Assessing the potential impact of English ivy (*Hedera helix*) on the arthropod community of Stanley Park

by

Tianbi Wu

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Name:	**Tianbi Wu**
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Examining Committee:	**Supervisor and Chair**
	Anayansi Cohen-Fernández Supervisor Faculty, BCIT
	Doug Ransome Examiner Faculty, BCIT
	Susan Owen Examiner Faculty, SFU
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Abstract

English ivy (*Hedera helix*) is a vine species that had been introduced to North America in colonial times. Extensive monocultures of English ivy and the attachment to other plants have been shown to impact native flora of North America. Its impact on native fauna has been overlooked. I sampled arthropods in six native plant plots and six English ivy plots in Stanley Park, British Columbia. A weekly collection of arthropods through pitfall traps was conducted from May to August 2019. There was no significant difference in arthropod diversity and total abundance of groups between native and ivy plots. Non-metric multidimensional scaling was used to show distances between beetle community compositions. There was a large overlap of beetle compositions despite three families found exclusively in native plots. Implications for managing and restoring English ivy of the park were discussed.

Keywords: *Hedera helix*; invasive species; arthropods; ecological restoration; beetles as indicators; NMDS

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Chapter 1. Introduction

Invasive species usually refer to exotic species that have come through a series of ecological and environmental filters and become problematic (Colautti and MacIsaac 2004). Invasive species can bring enormous ecological and economical consequences (Pimentel et al. 2000, Simberloff 2005, Roy et al. 2012). This is becoming a more prevalent problem as globalization advances (Meyerson and Mooney 2007, Hulme 2009). Some of the notorious examples in Canada include Japanese knotweed (*Reynoutria japonica* (Houtt.) Ronse decr.), purple loosestrife (*Lythrum salicaria* L.), European green crab (*Carcinus maenas* (Linnaeus, 1758)), and zebra mussel (*Dreissena polymorpha* (Pallas, 1771)) (Invasive Species Specialist Group 2015, Integrated Taxonomic Information System 2020).

There are several theories as to why some species could become such good invaders. The enemy release hypothesis roughly refers to the idea that when plants move into a new environment without their familiar herbivores, they can reproduce and grow without pressure (Keane and Crawley 2002). On the other hand, the invasion of one evolutionary familiar partner could facilitate the invasion of another, causing an "invasional meltdown" (Simberloff and Von Holle 1999). One example of this would be *Myrmica rubra,* the European fire ant (Prior et al. 2014). In Eastern Canada, it was shown that their ability to dispersed seeds of introduced plants is better than dispersing seeds from native plants (Prior et al. 2014).

English ivy (*Hedera helix* L.) is an invasive evergreen vine that was introduced from Eurasia to North America in colonial times (Reichard 2000). As an invasive plant, it thrives with disturbances and is well suited to the urban-forest environment where roads and trails are inevitably built. Additionally, in its native range, there is evidence suggesting that English ivy would benefit from increased CO_2 levels more than its tree hosts under warm conditions (Manzanedo et al. 2018). English ivy tends to generate massive monocultures in the understory of forests and climb onto trees (Quinn and Best 2002, Schnitzler and Heuzé 2006). This drastically alters the native plant community and negatively impact the seed bank of native plants (Dlugosch 2005, Biggerstaff and Beck 2007). Although English ivy is known to disrupt native plant communities, there is a lack of literature on its potential effect on the fauna (Hartley 2018). This is of special concern because invasive plants can have different levels of impact on native fauna in general (Fletcher et al. 2019).

There is a significant knowledge gap in the literature on the responses of arthropods to invasive plants (Spafford et al. 2013). Arthropods often make up the foundation of a food web and are closely associated with plants (Spafford et al. 2013). The distribution pattern of arthropods has implications on birds as well (Van Wilgenburg et al. 2001). In a 2018 global biomass assessment, it was estimated that the carbon in biomass of terrestrial arthropods was 0.2 gigatons of carbon (Bar-On et al. 2018). In comparison, mammals were only 0.007 gigatons of carbon (Bar-On et al. 2018). Terrestrial arthropods account for a large portion of the biomass on earth. It is worth keeping track of the abundance of arthropods as many of them play crucial roles in the nutrient cycle as detritivores, herbivores, carnivores, and other specialized roles such as fungivores.

Within Arthropoda, insects are an important part of ecosystems. They recycle nutrients, pollinate plants, feed other wildlife as part of the food web and are indicative of the ecosystem health (Schowalter et al. 2018). As closely associated with plants as the insects are, both generalists and specialists have been found to have reduced, equal, or increased fertility on invasive plant hosts (Sunny et al. 2015). Recently, there are some concerns over the declining abundance of insects (Wagner 2020).

Coleoptera (beetles) is one of the largest orders in which members occupy an extremely wide range of niches (World Conservation Monitoring Centre 1992; Jenny Cory, Simon Fraser University, pers. comm. February 2019). Beetles can be a good way to indicate ecological changes within a community (Koivula 2011, Mexia et al. 2020). In a recent ecological restoration article, the authors found that identifying beetles at the family level was enough to detect a difference between reference and restored sites (Mexia et al, 2020). In our context, analyzing their diversity could be a starting point for diagnosing the health of an ecosystem.

1.1. Background and Rationale

Stanley Park is an important habitat for a variety of wildlife species (Worcester 2010). Urban forests like Stanley Park provide much-needed habitat as well as connectivity for wildlife living in the Greater Vancouver Region. Invasive species like the English ivy are a major threat to the park's ecological integrity. The negative impact of ivy was supported by a 2002 study in Stanley Park where researchers found reduced diversity of native plants with increased ivy density (Quinn and Best 2002). It was observed that ivy monocultures often take over the native understory vegetation, especially in ecotones at the edges of disturbances (Worcester 2010). Since the mapping of English ivy was first digitized in 2002 (Worcester 2010), it had continued to colonize many parts of Stanley Park even with management efforts (Figure 1). It is important to keep in mind that linear disturbances such as trails are inevitable in an urban park like Stanley Park.

Located on the west shore of Canada, Stanley Park also provides important habitat for migratory birds, especially in the breeding season (Worcester 2010). Arthropods are arguably the most important part of many birds' diet as they prepare for reproduction (Robinson and Holmes 1982, Holmes and Robinson 1988, Hagar et al. 2007, Narango et al. 2017). Although many birds rely more on soft-bodied caterpillars, other arthropods can still be a considerable part of their diet, especially for generalist birds (Robinson and Holmes 1982, Holmes and Robinson 1988). In such cases, if English ivy has an undetected negative impact on the local arthropods, it would be detrimental for certain insectivorous birds. Restoration research on this is necessary to better prioritize restoration efforts for the park. Not only is English ivy impacting native plants that some arthropods might rely on, it could also be influencing the microclimate they are experiencing and thus affecting their distribution pattern.

Additionally, biodiversity is crucial to increasing resilience to invasive species (D'Antonio et al. 2016). This can be attributed to many ecological reasons. Two of the leading theories are 'niche preemption' and 'competition' (D'Antonio et al. 2016). 'Niche preemption' is part of the 'priority effects' (Diamond 1975): Composition of an ecological community could be shaped by early species and the types of niches they occupy (D'Antonio et al. 2016). 'Competition' refers to the assumption of invasive species being better competitors. This can sometimes be true as they can come with a lower cost of growth and higher phenotypic plasticity (Daehler 2003). Phenotypic plasticity can lead to physiological and morphological changes, which allow plants to adapt to short-term changes without evolution over generations (Matesanz et al. 2010). Both theories suggest that when a community is diverse with many niches occupied, it could be very resilient against invasion (D'Antonio et al. 2016). Thus, ensuring biodiversity is the best way to combat potential invasions by newcomers. Using arthropods and beetles as indicators, this study will give us a better understanding of the current resilience state of the park. As we have discussed before, English ivy would likely thrive with more changes and disturbances to come. Detecting any potential impacts on biodiversity early would help park managers plan for long-term resilience and other future challenges.

1.2. Goals and Objectives

Arthropods are ecologically important. My main goal was to detect any potential difference between the English ivy and native plant plots for arthropod compositions and microclimate characteristics. Any significant difference would have implications for ivy management. These were the questions I wanted to answer with this study:

1. Is there a lowered diversity of arthropods in plant patches predominantly occupied by English ivy? Are there specific groups associated with the ivy?
2. Is there a lowered diversity of beetles in plant patches predominantly occupied by English ivy?
3. Are the microclimate conditions experienced by the arthropod community different between native and English ivy patches?

The analyses of results obtained will be used to provide recommendations for the management methods for English ivy focusing on potential benefits to the arthropod community. My data will also update the arthropod inventory for Stanley Park.

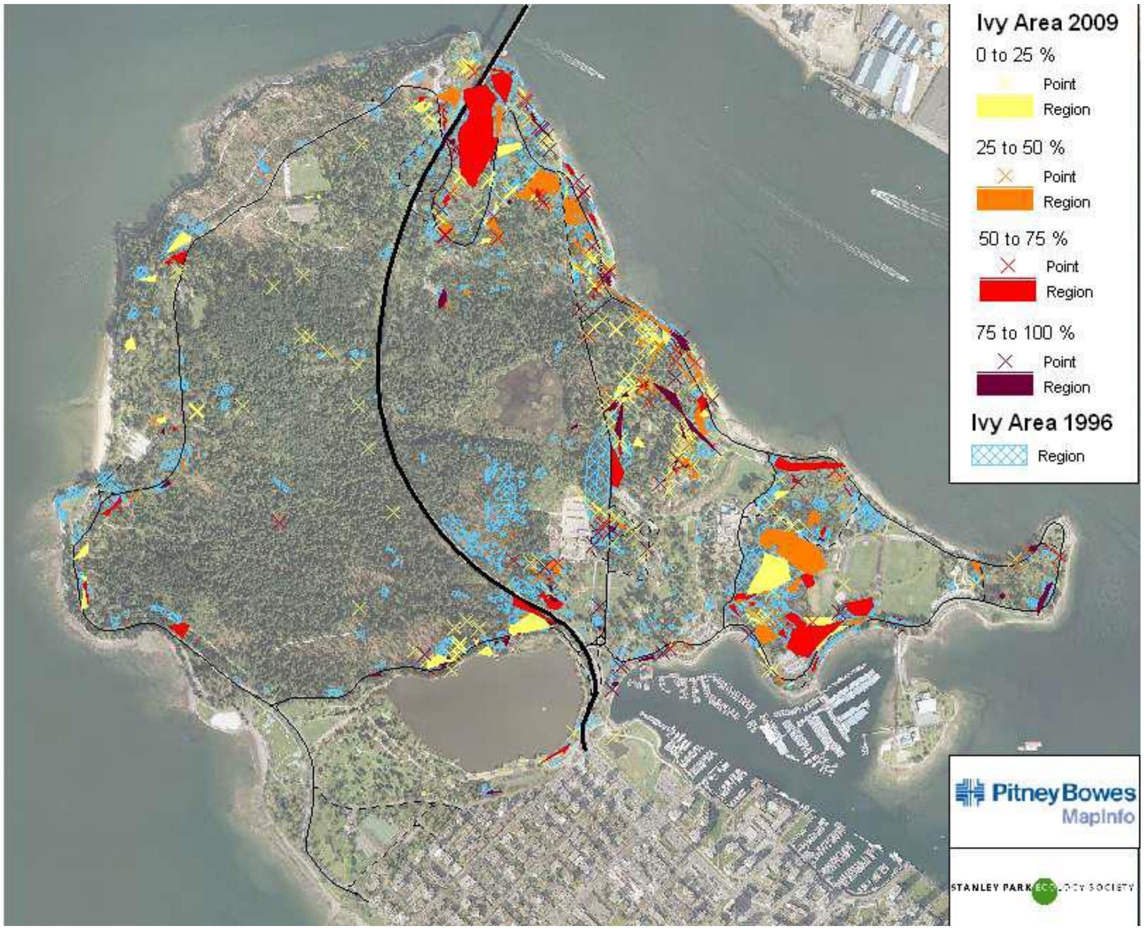

Figure 1. *Cover of English ivy in Stanley Park in 1996 and in 2009 (Image reprinted from Worcester 2010). The 1996 survey was the first time that ivy was mapped and digitized for Stanley Park (Worcester 2010). Reduction in biodiversity of native plants was associated with a higher density of English ivy in Stanley Park (Quinn and Best 2002).*

Chapter 2. Experimental Design and Methods

2.1. Research Site

The insect survey was carried out in Stanley Park in Vancouver, British Columbia, with permission from Parks Canada and the Vancouver Park Board. Stanley Park Ecology Society (SPES) had kindly granted access to the research area.

