|---|---|---|---|
| | | Significance | EI | HB | KW | YA | | |
| **Topographic and park variables** | | | | | | | | |
| Elevation | Greenspace | Yes | - | - | - | - | Based on "favorite" habitats of these species in the lower mainland. | Gilbert (1991) |
| Slope | | NS | | | | | | |
| Area | | Yes | + | + | + | + | | |
| Trail density | | Yes | + | + | + | + | Trails are corridors through which invasive species can be distributed (but it might also depend on type of park). | (Raduła et al. 2018) |
| Distance to roads | | NS | | | | | | |
| Distance to water channel | | Yes | - | - | - | - | Water channels are corridors through which invasive species can be distributed; invasive plant species prefer moist soil near stream habitats. | (Foster & Sandberg, 2010) |
| **Land use variables** | | | | | | | | |
| Agricultural | Within 100-metre buffer | NS | | | | | | |
| Residential | | Yes | + | + | + | + | Related to roadsides—one of the favorite habitats of invasive plants. | (Borgmann & Rodewald, 2005); (Pauchard & Alaback, 2004); (Vilà & Pujadas, 2001); (Gulezian & Nyberg, 2010) |
| Industrial | | NS | | | | | | |
| Recreation, open space, and natural areas | | Yes | + | + | + | + | Greenspaces are where invasive plant species are typically found; invasions can spread if there are more greenspaces close by. | |
| **Socio-economic variables** | | | | | | | | |
| Median household income | Dissemination area | Yes | + | + | + | + | Median household income is positively associated with gardening expense | (Gavier-Pizarro et al. 2010); (Vilà & Pujadas, 2001); (Gulezian & Nyberg, 2010); (Cameron et al., 2012); (Padullés Cubino et al. 2015) |
| Population density | | Yes | + | + | + | + | Increasing population density means increasing the chance of introducing non-native plant species | |
| Single-detached house density | | Yes | + | + | + | + | Single-detached houses have garden/backyard | |
| Expenditure for fertilizers and nursery | | Yes | + | + | + | + | Horticulture activities could be a path for introducing invasive plant species to residential areas | |
| **+** | Increase in explanatory variable related to increase in probability of invasive plants occurrences | | | | | | | |
| **-** | Increase in explanatory variable related to decrease in probability of invasive plants occurrences | | | | | | | |
| **NS** | Not significant | | | | | | | |

## A.4 Summary statistics of explanatory variables

**Table A.4.1. Mean and standard deviation (SD) of the of topographic and park variables**

| Variable | Area ($km^2$) | Distance to road (m) | Distance to water channel (m) | Trail density ($km^{-2}$) | Elevation (m) | Slope |
|---|---|---|---|---|---|---|
| | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| CNV[1] | 2.5 (4.5) | 9 (15) | 306 (310) | 169 (268) | 61 (46) | 32 (19) |
| Delta | 73.0 (374.4) | 7 (14) | 9 (42) | 11 (40) | 22 (24) | 28 (27) |
| Surrey | 2.6 (10.5) | 171 (593) | 16 (25) | 91 (151) | 42 (27) | 36 (22) |
| Coquitlam | 4.5 (15.2) | 10 (15) | 29 (66) | 243 (605) | 97 (78) | 54 (108) |
| Burnaby | 13.5 (51.2) | 5 (11) | 26 (55) | 53 (116) | 61 (62) | 43 (32) |
| Richmond | 22.0 (69.0) | 2 (3) | 41 (118) | 41 (109) | 5 (2) | 7 (5) |

[1]The city of North Vancouver

**Table A.4.2 Mean and standard deviation (SD) of land use variables (percentage)**

| Variable | Agricutural proportion | Residential proportion | RONAs[2] proportion | Industrial proportion |
|---|---|---|---|---|
| | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| CNV[1] | 0 (0) | 32.8 (22.3) | 15.3 (17.7) | 3.4 (8.8) |
| Delta | 8.8 (16.9) | 27.9 (24.1) | 16.4 (16.2) | 4.7 (12.0) |
| Surrey | 3.2 (10.7) | 48.4 (22.0) | 27.8 (16.8) | 1.2 (7.1) |
| Coquitlam | 0.3 (3.1) | 43.6 (21.5) | 17.4 (16.2) | 2.3 (9.6) |
| Burnaby | 1.2 (5.5) | 30.7 (23.1) | 26.7 (19.2) | 6.8 (12.2) |
| Richmond | 8.2 (18.5) | 16.1 (22.1) | 7.2 (9.3) | 13.3 (15.5) |