Located on the north shore of the City of Vancouver, Stanley Park occupies an area of around 404 ha (City of Vancouver 2019). As part of the Coastal Western Hemlock biogeoclimatic zone, this temperate rainforest experiences mild winter and long growing seasons (Pojar et al. 1991). The park contains a variety of different habitats, including but not limited to wetlands, riparian areas, ecotones, and forests (Worcester 2010). Forest covers the largest portion of the park, occupying up to 65% of the park (Worcester 2010). Some of the typical tree species include western red cedar (*Thuja plicata* Donn ex D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco); some of the typical understory plants include sword fern (*Polystichum munitum* (Kaulf.) C. Presl), spiny wood fern (*Dryopteris expansa* (C. Presl) Fraser-Jenk. & Jermy), deer fern *(Blechnum spicant* (L.) Sm.), and salmonberry (*Rubus spectabilis* Pursh).

The Stanley Park area has long been home to the Musqueam, Squamish, and Tsleil-Waututh Peoples before becoming a park (Kheraj 2017). It is an important National Historic Site of Canada. In 1888, the park is opened and named after the Governor General of Canada at the time (City of Vancouver 2019). Today, it is a major tourist attraction with up to 8 million visitors per year (City of Vancouver 2019). The Vancouver Park Board aims to manage the park sustainably for future generations to come (City of Vancouver 2019). Working together with the Vancouver Park Board, SPES plays an important role in maintaining the ecological integrity of the park with a focus on stewardship and environmental education (Stanley Park Ecology Society 2013). My research would provide valuable information to strengthen the ecological integrity of this special park.

2.2. Experimental Design

To compare arthropod diversity among native vs. ivy predominated plant communities, I set up vegetation plots at six locations across Stanley Park (Figure 2). Some areas were avoided to reduce confounding factors such as main roads. The choices of locations were also influenced by the presence of relatively undisturbed native vegetation as well as potential habitats for the protected Pacific water shrew (*Sorex bendirii* Merriam). To create interspersion, I set up one native plot and one ivy plot at each location (Figure 2). Each of the paired plots was at least 10 m apart to remain independent plots and conserve similarities in the microclimate. Once the plot location was selected, GPS waypoints were recorded as markers to prevent vandalism. The plots and their corresponding pitfall traps were named after the closest trail names: Brockton Oval Trail (BO), Chickadee Trail (C), Eagle Trail (E), Lovers Walk (L), Mallard Trail (M), and Rawlings Trail (R). They were assigned either number 1 or 2 to refer to the types of vegetation (1 = ivy, 2 = native plants) (Figure 2). For example, R1 would be the English ivy plot/trap near the Rawlings Trail; R2 would be the native plant plots/trap near the Rawlings Trail. The size of the plots was 4 m^2. Pitfall traps were installed in the centres of these 12 plots.

2.3. Characterization of Vegetation and Microclimate

Pitfall traps were set up at selected vegetation patches. Using the pitfall traps as the centre of each plot, two metres was measured using a surveying tape. The direction of the tape was kept consistent at north (0 degrees), south (180 degrees), east (90 degrees), and west (270 degrees). Stake flags were subsequently used to mark an area of 2 m by 2 m. The prevent vandalism, the plots were only marked for the duration of the vegetation survey. After the plots were marked, the vegetation in each plot was characterized in detail. Using the 6 plots as my replications, I used Welch's t-test to determine if the two types of vegetation plots were statistically different in terms of ivy cover and vegetation diversity.

To characterize vegetation, a 1 m by 1 m Daubenmire frame was used. The frame was used 4 times for the 4 quadrats of each plot. Two surveyors estimated the percent cover of each plant species within the frame. Data from each quadrat were converted into areas and added together for the percent cover of the whole plot. Part of the plant identification was made possible by Seek ---- an app developed by iNaturalist. Suggested species were subsequently confirmed by a field guide (Varner 2018). Vegetation survey was conducted twice for the 12 plots. The first vegetation survey was conducted on June 5th and 12th, 2019; the second survey was done on July 31st and August 7th, 2019. Data from the two surveys were averaged to ensure changes in vegetation community throughout the summer were covered. Shannon-Wiener Index of Diversity (Shannon 1948) was calculated for every plot in R 3.6.1. The formula used was as follows:

$$-\sum_i (p_i \log p_i)$$

Ivy cover, species richness, vegetation diversity, and the total plant cover between the two types of vegetation plots were compared using the Welch's t-test (two-tailed).

To estimate canopy cover, the same surveyor stood directly above the pitfall traps and held a densiometer (Forestry Suppliers, Spherical Crown Densiometer Concave Model C) at around chest height and where her reflection was at the edge of the squares. The surveyor then counted open or covered spaces in the squares and recorded counts. Percent canopy cover was then calculated according to instructions on the densiometer. Canopy cover for each plot was estimated twice: on June 1st and on August 9th, 2019. Data from these two surveys were averaged to cover for possible changes in the canopy throughout the summer.

Air moisture, ambient temperature, and soil temperature were recorded every Wednesday from May to August 2019 for all the vegetation plots. Percent air moisture and ambient temperature were measured by two thermometers (Daiso, Thermometer and Hygrometer) at two random locations within the plot. Soil temperature was taken at two random locations within the plot by soil thermometers (Taylor Precision Products, Bi-Therm Dial Thermometer). Averaged data were used for analysis. Using 6 plots as the replications of each vegetation type, two-tailed Welch's t-tests were performed on all environmental data between the ivy and the native plots.

2.4. Arthropod Community Sampling and Analyses

To obtain permission for arthropod sampling from Parks Canada, I went through the Species at Risk registry regarding arthropod species in British Columbia and checked the range maps available. The protected Monarch butterfly fell into the range of Stanley Park. This was confirmed in the invertebrate inventory list of Stanley Park. It was relatively simple to avoid bycatch since they rely on milkweed and have distinct appearances for both the caterpillar and adult life stages. In addition, milkweed was not detected during selection of research sites in February 2019.

As suggested in a previous study (Dlugosch 2005), ivy had apparent impacts to the understory vegetation. Thus, I chose pitfall traps to target arthropods close to the soil surface. Pitfall traps were set up at suitable vegetation patches. The traps were made of plastic cups with a diameter of 8.7 cm and a height of 11.5 cm. Covers made of hardboard and nails covered the openings of traps to prevent rainwater from overflowing the traps (Figure 3). A killing agent was added to preserve the specimens and to prevent arthropods from damaging each other. These wet pitfall traps were set up every Wednesday and collected every Friday from May 1st to August 31st, 2019. Soapy water was used as the killing agent for the first month. However, with a closer inspection under the microscope, I found that soft-bodied arthropod samples such as arachnids started to decompose, causing issues for identification. For this reason, propylene glycol was used instead from June 19th onward. To reduce mortality of small mammals and amphibians, starting from July 10th, 2019, I improved traps by reducing the diameter and height of the traps to 7.3 cm and 4.5 cm respectively.

Arthropod specimens that were greater than 0.5 mm in length were picked out using a paintbrush and transferred into 80% ethanol. Specimens from each trap were stored in individual vials with labels. These specimens were identified under a dissecting microscope (Nikon SMZ1500). Adult beetles (Coleoptera) were identified to the family level with help from experts and according to field guides (White 1983, Peterson 2018).

The Shannon-Wiener diversity indices (H') for the arthropods were calculated. Two-tailed Welch's t-test was used to see if they were different between ivy and native plots. Using the 6 replications of the 2 vegetation types, two-tailed Student's t-tests were performed for the total abundance of each arthropod group (including the beetles). The Shapiro-

Wilk test for normality and the Bartlett's test for equal variance were used to check for assumptions.

Two-tailed Welch's t-test was used to compare total abundance of beetles for each beetle family between the two types of vegetation plots. To visualize similarities and differences between arthropod compositions at each plot, non-metric multidimensional scaling (NMDS) was used. This was done using the "metaMDS" function in the R vegan package (Appendix A) (Oksanen et al. 2019): Bray-Curtis dissimilarity matrix was calculated through the number of individuals for each beetle family at the 12 vegetation plots. The results were plotted into a two-dimensional ordination space.

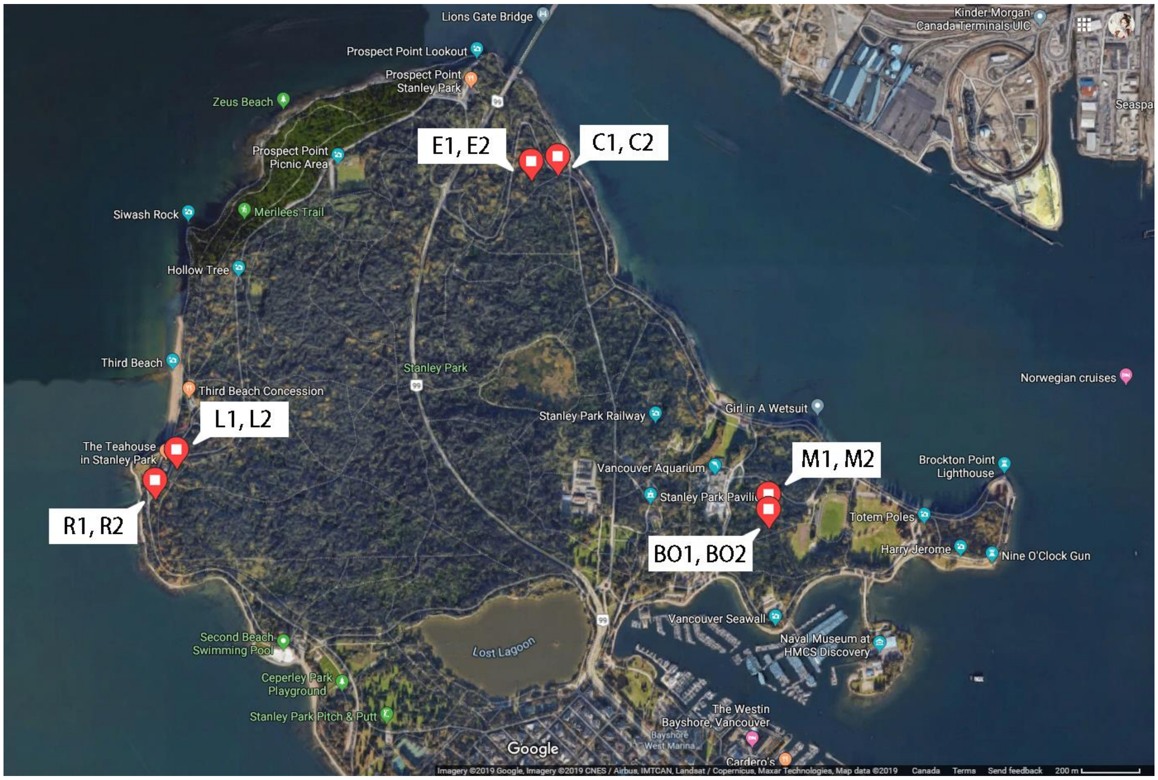

Figure 2. *Sampling locations in Stanley Park, Vancouver, British Columbia. Data collected from May 1st to August 31 st, 2019. Each red pin is representing one pair of plots. In total, there were 12 pitfall traps within 12 plots across the park. The middle of the park was avoided due to main roads, potential habitat of the pacific water shrew, as well as a lack of suitable native plant plots. R1, R2, L1, L2, E1, E2, C1, C2, BO1, BO2, M1, and M2 refer to the names of the plots/traps. The numbers indicate if it was an ivy or native plot (1 = ivy plot, 2 = native plot). (Image modified from Google Maps, accessed Oct 2019.)*