[1]The city of North Vancouver
[2]Recreational, Open space and Natural Areas

**Table A.4.3. Mean and standard deviation (SD) of socio-economic variables**

| Variable | Median household income (CAD) | Population density ($km^{-2}$) | Single-detached house density ($km^{-2}$) | Nursery expenses (CAD) | Fertilizer expenses (CAD) |
|---|---|---|---|---|---|
| | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| CNV[1] | 68,483 (26,810) | 5,009 (5,166) | 229 (231) | 179 (81) | 68 (27) |
| Delta | 114,715 (67,145) | 84,048 (152,344) | 19,422 (35,643) | 399 (231) | 117 (76) |
| Surrey | 95,427 (42,374) | 2,392 (1,952) | 339 (247) | 298 (149) | 92 (48) |
| Coquitlam | 107,696 (63,200) | 2,355 (2,320) | 306 (252) | 112 (76) | 328 (211) |
| Burnaby | 71,703 (23,508) | 2,326 (2,995) | 131 (176) | 204 (66) | 62 (26) |
| Richmond | 109,726 (148,308) | 566 (1,146) | 43 (73) | 348 (526) | 99 (132) |

[1]The city of North Vancouver

**Appendix B**

## B.1 Questionnaire

THE UNIVERSITY OF BRITISH COLUMBIA

Faculty of Forestry

The University of British Columbia

Faculty of Forestry, Forest Resources Management
2$^{nd}$ Floor, Forest Sciences Centre
2045-2424 Main Mall, Vancouver, B.C., V6T 1Z4

**Cover letter for the online survey**

**Project title:** Invasive plant species in urban green spaces within Metro Vancouver: Risk perception assessment

**Principal Investigator:**
Dr. Bianca Eskelson
Assistant professor
Department of Forest Resources Management

**Co-Investigators:**
Dr. Michael Meitner
Associate professor
Department of Forest Resources Management

Ms. Nguyet-Anh Nguyen
Master of Science in Forestry
Department of Forest Resources Management

This research project aims to assess the public's risks perception regarding invasive plant species (invasive plants) in Metro Vancouver, British Columbia, Canada. Your answers will help researchers to answer the following questions: (1) How much does the public know about invasive plants? (2) How does the public perceive risks related to invasive plants? And (3) to what degree does the public support invasive plants management activities?

If you agree to participate in this online survey, you will be asked to answer a series of questions including (1) your general knowledge of invasive plants, (2) your risks perception regarding invasive plants, and (3) your willingness to support invasive plants management activities.

Some questions require you to provide opinion or check a box representing your choice, while other questions ask you to indicate your opinions using a **9-point or 10-point rating scale**.

In this survey, there is absolutely no emphasis on right or wrong answers. Therefore, you do not need to look on the internet to find relevant information. The survey should take between 10 and 15 minutes.

The results of this study will be part of a Master's thesis and may also be published in academic journal articles. Only the authorized researchers have access to the database during the study. In the future, the data might be requested by other researchers at the time of publication to do the following: (1) Assess the data accuracy; (2) Evaluate intellectual processes of the publication. The participant will not be able to withdraw their data once it is made publically available. The data will be de-identified to preserve participants' privacy.

If you participate in this study, there are no risks greater than what you would experience in your daily life. Taking part in this study will help you learn more about invasive plants, and provide others (e.g. researchers, managers, etc.) with an understanding of the public's risk perception.

We will have one CAD $100 and five CAD $40 Amazon gift cards as the incentives to be offered to participants. Everyone who participates in the survey, even those who withdraw, have equal chance to enter the draw.

All data resulting from this survey will be stored on an encrypted and password protected computer database at the University of British Columbia. A sequentially generated number will be used to identify your responses, and that number will be on all documents. The data will be retained for a minimum of 5 years after the date of publication. The data will be permanently deleted as required after the minimum of 5 years period. The responsibility for the security of the data rests with the Principal Investigator.

If you have any questions or concerns about the procedures of this research, Dr. Eskelson, Dr. Meitner, and Ms. Nguyen have agreed to answer any questions and inquiries that you may have.

*If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the University of British Columbia office of Research Ethics at 604-822-8598 or if long distance email RSIL@ors.ubc.ca or call toll free 1-877-822-8598.*

Taking part in this study is entirely up to you. You have the right to refuse to participate in this study. If you decide to take part, you may choose to pull out of the study at any time without giving a reason and without any negative impacts on you.

*If the questionnaire is completed, it will be assumed that consent has been given.*

**Do you live in Metro Vancouver?**

☐ Yes

- ⇨ *Participants will be able to select their city from a dropdown menu, and there will be a follow up optional space to fill out their* ***postal code****. Then they can continue the survey.*

☐ No

- ⇨ Where do you live? City: ____________Country: _____________
- ⇨ *Continue with the survey*

**How did you get to know about this survey?**

- ☐ Via postal mail
- ☐ Via email
- ☐ Via poster/flyer at public places within Metro Vancouver region
- ☐ Via websites
- ☐ Others

**Question 1.** Do you know what an invasive plant is?

☐ Yes

- ⇨ Proceed to question 2

☐ No

- ⇨ Proceed to question 4

**Question 2.** To the best of your knowledge, what makes a plant 'invasive'?

______________________________________________________________________________

______________________________________________________________________________

**Question 3.** List as many impacts (positive or negative) that you can think of that invasive plants are having in your city?

______________________________________________________________________________

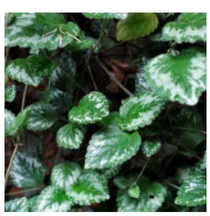
______________________________________________________________________________

**Question 4 to 10 use a 10-point rating scale, in which 1 = the lowest magnitude, 10 = the highest magnitude. Please move the point anywhere along the bar to indicate your preference. You also can choose "Do not know" by checking the provided option.**

**Question 4.** Please indicate to what extent you think invasive plants are problematic in your city.

| Not at all | | | | | | | | | | To a great extent |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 5.** Please indicate how much you know about each of the following plant species below (e.g., encountered them before, have them in your garden, have seen them in your city, etc.).

| Species (common name) | Pictures | How much do you know about each species? | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Very little | | | | | | | | A lot | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| English ivy |  | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Himalayan blackberry |  | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Giant hogweed |  | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Knotweeds (any knotweed species) |  | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Yellow archangel |  | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 6.** Please identify the **ecological risks*** caused by **each invasive plant**.

***Ecological risks:** Rate the risk the invasive plants have on the ecosystem/natural areas (e.g., competing with other native plants).

| Species | Low ecological risk | | | | | | | | | High ecological risk | Do not know |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| English ivy | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Himalayan blackberry | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Giant hogweed | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Knotweeds (any knotweed species) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Yellow archangel | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 7.** Please identify the **economic risks*** caused by **each invasive plant.**

***Economic risks:** Rate the risk the invasive plants have on infrastructure or maintenance costs in your city (e.g., damage, costs of control and eradication activities).

| Species | Low economic risk | | | | | | | | | High economic risk | Do not know |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| English ivy | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Himalayan blackberry | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Giant hogweed | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Knotweeds (any knotweed species) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Yellow archangel | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 8.** Please identify the **human health risks*** caused by **each invasive plant.**

***Human health risks:** Rate the risk the invasive plants have on health to your community, family, or yourself (e.g., allergic reactions, inflammation, etc.).

| Species | Low human health risk | | | | | | | | | High human health risk | Do not know |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| English ivy | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Himalayan blackberry | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Giant hogweed | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Knotweeds (any knotweed species) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Yellow archangel | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 9.** In your opinion, to what degree are the following environmental issues a problem in your city?

| | Not a problem 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Extremely problematic 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Habitat degradation | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Park overuse | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Invasive plant species | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Climate change (more frequent flooding, drought, sea level rise) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Reliance on fossil fuels | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Pipelines | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Water quality | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 10.** How would you like to receive information regarding invasive plant species?

| | Not at all 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | To a great extent 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| City Website | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Non-government Website | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Social media (e.g., Facebook, Instagram, Twitter, etc.) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printed materials (e.g., brochures, booklets) in the mail | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Community workshops/events | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Hands-on education activities | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Others (please specify): ________________ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Question 11 to 15 use a 9-point rating scale, in which 1 = no funding support, 5 = same/current amount of funding support, and 9 = double funding support. Please move the point anywhere along the bar to indicate your preference.