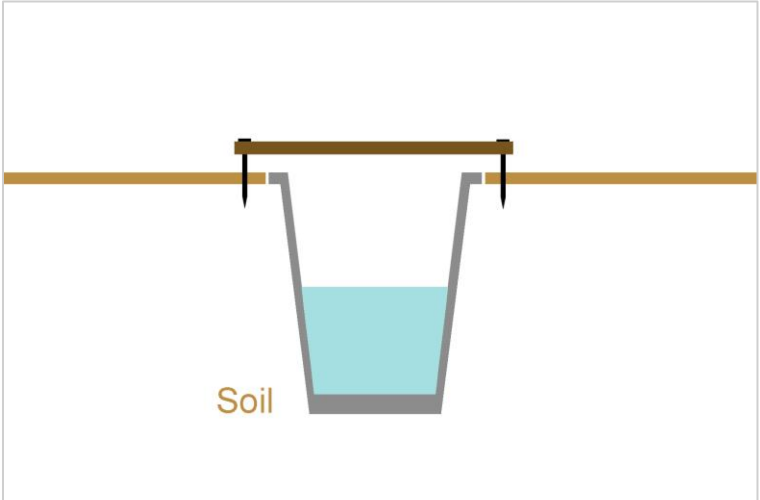

Figure 3. *Design of the Pitfall traps. The traps were set up leveled to the soil. A hardboard was nailed on top to prevent the trap from overflowing from rainwater. To prevent arthropods from damaging each other when trapped, a killing agent (soapy water/ propylene glycol) was used.*

Chapter 3. Results

Overall, native and English ivy plots were very similar in terms of microclimate, arthropod groups, and beetle community composition. I did not find specific groups that were associated with English ivy. However, three beetle families were exclusively found in native plant plots. The results are detailed in the following sections.

3.1 Vegetation and Microclimate

English ivy was present in all plots, including small proportions in the native plant plots. Since this study was designed to compare ivy and native plant plots, the amount of English ivy cover was of interest. All ivy plots had over 1 m^2 (25%) of ivy cover while all native plant plots had less than 0.5 m^2 (12.5%) of ivy cover (Figure 4).

Native plot C2 had the highest diversity of vegetation and contained herbaceous plants that were not found in other native plots (Table 1). Ivy plots and native plots were similar in species richness, diversity, and plant cover (Table 2). Two-tailed Welch's t-tests indicated that there was no statistically significant difference between the two types of vegetation plots in terms of species richness ($t = -1.50$, $p = 0.17$), Shannon-Wiener diversity index ($t = -1.26$, $p = 0.24$), and total plant cover ($t = 1.08$, $p = 0.31$). This is important to keep in mind as we look at results of arthropods and beetles in the following sections.

Microclimate records were mostly consistent across all plots. The average soil and ambient air temperature were not different between the native and English ivy plots (soil temperature: $t = 0.37$, $p = 0.72$; ambient temperature: $t = 0.42$, $p = 0.69$) (Figure 5). Percent moisture in air also showed no significant difference ($t = -0.85$, $p = 0.42$) (Figure 6). Canopy cover in ivy plots seemed to be a bit higher than native plots (Figure 7). The mean canopy cover was 89.47% for ivy plots, 82.52% for native plots. However, the difference was not statistically significant in a two-tailed t-test ($t = 1.22$, $p = 0.26$).

3.2 Arthropod Abundance and Diversity

In total, 9974 arthropods were examined. Arthropods were sorted into 20 distinct taxonomic groups (Table 3). Note that these groups were not taxonomically equivalent of each other. No statistically significant difference in total abundance of each arthropod group was detected between ivy and native plots (Table 4). The most abundant groups were the Collembola (springtails) and Oniscidea (woodlice). By observation, Oniscidea was especially abundant in July, which experienced several warmer sampling days. The number of Oniscidea (woodlice) was the highest in BO1 (Table 3). The ground cover of BO1 was consisted of English ivy (Table 1) with a thick layer of leaf litter from the western red cedar and other coniferous trees nearby. The presence of Parasitica (parasitoid wasps) in both ivy and native plots was interesting. Families of these parasitoid wasps included Ichneumonidae, Diapriid, Proctotrupidae, Platygastridae, Eulophidae, and Ceraphronoidea (superfamily).

Two-tailed Welch's t-test showed no significant difference between ivy and native plots for arthropod diversity ($t = -0.48$, $p = 0.64$) (Table 5). Not surprisingly, linear regression of the vegetation diversity and arthropod diversity showed a weak positive trend (Figure 8). However, this trendline became nearly flat when C2 was excluded. Native plot C2 had the highest diversity of both plants and arthropods (Figure 8). Ivy cover did not seem to affect the diversity of arthropods (Figure 9). Ivy plot C1 had the highest ivy cover of 3.36 m^2, or 84%, but still maintained a relatively high arthropod diversity index of 1.69 (Figure 9).

3.3 Beetle Abundance and Composition

There was a total of 329 adult beetles. They were sorted into 10 families (Table 6). Two-tailed Welch's t-tests showed no significant difference in the number of individuals within each family across ivy and native plots. Three families were exclusively found in native plot C2 and BO2: Agyrtidae (primitive carrion beetles), Ptiliidae (featherwing beetles), and Hydrophilidae (water scavenger beetles) (Table 6). Ivy plots had a smaller proportion of Staphylinidae and larger proportions of Carabidae and Curculionidae (Figure 10). NMDS showed a large overlap in beetle family composition between ivy and native plots (stress = 1.12, $k = 2$) (Figure 11). Beetle communities in the two types of vegetation plots were not significantly different.

Table 1. *List of plants at each of the twelve plots. Plot C2 was very diverse and had many unique herbaceous plants. Note there were some non-native plants in the native plant plots. Information based on Integrated Taxonomic Information System (2020) and B.C. Conservation Data Centre (2020).*

Plot	Plot Type	Species	Common Name	Type of plant	Native	% Cover
BO1	Ivy	*Hedera helix* L.	English ivy	vine	x	44.06%
		Thuja plicata Donn ex D. Don	Red Cedar	coniferous tree	✓	2.81%
BO2	Native	*Hedera helix* L.	English ivy	vine	x	1.69%
		Polystichum munitum (Kaulf.) C. Presl	Sword fern	fern	✓	37.75%
		Blechnum spicant (L.) Sm.	Deer fern	fern	✓	8.91%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	0.88%
		Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy	Spiny wood fern	fern	✓	0.75%
		Athyrium filis- femina (L.) Roth	Lady fern	fern	✓	0.31%
C1	Ivy	*Hedera helix* L.	English ivy	vine	x	84.06%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	11.88%
C2	Native	*Geranium robertianum* L.	Herb Robert	herbaceous	x	22.31%
		Ranunculus repens L.	Creeping buttercup	herbaceous	x	9.31%
		Hedera helix L.	English ivy	vine	x	5.00%
		Lapsana communis L.	Common nipplewort	herbaceous	x	3.31%
		Sambucus racemosa L.	Red-berried elder	shrub	✓	13.56%
		Tellima grandiflora (Pursh) Douglas ex Lindl.	Fringe cups	herbaceous	✓	6.19%
		Athyrium filis- femina (L.) Roth	Lady fern	fern	✓	5.69%
		Claytonia sibirica L.	Candy flower	herbaceous	✓	4.69%
		Circaea alpina L.	Alpine enchanter's nightshade	herbaceous	✓	3.63%
		Galium aparine L.	Catchweed bedstraw	herbaceous	✓	0.94%
		Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy	Spiny wood fern	fern	✓	0.13%
E1	Ivy	*Hedera helix* L.	English ivy	vine	x	32.19%
		Ilex aquifolium L.	English holly	shrub	x	2.88%

		Acer circinatum Pursh	Vine maple	deciduous tree	✓	6.50%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	4.69%
		Polystichum munitum (Kaulf.) C. Presl	Sword fern	fern	✓	2.75%
		Tiarella trifoliata L.	Threeleaf foamflower	herbaceous	✓	1.59%
		Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy	Spiny wood fern	fern	✓	1.06%
E2	Native	*Hedera helix* L.	English ivy	vine	x	0.31%
		Ilex aquifolium L.	English holly	shrub	x	0.13%
		Dryopteris expansa (C. Presl) Fraser-Jenk. & Jermy	Spiny wood fern	fern	✓	23.56%
		Blechnum spicant (L.) Sm.	Deer fern	fern	✓	10.69%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	7.81%
		Tiarella trifoliata L.	Threeleaf foamflower	herbaceous	✓	1.69%
		Vaccinium parvifolium Sm.	Red huckleberry	shrub	✓	1.13%
L1	Ivy	*Hedera helix* L.	English ivy	vine	x	43.75%
		Sorbus aucuparia L.	Rowan	shrub	x	0.31%
		Lapsana communis L.	Common nipplewort	herbaceous	x	0.13%
		Rubus ursinus Cham. & Schltdl.	Trailing Blackberry	shrub or vine	✓	9.13%
		Abies grandis (Douglas ex D. Don) Lindl.	Grand Fir	coniferous tree	✓	6.06%
		Vaccinium parvifolium Sm.	Red huckleberry	shrub	✓	3.00%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	1.38%
L2	Native	*Hedera helix* L.	English ivy	vine	x	0.44%
		Rubus ursinus Cham. & Schltdl.	Trailing Blackberry	shrub or vine	✓	36.56%
		Thuja plicata Donn ex D. Don	Red Cedar	coniferous tree	✓	9.25%
		Vaccinium parvifolium Sm.	Red huckleberry	shrub	✓	3.00%
		Polystichum munitum (Kaulf.) C. Presl	Sword fern	fern	✓	0.63%
		Tsuga heterophylla (Raf.) Sarg.	Western hemlock	coniferous tree	✓	0.13%
M1	Ivy	*Hedera helix* L.	English ivy	vine	x	45.63%

		Rubus spectabilis Pursh	Salmonberry	shrub	✓	9.13%
M2	Native	*Pinus*	Unidentified Pine	coniferous tree	N/A	0.63%
		Hedera helix L.	English ivy	vine	x	7.88%
		Polystichum munitum (Kaulf.) C. Presl	Sword fern	fern	✓	44.06%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	0.38%
R1	Ivy	*Hedera helix* L.	English ivy	vine	x	52.19%
		Rubus armeniacus Focke	Himalayan Blackberry	shrub	x	9.81%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	13.25%
		Thuja plicata Donn ex D. Don	Red Cedar	coniferous tree	✓	1.94%
		Rubus ursinus Cham. & Schltdl.	Trailing Blackberry	shrub or vine	✓	1.88%
		Polystichum munitum (Kaulf.) C. Presl	Sword fern	fern	✓	0.81%
R2	Native	*Hedera helix* L.	English ivy	vine	x	10.56%
		Rubus armeniacus Focke	Himalayan Blackberry	shrub	x	4.56%
		Polystichum munitum (Kaulf.) C. Presl	Sword fern	fern	✓	37.81%
		Rubus ursinus Cham. & Schltdl.	Trailing Blackberry	shrub or vine	✓	8.56%
		Rubus spectabilis Pursh	Salmonberry	shrub	✓	0.44%