**Question 11.** To what extent do you support your local government to fund the following activities to control **English ivy?**

**Species: English ivy**

| | No funding ← | | | Same/current | | → | | Double funding |
|---|---|---|---|---|---|---|---|---|
| **Activities/events** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Community invasive pulls | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Community restoration events to plant native or non-invasive plants | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printed materials (e.g., brochures) with invasive species information in the mail | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Manual removal of the plant by trained crews | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 12.** To what extent do you support your local government to fund the following activities to control **Himalayan blackberry?**

**Species: Himalayan blackberry**

| | No funding ← | | | Same funding | | → | | Double funding |
|---|---|---|---|---|---|---|---|---|
| Activities/events | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Community invasive pulls | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Community restoration events to plant native or non-invasive plants | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printed materials (e.g., brochures) with invasive species information in the mail | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Manual removal of the plant by trained crews | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Question 13.** To what extent do you support your local government to fund the following activities to control **Giant hogweed?**

**Species 3: Giant hogweed**

| Activities/events | No funding ← 1 | 2 | 3 | 4 | Same funding 5 | 6 | 7 | 8 | → Double funding 9 |
|---|---|---|---|---|---|---|---|---|---|
| Community restoration events to plant native or non-invasive plants | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printed materials (e.g., brochures) with invasive species information in the mail | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Manual removal of the plant by trained crews | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Targeted herbicide treatment by trained crews | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

If they rate “not at all” for Chemical control, the following part will appear

*If the city does not control giant hogweed, adults and children who touch this plant will develop severe burns and blistering of skin. Herbicide treatment is used to control giant hogweed when manual removal of this plant can pose a higher risk to staff or when manual removal will not be successful compared to the targeted use of herbicide.*

If you have indicated that you do not support funding for herbicide treatment for Giant hogweed. We would like to ask you one more question: Based on what you now know about giant hogweed, which of the following statements is true?

☐ Now that I know the health and safety risks from giant hogweed, I believe targeted herbicide use is okay.

☐ Even though I understand the risks, I still do not agree with the use of herbicides.

**Question 14.** To what extent do you support your city to fund the following activities to control **Knotweeds?**

**Species: Knotweeds (any knotweed species)**

| Activities/events | No funding ← 1 | 2 | 3 | 4 | Same funding 5 | 6 | 7 | 8 | → Double funding 9 |
|---|---|---|---|---|---|---|---|---|---|
| Community restoration events to plant native or non-invasive plants | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printed materials (e.g. brochures) with invasive species information in the mail | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Targeted herbicide treatment by trained crews | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

If they rate "not at all" for Chemical control, the following part will appear

*Herbicide treatment is used for knotweeds because manual removal of this plant will not be successful and can be more damaging to the habitat than the use of targeted herbicide. Manual removal also poses significant risk for further spread of this plant as it can easily re-grow if even small fragments (size of a thumbnail) are left behind in the soil. Knotweed can grow through concrete, house foundations, and walls causing property damage.*

If you have indicated that you do not support funding for herbicide treatment for Knotweeds. We would like to ask you one more question: Based on what you now know about giant hogweed, which of the following statements is true?

☐ Now that I know the risks to infrastructure and property, I believe targeted herbicide use is okay.

☐ Even though I understand the risks, I still do not agree with the use of herbicides.

**Question 15.** To what extent do you support your city to fund the following activities to control **Yellow archangel?**

**Species 5: Yellow archangel**

| Activities/events | No funding ← 1 | 2 | 3 | 4 | Same funding 5 | 6 | 7 | 8 | → Double funding 9 |
|---|---|---|---|---|---|---|---|---|---|
| Community invasive pulls | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Community restoration events to plant native or beneficial plants | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Printed materials (e.g. brochures) with invasive species information in the mail | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Manual removal of the plant by trained crews | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Census-related information (optional):**

*In attempting to interpret and understand the range of results of the survey it is useful to record some background information about each respondent and seek patterns between your information and responses. This will be kept confidential.*

**Age:** _____

**Gender:** ☐ Female ☐ Male ☐ Other

**Ethnicity:**

- ☐ North American Aboriginal origins
- ☐ Other North American origins
- ☐ European origins
- ☐ Caribbean origins
- ☐ Latin, Central and South American origins
- ☐ African origins
- ☐ Asian origins
- ☐ Oceania origins (Polynesia, Micronesia, Malay Archipelago, and Melanesia)

**Education** (Highest certificate, diploma or degree completed):

☐ No certificate or diploma

☐ Secondary (high) school diploma

☐ Certificate or diploma below bachelor level

☐ Bachelor's degree

☐ University certificate, diploma or degree above bachelor level

**Household size** (number of family members only):__________

**Income:** What is the approximate annual gross income of your household (include all working members living most of the time in this house)?

☐ Less than CAD $ 24,000 ☐ CAD $ 24,000 - $ 50,000 ☐ CAD $ 50,000 – 100,000

☐ CAD $ 100,000 - $ 200,000 ☐ More than CAD $ 200,000

**Environmental preferences/experiences** – Please select activities you participated in during the last year: (check all that apply).

☐ Gardening

☐ Walking around parks

☐ Hiking

☐ Camping

☐ Biking

Others (please specify): ______________________

☐ Harvesting food from nature

☐ Swimming

☐ Birdwatching

☐ Kayaking

☐ Picnicking

☐ Volunteering (e.g., environmental activities)

**Membership**

Are you a member of any environmental or professional organizations/groups (can be global, national, regional or local organization/groups that seek solutions to environmental issues)?

☐ Yes

☐ No

If yes, which ones?

_______________________________________________________________________________

Are you a member of any recreational organizations/groups (e.g., sport clubs, birdwatching teams, etc.)?

☐ Yes

☐ No

If yes, which ones?

_______________________________________________________________________________

Please leave your email address if you want to enter the draw to win a $100 or $40 Amazon gift card. Winners will be selected randomly on May 15$^{th}$ 2019. Participants can only win once.

Email:__________________________________________________________________________

**____End of the survey____**

*We thank you for your time spent taking this survey!*

*Your response has been recorded.*

## B.2 Recruitment material

**Image B.2.1. Offiline poster**

## B.3 Demographics of participants (percentage of respondents in group by variable)

**Table B.3.1. Age**

| | Percentage |
|---|---|
| 19 – 24 (Youth) | 10 |
| 25 - 35 | 22 |
| 36 - 45 | 27 |
| 46 - 55 | 18 |
| 56 - 65 | 15 |
| Older than 65 (Seniors) | 9 |

**Table B.3.2. Gender**

| | Percentage |
|---|---|
| Female | 59 |
| Male | 39 |
| Others | 2 |

**Table B.3.3. Ethnicity**

| | Percentage |
|---|---|
| European origins | 62 |
| Other North American origins | 17 |
| Asian origins | 11 |
| North American Aboriginal origins | 5 |
| Oceania origins | 4 |
| Latin, Central and South American origins | 1 |
| Caribean origins | 0 |
| African origins | 0 |

**Table B.3.4. Annual household income**

| | Percentage |
|---|---|
| CAD $ 50,000 - $ 100,000 | 41 |
| CAD $ 100,000 - $ 200,000 | 33 |
| CAD $ 24,000 - $ 50,000 | 16 |
| More than CAD $ 200,000 | 6 |
| Less than CAD $ 24,000 | 4 |

**Table B.3.5. Education**

| | Percentage |
|---|---|
| Certificate/diploma/degree above bachelor level | 21 |
| Bachelor's degree | 36 |
| Certificate or diploma below bachelor level | 25 |
| Secondary (high) school diploma | 16 |
| No certificate or diploma | 2 |

**Table B.3.6. Memberships**

| Percentage | Yes | No |
|---|---|---|
| Professional organizations/groups | 24 | 76 |
| Recreational organizations/groups | 32 | 68 |

9% of total responses have membership of both professional and recreational organizations/groups

## B.4 The public's self-reported knowledge levels about invasive plants by region

**Table B.4.1. Mean and standard deviation (SD) of the public's self-reported knowledge levels about invasive plants by region**

| | All regions | City of Vancouver | North shore | Northeast | Southeast | Southwest |
|---|---|---|---|---|---|---|
| | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| Himalayan blackberry | 8 (2.5) | 8.0 (2.6) | 7.4 (2.6) | 7.9 (2.6) | 7.8 (2.6) | 7.8 (2.6) |
| English ivy | 7.9 (2.6) | 7.6 (2.7) | 7.7 (2.7) | 7.7 (2.7) | 6.3 (2.7) | 7.5 (2.7) |
| Knotweeds | 6.8 (2.9) | 6.9 (2.8) | 6.4 (2.8) | 7.1 (2.8) | 6.5 (2.8) | 6.6 (2.8) |
| Yellow archangel | 6.3 (3.1) | 6.2 (2.9) | 6.0 (2.8) | 6.1 (2.9) | 5.7 (2.5) | 7.0 (2.8) |
| Giant hogweed | 6.3 (2.8) | 6.2 (2.7) | 5.8 (2.7) | 7.2 (2.8) | 5.3 (2.9) | 6.7 (2.9) |