Table 2. *Species richness, Shannon-Wiener diversity index, and the total cover of plants in the 12 plots at Stanley Park. The percent cover of plant species was converted into area to calculate Shannon-Wiener diversity. Note that although plants can overlap and the total cover can exceed 100%, none of the plots did. This data was the average of the two vegetation surveys conducted on June 5th & 12th, and on July 31st & August 7th, 2019.*

Plot	**Type**	**Species richness (S)**	**Shannon-Wiener diversity index (H')**	**Total Cover (m^2)**	**% Cover**
BO1	Ivy	2	0.23	1.88	47%
BO2	Native	6	0.80	2.01	50%
C1	Ivy	2	0.37	3.84	96%
C2	Native	11	2.04	2.99	75%
E1	Ivy	7	1.28	2.07	52%
E2	Native	7	1.25	1.81	45%
L1	Ivy	7	1.03	2.55	64%
L2	Native	6	0.82	2.00	50%
M1	Ivy	2	0.45	2.19	55%
M2	Native	4	0.52	2.12	53%
R1	Ivy	6	1.06	3.20	80%
R2	Native	5	1.10	2.48	62%

Table 3. *Number of arthropod individuals collected in the 12 traps from May 1st to August 31st, 2019. The numbers in the names of the traps indicate if it was from an ivy or native plot (1 = ivy plot, 2 = native plot).*

Group/Trap	**M1**	**M2**	**BO1**	**BO2**	**C1**	**C2**	**E1**	**E2**	**L1**	**L2**	**R1**	**R2**
Collembola	140	191	304	311	219	191	264	217	291	342	110	105
Oniscidea	831	265	1172	774	88	50	119	75	433	271	477	665
Coleoptera	26	24	45	29	22	95	14	18	22	37	13	8
Diptera	2	9	10	9	22	31	9	9	24	15	2	11
Opiliones	11	14	19	15	1	0	14	4	37	3	3	1
Araneae	23	34	48	33	12	16	28	34	18	18	28	23
Acari	40	17	15	22	63	41	14	27	8	20	17	6
Diplopoda	61	48	19	16	37	100	4	11	53	28	22	42
Chilopoda	0	0	0	0	0	1	2	2	0	0	0	0
Formicidae	13	23	10	13	16	3	24	2	51	50	20	18
Parasitica	0	0	4	2	2	5	1	1	6	0	1	0
Lepidoptera	0	0	0	0	1	0	0	1	1	1	0	0
Symphyta	0	0	0	0	0	1	0	0	0	0	0	0
Dermaptera	3	4	0	1	0	0	1	0	2	0	0	0
Pseudoscorpiones	1	1	0	1	0	1	0	2	2	1	4	1
Symphyla	0	0	0	0	0	0	0	0	0	0	1	0
Hemiptera	2	2	22	5	3	10	2	0	3	1	2	1
Diplura	0	0	0	0	0	1	0	0	0	0	0	0
Rhaphidophoridae	4	2	1	1	0	0	0	0	5	0	5	3
Psocodea	1	1	5	1	0	3	1	0	4	1	2	0
Total	9974											

Table 4. *P-values of independent t-tests on artrhopod abundance between the two types of vegetation. Two-tailed Student's t-test was used to detect potential differences in the total abundance of each arthropod groups. No significant result was found for any arthropod group. Some groups violated assumptions and were not tested.*

Common Name	**Group Name**	**t-value**	**df**	**p-value**
Mites and ticks	Acari	0.41	10	0.69
Spiders	Araneae	N/A	N/A	N/A
Centipedes	Chilopoda	N/A	N/A	N/A
Beetles	Coleoptera	-0.85	10	0.41
Springtails	Collembola	-0.1	10	0.92
Earwigs	Dermaptera	N/A	N/A	N/A
Millipedes	Diplopoda	-0.51	10	0.62
Two-pronged bristletails	Diplura	N/A	N/A	N/A
Flies	Diptera	N/A	N/A	N/A
Ants	Formicidae	0.44	10	0.67
True bugs	Hemiptera	N/A	N/A	N/A
Butterflies and moths	Lepidoptera	N/A	N/A	N/A
Woodlice	Oniscidea	0.81	10	0.44
Parasitoid wasps	Parasitica	N/A	N/A	N/A
Harvestmen	Opiliones	1.34	10	0.21
Pseudoscorpions	Pseudoscorpiones	N/A	N/A	N/A
Bark lice	Psocodea	1.28	10	0.23
Camel crickets	Rhaphidophoridae	1.34	10	0.21
Garden centipede	Symphyla	N/A	N/A	N/A
Sawflies	Symphyta	N/A	N/A	N/A

Table 5. *Shannon-Wiener diversity indices (H') for the arthropod groups at each plot. Two-tailed Welch's t-test did not a reveal a significant difference between the ivy and the native plots (t = -0.48, p = 0.64).*

Plot	Type	H' for Arthropod Groups
BO1	Ivy	1.056693
BO2	Native	1.14643
C1	Ivy	1.692994
C2	Native	1.877029
E1	Ivy	1.48168
E2	Native	1.512545
L1	Ivy	1.58832
L2	Native	1.476549
M1	Ivy	1.091742
M2	Native	1.651861
R1	Ivy	1.21063
R2	Native	0.959561

Table 6. *Number of beetles identified in the 12 traps. Specimens were collected from May to August 2019 in Stanley Park and only adult beetles were identified. In total, 329 beetles of 10 beetle families were examined.*

Vegetation	**English Ivy**						**Native Plants**					
Group/Trap	**M1**	**BO1**	**C1**	**E1**	**L1**	**R1**	**M2**	**BO2**	**C2**	**E2**	**L2**	**R2**
Curculionidae	0	5	5	2	8	0	0	0	3	2	5	2
Carabidae	7	18	2	2	1	0	2	4	5	10	0	0
Staphylinidae	22	4	11	2	8	10	12	10	64	3	19	5
Latridiidae	0	4	2	2	0	2	3	0	1	1	6	1
Leiodidae	1	4	2	2	0	0	2	8	3	0	0	0
Elateridae	0	0	0	1	1	0	1	1	0	0	2	0
Cryptophagidae	0	5	0	1	1	0	1	3	0	0	4	0
Agyrtidae	0	0	0	0	0	0	0	1	0	0	0	0
Ptiliidae	0	0	0	0	0	0	0	1	7	0	0	0
Hydrophilidae	0	0	0	0	0	0	0	0	2	0	0	0
Total	30	40	22	12	19	12	21	28	85	16	36	8
Grand Total												**329**

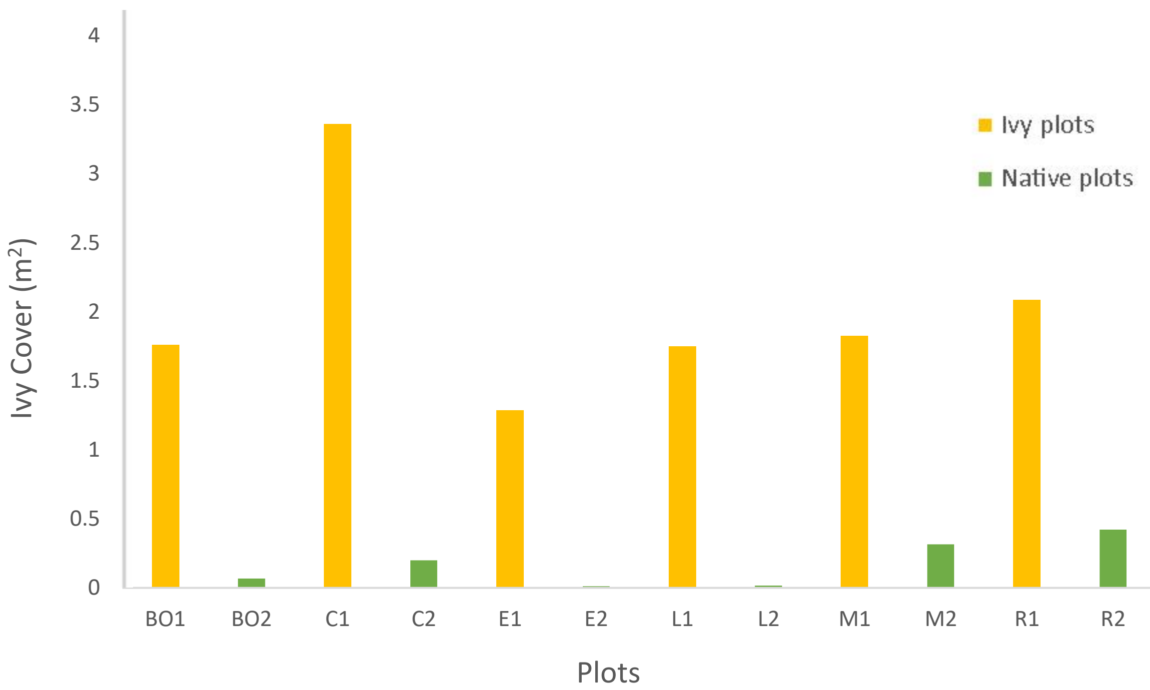

Figure 4. *Amount of English ivy cover within each plot. Data was the average of two surveys conducted on June 5th & 12th, and on July 31st & August 7th, 2019 in Stanley Park. Ivy plots had significantly higher ivy coverage than the native plots (t = 6.17, p = 0.001). Native plot C1 had the highest ivy cover (84% or 3.36 m^2).*

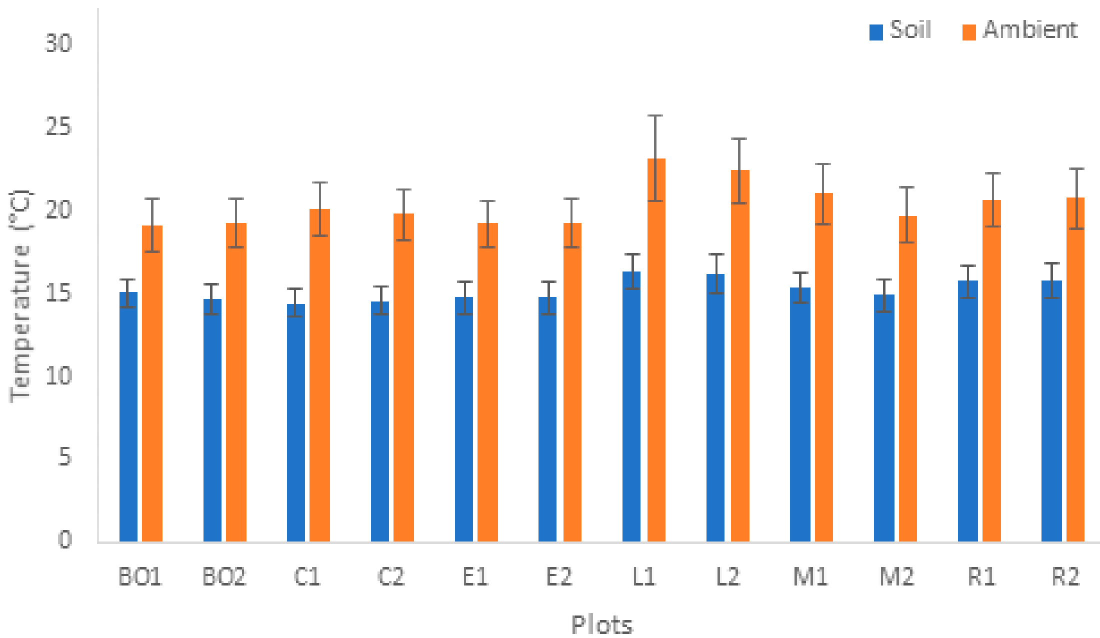

Figure 5. *Average soil and ambient air temperature from May to August 2019 at the 12 plots in Stanley Park. Two-tailed Welch's t-test did not reveal statistically significant differences between ivy and native plots (Soil Temperature: t = 0.37, p = 0.72; Ambient Temperature: t = 0.42, p = 0.68). The error bars are showing the 95% confidence intervals. Numbers in the names of the plots indicate if it was an ivy or native plot (1 = ivy plot, 2 = native plot).*

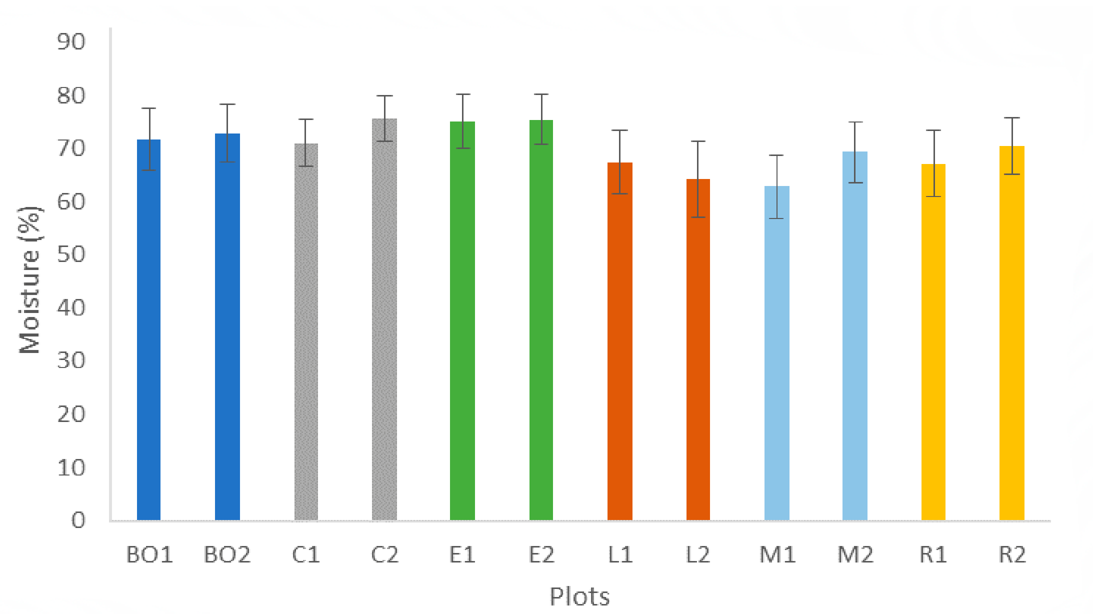

Figure 6. *Mean air moisture (%) from May to August 2019 at the 12 plots in Stanley Park. Two-tailed Welch's t-test did not reveal statistically significant differences between ivy and native plots (t = -0.85, p = 0.42). The error bars are showing the 95% confidence intervals. Numbers in the names of the plots indicate if it was an ivy or native plot (1 = ivy plot, 2 = native plot).*

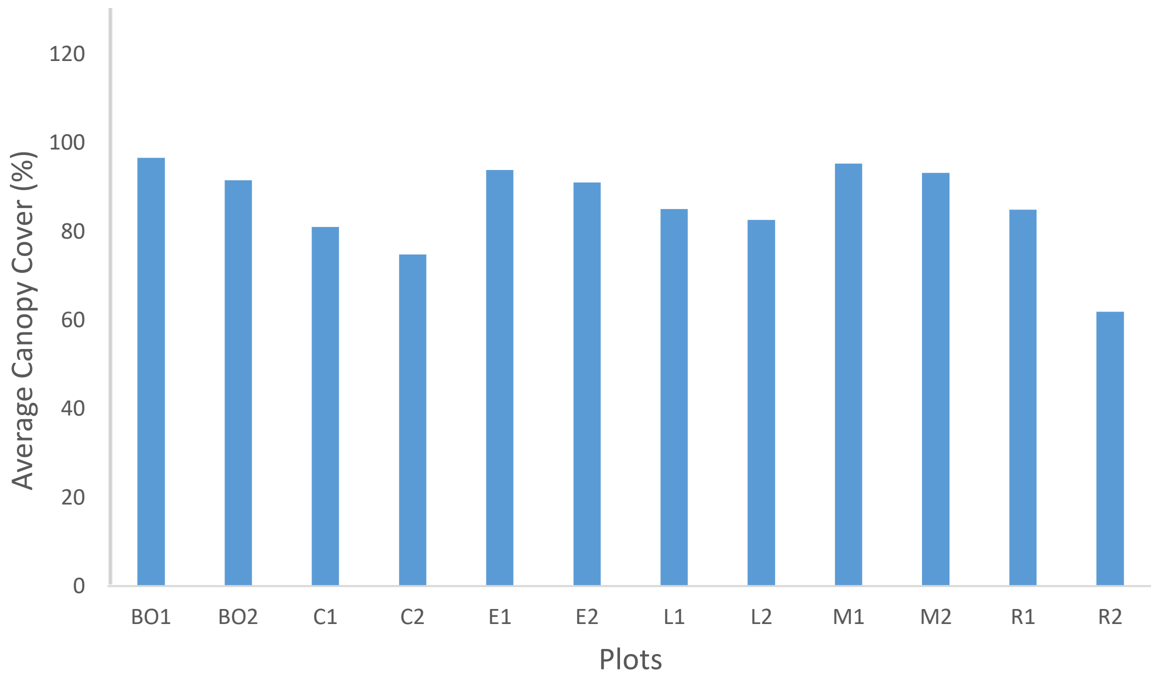

Figure 7. *Canopy cover at each plot in percentages. This graph is using the average of two surveys conducted on June 1st and on August 9th, 2019. Since the data was based on only two surveys, no error bar was inserted. Two-tailed Welch's t-test did not reveal statically significant differences between ivy plots and native plots (t = 1.22, p = 0.25). Numbers in the names of the plots indicate if it was an ivy or native plot (1 = ivy plot, 2 = native plot).*

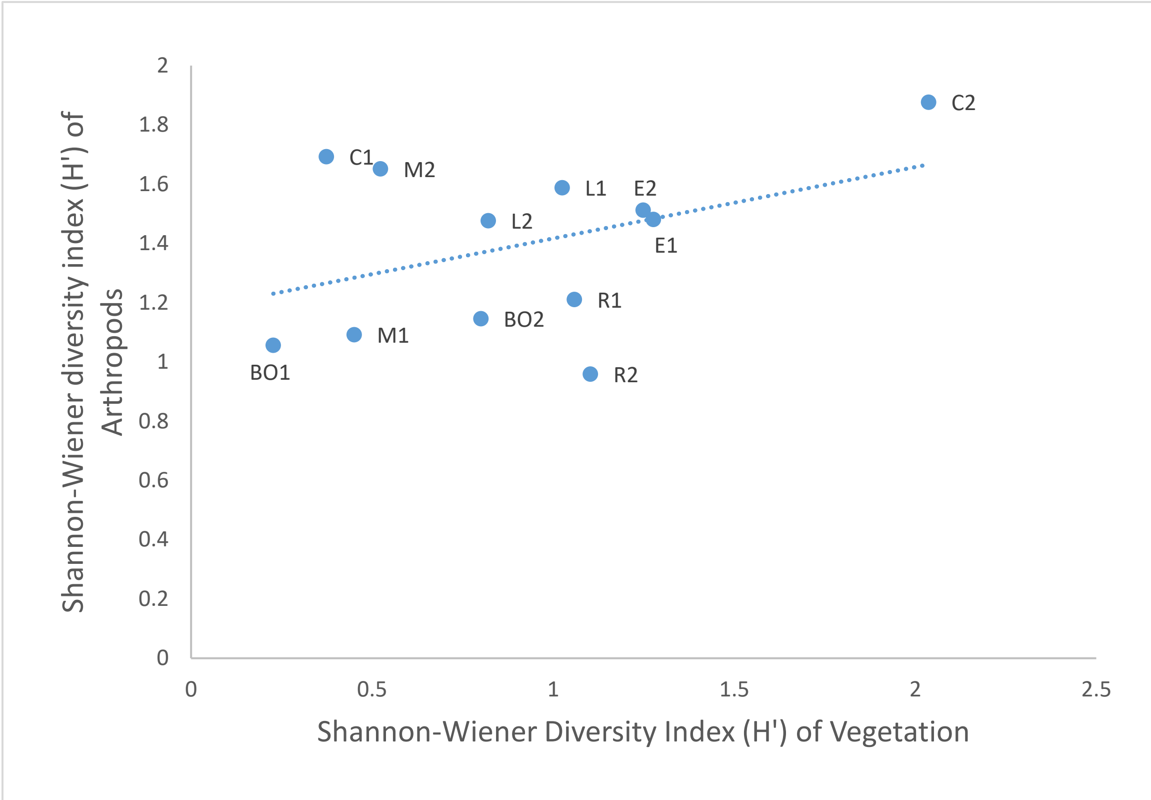

Figure 8. *Linear regression between the diversity of vegetation and the diversity of arthropods. Vegetation diversity have some influence on the diversity of arthropod groups (R^2 = 0.17). The sample was small and thus data violated certain assumptions of the linear regression model. When C2 was taken out, trendline became nearly flat. Numbers in the names of the traps indicate whether it was from an ivy or native plot (1 = ivy plot, 2 = native plot).*

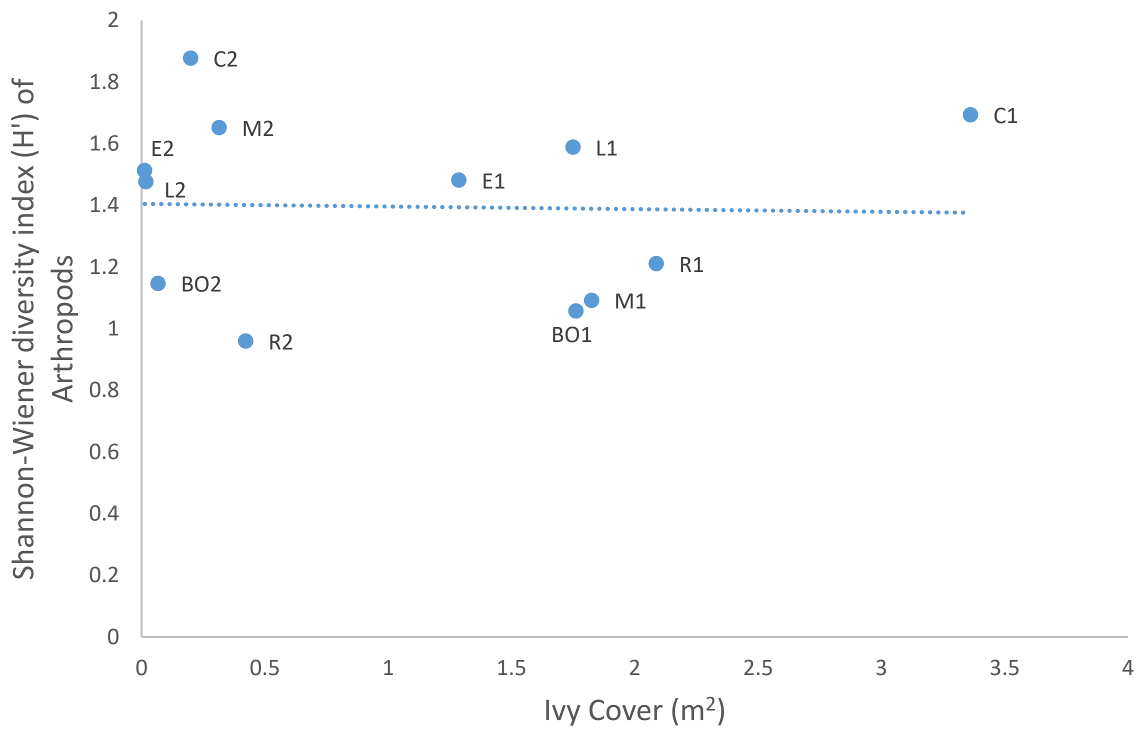

Figure 9. *Linear regression between amount of ivy cover and arthropod diversity. The amount of ivy cover does not seem to influence the diversity of arthropod groups (R^2 = 0.001). The sample size was small and thus data violated certain assumptions of the linear regression model. Numbers in the names of the traps indicate whether it was from an ivy or native plot (1 = ivy plot, 2 = native plot).*

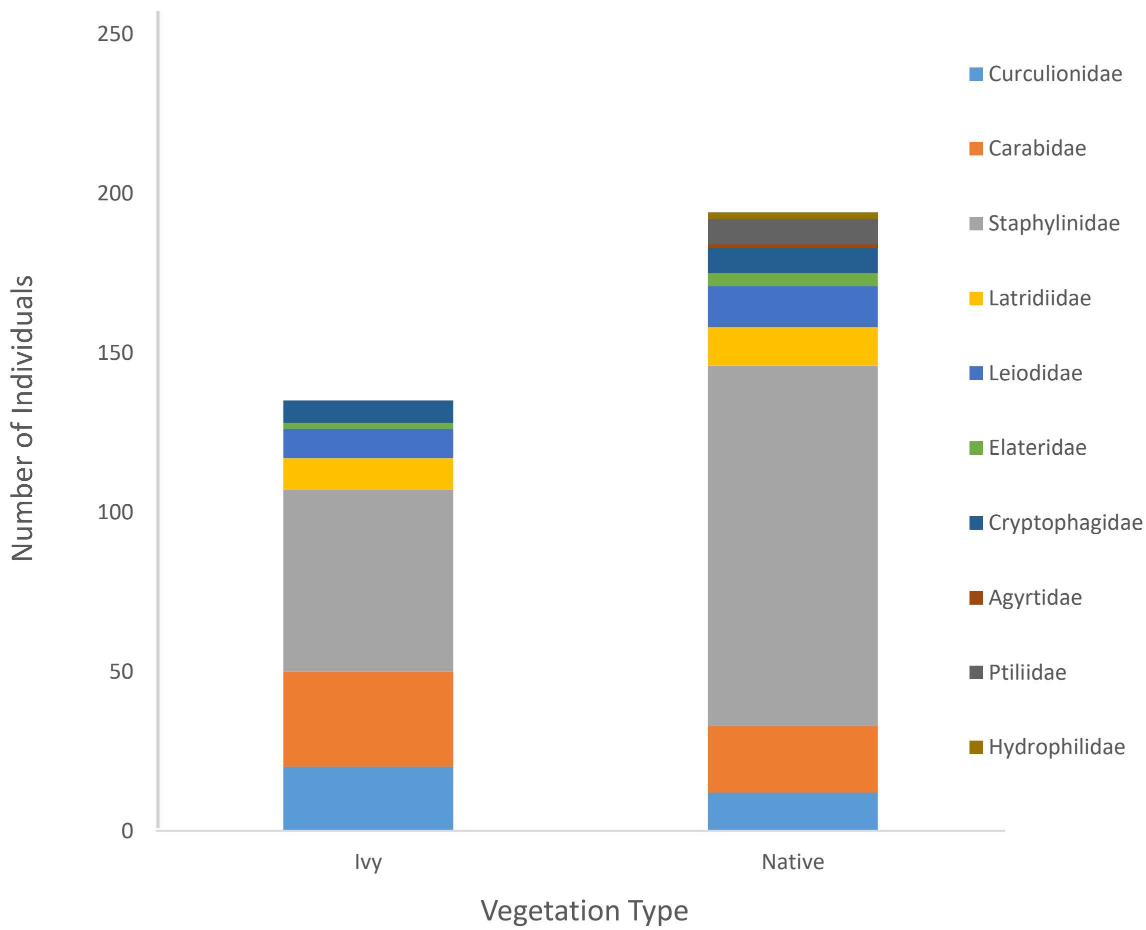

Figure 10. *Number of beetles found in ivy and native vegetation type when all six replications were compiled. There were 10 beetle families detected. Two-sample t-tests were performed on these families (n = 6). The difference in the total abundance of each family between the two vegetation types was not significant.*

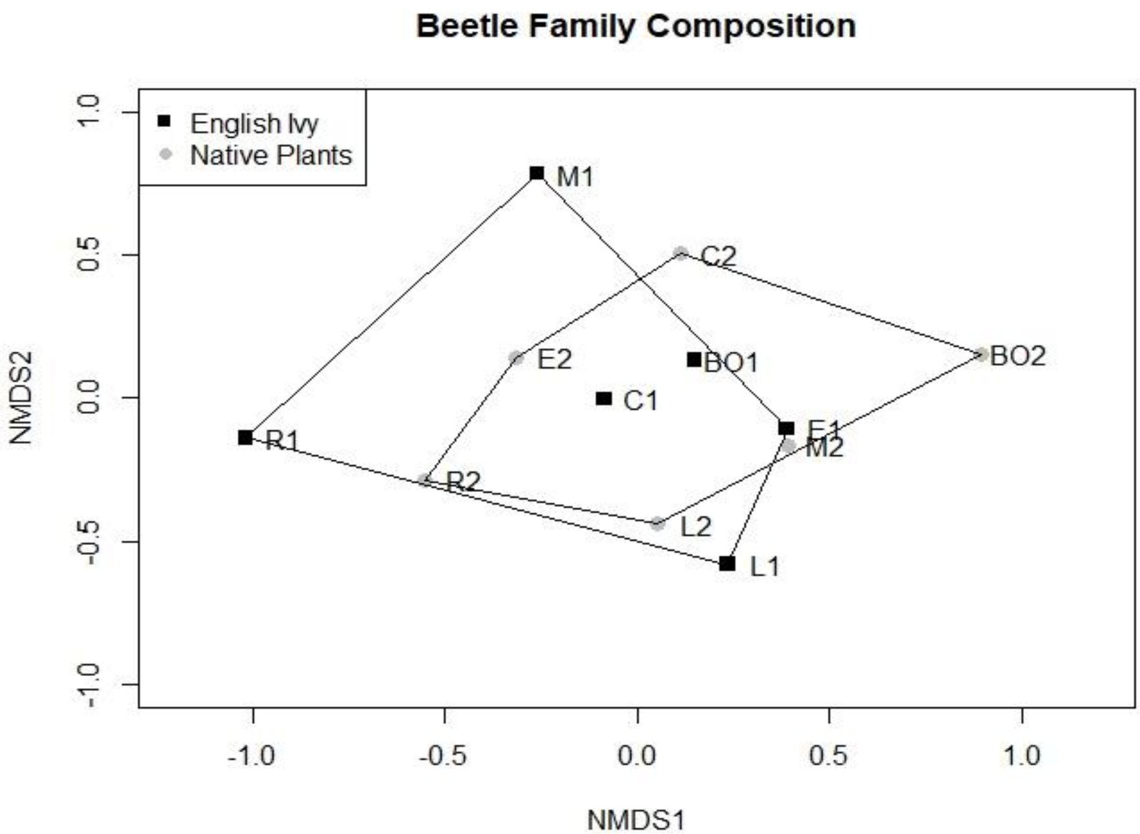

Figure 11. *NMDS plot showing the distances between the beetle compositions of the 12 traps. The number of individuals detected from the 10 beetle families were used to generate a matrix of Bray-Curtis index of dissimilarity. The results were plotted in a two-dimensional ordination space (stress = 0.12, k = 2).*

Chapter 4. Discussion and Recommendations

4.1 Vegetation and Microclimate

Since vegetation was estimated from a top-down perspective, plants can overlap, and thus the total cover can exceed 4 m^2. However, none of the total plant covers exceeded this threshold (Table 2). This could be attributed to the trampling of plots throughout the weekly arthropod collection. Trampling was observed on-site as the vegetation within plots showed more reduced cover than vegetation immediately outside of the plots. In addition, these data were the average of the two vegetation surveys conducted on June 5^{th} & 12^{th}, and on July 31^{st} & August 7^{th}, 2019. Some of the herbaceous plants had reduced biomass at the time of the second survey.

Native plot C2 had a very diverse plant community (Figure 8) and hosted more herbaceous plants that were not seen in other native plant plots (Table 1). This could have brought in more diversity for arthropods and beetles. However, I still did not detect statistically significant results with the inclusion of this outlier. Future studies could set up more categories of ivy cover and account for herbaceous plant cover.

Excluding the invasive English ivy and creeping buttercup, there were 9 species of plants at native plot C2 (Table 1). Lady fern and spiny wood fern are native evergreen ferns that were also found at other vegetation plots. Alpine enchanter's nightshade, candy flower, Herb Robert, and fringe cups were unique herbaceous plants found at C2. Common nipplewort and red-berried elder were structurally taller than other plants and possibly provided some habitat heterogeneity for arthropods. The origin of catchweed bedstraw was debated but most consider it to be a native species to Canada (Gucker 2005, B.C. Conservation Data Centre 2020, Integrated Taxonomic Information System 2020). Catchweed bedstraw is covered in dense Velcro-like trichomes, which might be an effective defense against large but not small herbivorous arthropods. The specific interactions between these plants and arthropod communities were not well studied. Nonetheless, there was evidence suggesting that deciduous shrubs supported more arthropods than evergreen shrubs (Hagar et al. 2007). Even though Herb Robert and common bedstraw were considered trailside weeds by managers (Stanley Park Ecology Society 2013), I believe they were still contributing to the diverse community of arthropods along with other plants found at C2. Future research could incorporate native or non-native plants at C2 to validate their importance to arthropods.

English ivy cover in Figure 9 showed clustering either between 0 to 1 m^2, or 1 to 2 m^2, except for C1. Although compositions of vegetation would be better controlled in a common-garden experiment, it might have limited use to capture what is happening in the field. But there were limitations to doing the type of field study undertaken in this applied research project. Many herbaceous plants would be at their fullest in summer (Eric Anderson, British Columbia Institute of Technology, pers. comm. March 2019). Moreover, arthropods, especially insects would be active in summer (Reddy 1984, Yagi 2008) (Jenny Cory, Simon Fraser University, pers. comm. February 2019). Due to the one-summer time frame of this project, it was only possible to survey vegetation while collecting arthropods. Ideally, vegetation surveys should be conducted in the first summer, followed by arthropod collection in the second summer. Doing vegetation surveys in advance could help to achieve more comparable ivy cover across ivy plots. Without manual removal, it might be difficult to obtain the same levels of ivy cover in plots. Nonetheless, it is possible to group ivy plots with similar levels of ivy cover (e.g. 1-25%, 25-50%). Dividing them into categories would better mimic realistic scenarios and better detect the effect of English ivy. Finally, excessive variation in the amount and type of native plant species could also be avoided by doing vegetation surveys a head of time and choosing more randomized sites to set up the plots/traps.

Microclimate was very consistent across all plots (section 3.1). Percent canopy cover was slightly higher in ivy plots, but this difference was not statistically significant (Figure 7). Although the perceived difference was small, it was consistently higher across ivy plots. Thus, this insignificance could be an artifact of my small sample size. The addition of more replications could yield a statistically significant result. If canopy cover is indeed higher in ivy occupied spaces, one possible explanation would be that ivy had difficulty penetrating occupied spaces in the open canopy area (priority effect).

4.2 Arthropod Abundance and Diversity

Results from arthropod abundance and diversity implied that English ivy did not have a detectable impact on the arthropod community. The effect of vegetation diversity on arthropod diversity was weak as the R^2 value was small ($R^2 = 0.17$) and the trend was nearly flat when C2 was removed from Figure 8. As discussed in section 4.1, well-designed ivy and native plants categories could help to detect more potential trends. The two most abundant groups were the springtails (Collembola) and the woodlice (Oniscidea). The woodlice are mostly detritivores and they are widespread throughout the world (Zimmer 2002, Devigne et al. 2011). Similarly, springtails are also widespread but have more niche diversity. Some springtails have prominent furcula which helps them jump many times as their own body length (Hopkin 1997).

One of the limitations of this study was the small sample size. There were only 6 replicates for each type of vegetation plot. The statistically insignificant results for arthropod abundance and diversity between the two vegetation types could also be attributed to dispersion. The mobility of each arthropod group would be variable and thus population dynamics could be replenishing plant patches. Ivy might have created some degree of habitat fragmentation, but this would not stop some arthropods who were known for wandering (David and Handa 2010). In a global review, the millipedes (Diplopoda) and woodlice (Oniscidea) were not sensitive to habitat fragmentation (David and Handa 2010). In Table 3, these two groups were also abundant with a few exceptions. In addition, some species such as predatory beetles may be territorial (Fitzpatrick and Wellington 1983). Future studies could design bigger vegetation plots and look at the connectivity of native/ivy patches at a broader landscape level. Lastly, pitfall traps tend to capture ground-active arthropod groups more than others (Sabu et al. 2009). Sampling biases can be introduced depending on the body mass and median speed of the species (Engel et al. 2017). Even though there were these biases introduced, results between ivy and native traps were still valid since the method was standardized.

The killing agent was switched from water to propylene glycol and shallow traps were implemented in June and July (see section 2.4). This was kept consistent across all 12 traps. This switch of methods did not affect the results since this study was not designed to capture temporal changes of the arthropod groups. However, this would make my results less comparable to other studies using pitfall traps. The fluctuation of populations was another reason to avoid presenting weekly results for each arthropod group. It is common for populations to fluctuate throughout the season (Reddy 1984, McLean 2007, Yagi 2008). Presenting temporal changes of arthropods would result in one replication, which was the summer of 2019.

Life history data such as the level of herbivory and reproduction could also be useful. These data would be able to show us how much of the ivy plant was utilized by arthropods. In the native range of English ivy, *Vespula* wasps are one of its most efficient pollinators (Jacobs et al. 2010). In Western Canada, there is anecdotal evidence that bald-faced hornets (*Dolichovespula maculata* (Linnaeus)) may be pollinating English ivy (Karen Needham, Beaty Biodiversity Museum, pers. comm. 14 February 2019). This would be relevant to not only the wasps but also to birds who utilize the berries and disperse English ivy (Metcalfe 2005).

4.3 Beetle Abundance and Composition

For most of the vegetation plots, Staphylinidae had the greatest number of individuals in total (Table 6). This was not surprising since Staphylinidae is a very diverse family of beetles who are most active on the ground. Some of them are found to mimic the scent of ant and live in ant nests (White 1983). For ivy plot BO1 and native plot E2, Carabidae was the most abundant family (Table 6). This was perplexing at first glance as the plant species were completely different between these two plots (Table 1). Since many members of the Carabidae family are carnivorous (White 1983), one explanation could be that these beetles followed their prey. BO1 had 1172 individuals of woodlice (Oniscidea), the highest out of all 12 plots (Table 3). Many of the beetles found at BO1 belonged to the genus *Pterostichus* and there is evidence suggesting that *Pterostichus* can consume woodlice (Sutton 1970). Native plot E2 had many beetles from the genus *Scaphinotus*, which was a genus of snail-eating beetles. E2 was a fairly moist site (Figure 6). it was possible that these beetles were attracted by snails on site.

Interestingly, although I did not find specific groups associated with ivy, three families of beetles were missing entirely from ivy plots: Agyrtidae (primitive carrion beetles), Ptiliidae (featherwing beetles), and Hydrophilidae (water scavenger beetles) (Table 6). Given that the primitive carrion beetle was found only once during the four months of sampling, it was very likely that it was found in the native plot by chance. On the contrary, Ptiliidae was found repeatedly at native plot C2 ---- The plot which hosted a diverse collection of herbaceous plants (Table 1). A possible explanation would be that herbaceous plants created a better environment for the growth of fungi, which was what Ptiliidae relied on (White 1983). More replication of herbaceous plant plots may help to further validate this finding. Adult beetles of the Hydrophilidae family are mostly scavengers and prefer shallow water (White 1983). There were two water scavenger beetles found at C2. These beetles could have preferred the decaying organic matter from herbaceous plants or the shallow surface water that C2 was able to contain with its soil. More monitoring is needed as this could also be an incidental find. One observation was that even though E1 and E2 had comparable levels of moisture (Figure 6), the leaf litter layer allowed water to drain through quickly compared to C2. Further research could look at soil porosity and leaf litter.

There were several invertebrate studies done in Stanley Park before this study (Quinn and Best 2002, McLean 2007, Yagi 2008, McLean et al. 2009). These previous studies did not measure microclimate data at sampling locations. Since samples from different sampling methods are not comparable, here we will discuss their results from pitfall traps only. In 2007, McLean (2007) set up pitfall traps to check on the biodiversity of insects in Stanley Park after the winter storm of 2006. His sampling took place in a reference site at Hollow Tree area, and a damaged site by the Vancouver Aquarium. Carabidae was the most abundant group from both of his sampling sites (McLean 2007). In my study, Staphylinidae was the most abundant beetle family (Figure 10). This inconsistency may be attributed to different trapping locations. The most numerous species in his study were *Pterostichus spp*. and *Scaphinotus angusticollis (*Mannerheim in Fischer von Waldheim, 1823) (McLean 2007), both of which were present in this study. Specifically, *Scaphinotus angusticollis* was found only at the damaged Hallow Tree site (McLean 2007). Using the specimens collected in 2007, McLean et al. (2009) also examined Staphylinidae in more detail and described a new species of rove beetle. In 2008, a student from Douglas College surveyed invertebrates at 6 monitoring stations established by SPES (Yagi 2008). Some of her beetle families were not found in this study and this is attributable to our different sampling locations. Numbers of captures from these studies were not suitable for comparison since sampling sites, methods, and duration all varied to differing degrees.

In an ecological restoration study in the Mediterranean, Mexia et al. (2020) compared a restored site of a limestone quarry and a selected reference site and used beetles as an indicator. The study compared ‘intact’ vs invaded sites and found non-overlapping compositions using NMDS (Mexia et al. 2020). This was not the case for my results (Figure 11). One possible explanation would be that the park is under constant disturbance and that my native plots were subjected to the same level of disturbances as the English ivy plots. Comparing Stanley Park with other ecologically similar but less disturbed forests might be an option as a follow up of this study.

When the goal is to boost arthropod or beetle diversity, managers could consider using combinations of native herbaceous plants to replace English ivy. This recommendation is based on my findings at native plot C2 (section 4.1). C2 had the highest diversity of arthropods (Table 5) as well as presences of unique beetle families (section 3.3). This was consistent with a previous study conducted in the understory of coniferous forest (Hagar et al. 2007). Hagar et al. (2007) was investigating the prey of Wilson's Warbler and found that deciduous shrubs supported a higher prey load than evergreen shrubs. More replications can be set up in Stanley Park to validate my results. Recently, restoration practitioners have had some new reflections on whether we should be more accepting of non-native species as they can provide habitats and some ecological functions (D'Antonio et al. 2016, Padovani et al. 2020). Further research is needed to conclude on the when ivy would be a valid replacement of native flora of Stanley Park.

My findings also have some implications for ground-foraging birds of Stanley Park. According to an early study in 1988, some ground-foraging birds consume several beetle families: Staphylinidae, Scarabeidae, Curculionidae, Cerambycidae, and Elateridae (Holmes and Robinson 1988). At least one bird species listed in that study, Swainson's thrush (*Catharus ustulatus* (Nuttall, 1840)), was heard on-site at Stanley Park. One caveat of this study is that my plot size was relatively small. Furthermore, many of the species I captured were ground-active detritivores. This implied that pitfall traps may not capture all the details in these vegetation plots. To conclude more on how birds may be affected, futures studies could look at the biomass of caterpillars and other insects that are important to birds. Using pitfall traps in combination with other methods such as Berlese funnel, beat sheets, and Malaise traps might be necessary.

4.4 Other Management Methods for English ivy

The earliest study on English ivy at Stanley Park was conducted by students from the University of British Columbia (Quinn and Best 2002). The locations of English ivy were first mapped in Geographic Information System and digitized in 2002 (Worcester 2010). In 2004, Stanley Park Ecology Society began a program called Ivy Busters to remove ivy

(Stanley Park Ecology Society 2013). Subsequently, the Tree Ivy Removal Program was created in 2009 to map and remove ivy (Stanley Park Ecology Society 2011). Since then, volunteers of this program had made great progress in keeping ivy cover in check. From 2009 to 2013, volunteers cleared English ivy from 8228 structures, 79% of which were trees (Stanley Park Ecology Society 2013). Stanley Park also has an invasive species management plan (Stanley Park Ecology Society 2013). It was found that pruning and root pulling were the most efficient removal methods for ivy. In the management plan, Vancouver Park Board limited herbicide use to difficult invasive species such as Japanese Knotweed. This is reassuring since herbicide application may cause adverse effects for arthropods (Sabatini et al. 1998, Lakhal 2010). Overall, the current management strategies are successful, and managers should continue to engage volunteers to remove English ivy.

4.4.1. Biological Control Methods

Another effective approach would be browsing by goats (Ingham and Borman 2010). Researchers found that just one day of browsing by experienced doe-kid pairs reduced the ivy cover to just 4% after two consecutive years of treatments (Ingham and Borman 2010). The goats must be conditioned to eating English ivy from a young age to digest hederin, a saponin secondary compound from the plant (Cheeke 1998). To be cost-effective, this method can be implemented yearly on extensive ground monoculture of English ivy. It will be effective up to where the goats can reach. Managers will need to be extra careful at cleaning up droppings when ivy bears fruits. This will be necessary to prevent the goats from spreading ivy seeds. For English ivy that had climbed high onto trees, volunteer work from the Tree Ivy Removal Program would be needed. The involvement of animals can create an opportunity to engage visitors and promote environmental education. Goats at Stanley Park can be marketed through social media as part of public outreach for SPES. This method mimics what ivy would be experiencing in its native range. According to Metcalfe (2005), ivy would be browsed by roe, red, and fallow deer in Europe, especially in the winter. Even though the fallow deer, *Dama dama* (Linnaeus, 1758), was already introduced to Canada, I would recommend against using the deer. Handling and training deer to eat only English ivy might be more difficult than training domesticated animals like goats. Using the deer could risk collateral damage to native plants.

In the British Isles, English ivy is targeted by a parasitic plant, the ivy broomrape, *Orobanche hederae* Duby (Metcalfe 2005). It was suspected to be intentionally introduced to California to control English ivy (Calflora 2020). This specialized plant can be an option if the intensive long-term management of ivy becomes unbearable. Though the ivy broomrape is not well studied, other plants from the genus *Orobanche* are known to be serious pests of agriculture (Fernández-Aparicio et al. 2016). As with any biological introduction, this should be taken with caution. The introduction should only proceed if the ivy broomrape is proven to be low risk for native plants. The decision to introduce the ivy broomrape as a biological control would have to pass through many jurisdictions. These include but not limited to Parks Canada, Canadian Food Inspection Agency, the Musqueam, Squamish, and Tsleil-Waututh Peoples. Finally, public perception would heavily influence the decision since Stanley Park is an urban park.

4.4.2. Developing New Methods

In a study conducted in a temperate alluvial forest, English ivy preferred large, isolated trees as their host (Castagneri et al. 2013). Restoration efforts can prioritize large isolated trees. These trees can often be found near trails of Stanley Park and can provide efficient space and solar radiation for photosynthesis. Implementing new methods on these host trees can be effective at impeding the colonization rate of English ivy. The attachment mechanisms of English ivy evolved to be successful at attaching most tree barks and even some artificial surfaces (Melzer et al. 2012). Melzer et al. (2012) had suggested to develop an easy-to-shed outer peel to prevent permanent attachment of English ivy on trees. This would not be easy since the peel would have to be cost-effective and neutral to other plants and wildlife that normally utilizes tree trunks (e.g. lichens, mosses, fern, and squirrels). Ideally, it would also need to be aesthetically pleasing to gain public support. More research on developing the peel is recommended.

4.5. Conclusion

Although this study found no significant reduction in the abundance and diversity of arthropods in English ivy, we need to keep in mind that the reference vegetations (native plant plots) were also limited to this heavily used urban park. Despite similarities in beetle community compositions between English ivy and native plant plots, three families of beetles were only found at native plant plots. Future studies could look to improve designs by adding replications, using more randomized plots, and dividing various types of vegetation cover into more categories.

Based on the results of this study, managers could consider using a diverse combination of native herbaceous plants to replace English ivy to increase diversity of arthropods. Overall, this research furthered our knowledge of arthropods of Stanley Park and added valuable information for managers.

Climate change is knocking on our door and a shift in forest structure might be inevitable (Haughian et al. 2012, Mahony et al. 2018). The management of invasive species such as the English ivy would likely face unseen challenges. Thus, it will be beneficial for managers to start looking at new management strategies. Experimentation with novel management strategies could also provide more opportunities for research. Ultimately, long-term monitoring is needed to develop adaptive management strategies for English ivy and other invasive species.

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Appendix A: R script for Beetle NMDS

```
#set working directory
setwd("C:/Users/wtb/Desktop/ARP/R stuff")

##install.packages("vegan")
##install.packages("ggplot2")
library(vegan)
library(ggplot2)

#load file
beetles <- read.csv(file = "beetles.csv", header = TRUE)
  head(beetles)

#NMDS
data_1 <- beetles[, 3:11]
  rownames(data_1)=beetles[,2] # give data_1 some row names
data_2 <- beetles[,1:2]

#trying it with 2 dimensions
NMDS <- metaMDS(data_1, distance = "bray", k = 2)
NMDS$stress
stressplot(NMDS)
#stress = 0.119428, lower than 0.2

#visualize data
co = c("black","gray")
shape = c(15,16)
plot(NMDS$points, col=co[data_2$Type], pch = shape [data_2$Type],
     xlim=c(-1.2,1.2),ylim=c(-1,1),
     cex=1.2, main="Beetle Family Composition", xlab = "NMDS1", ylab = "NMDS2")

#add lines
ordihull(NMDS, groups = data_2$Type)
```

```
#add legend
txt <- c( "English Ivy","Native Plants")
legend('topleft', txt, pch=c(15,16), col=c("black","gray"), cex=1, bty ="y")

text(NMDS$points[,'MDS1']+.1,NMDS$points[,'MDS2'],
    label=dimnames(NMDS$points)[[1]])
```

Appendix B: NMDS Arthropod Composition

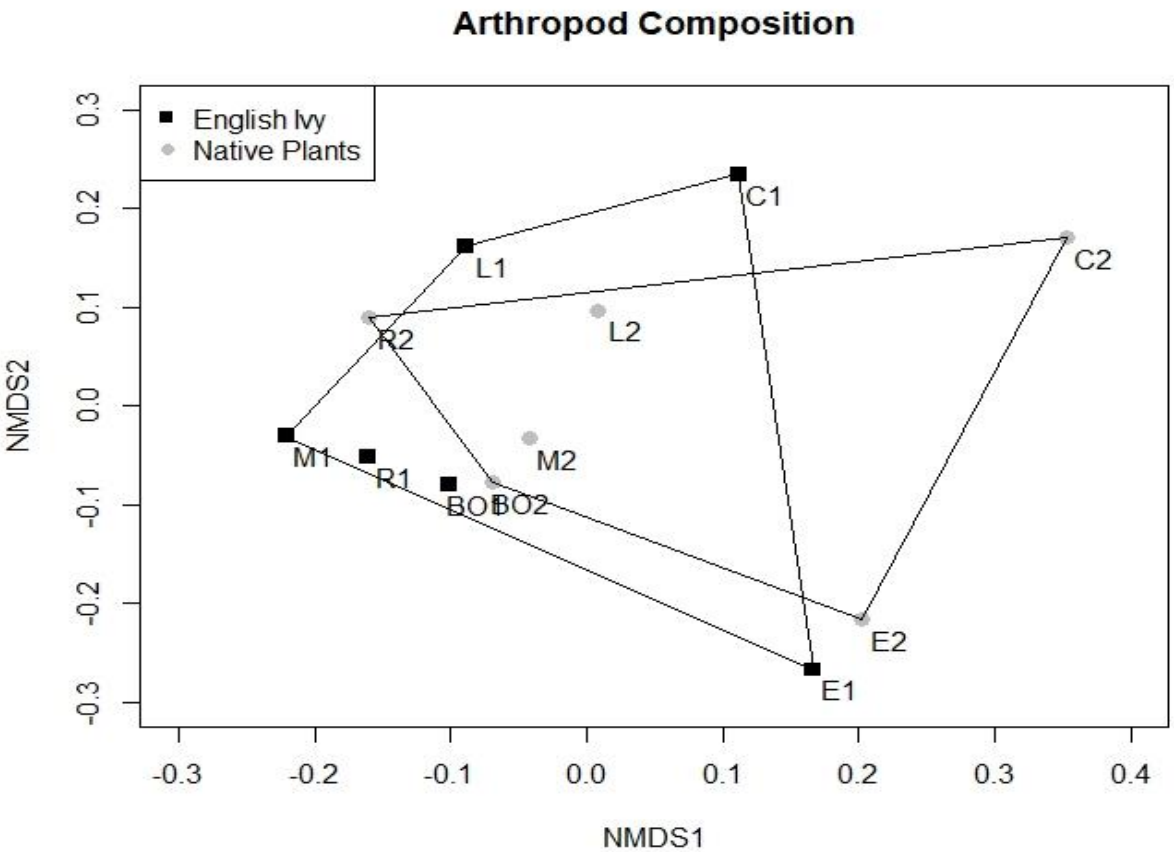

Figure 12. *NMDS show the Bray-Curtis dissimilarity between arthropod composition (stress = 0.11, k = 2). There is considerable amount of overlapping between the two types of vegetation plots. Since the arthropod groups I used were not taxonomically equivalent of each other, this NMDS was presented in this appendix section as a reference.*

Appendix C: Photos of Beetles

Figure 13. *A member of the Curculionidae family. This is Barypeithes pellucidus, the hairy spider weevil (length = 4 mm). It is a species of weevil native to Europe.*

Figure 14. *A member of the Curculionidae family. This is Trypodendron betulae, a species of weevil native to Canada (length = 3 mm).*

Figure 15. *A member of the Curculionidae family. This is Steremnius carinatus, the conifer seedling weevil (length = 8.5 mm).*

Figure 16. *A member of the Latridiidae family. This one is Cartodere nodifer, a minute brown scavenger beetle that is native to Australia and New Zealand (length = 2 mm).*

Figure 17. *A member of the Leiodidae family. This round fungus beetle belongs to the genus Catops (length = 3.5 mm).*

Figure 18. *A member of the Staphylinidae family, a rove beetle (length = 8.5 mm).*

Figure 19. *A member of the Staphylinidae family. This is Deinopteroloma subcostatum (length = 4.5 mm).*

Figure 20. *A member of the Staphylinidae family. This is Proteinus atomarius (length = 1.5 mm).*

Figure 21. *A member of the Carabidae family. This ground beetle belongs to the genus Pterostichus (length = 12 mm).*

Figure 22. *A member of the Elateridae family. This is Hemicrepidius pallidipennis (length = 10 mm).*

Figure 23. *A member of the Cryptophagidae family. This silken fungus beetle belongs to the genus Atomaria (length = 1.2 mm).*

Figure 24. *A member of the Agyrtidae, the primitive carrion beetle family. This is Ipelates latus (length = 4.5 mm).*

***Figure 25**. A member of the Ptiliidae family from the genus Acrotrichis (length = 0.9 mm). The hindwings are feather-like.*

Figure 26. *A member of the Hydrophilidae family (length = 2.3 mm). This species is Cercyon adumbrates and it is native to North America.*

Appendix D: Photos of Arthropods (Excluding Coleoptera)

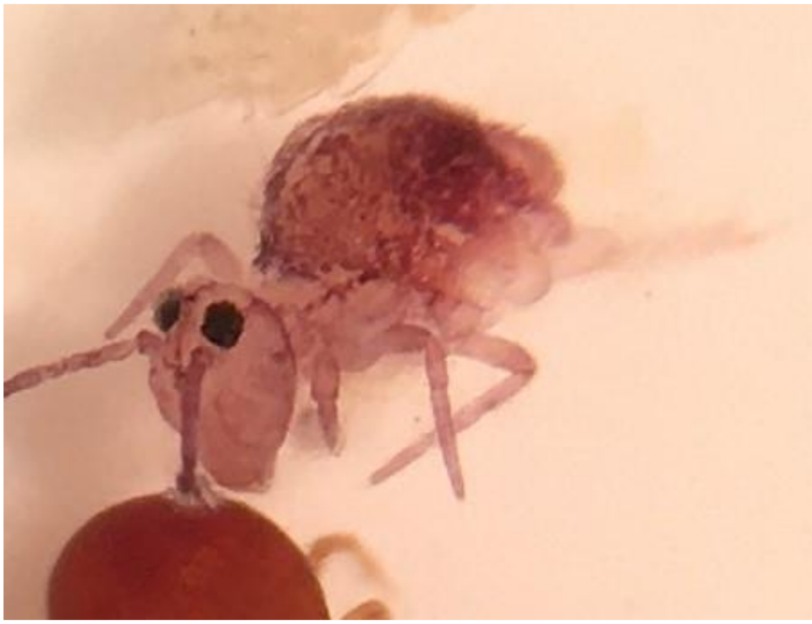

Figure 27. *An example of a round springtail (Collembola).*

Figure 28. *Examples of mites (Acari). The darker one belongs to the order Oribatida. The one on the right appears to be a predatory mite belonging to the order Mesostigmata. (Body lengths for both mites = ~ 1 mm).*

Figure 29. *An example of a harvestman (Opiliones). This one is in an early instar stage (length = 2 mm).*

Figure 30. *An example of spider (Araneae).*

Figure 31. *A camel cricket (Rhaphidophoridae) (length = 4.5 mm).*

Figure 32. *A sawfly larvae (Hymenoptera) that resembles a caterpillar.*

Figure 33. *An example of an Ichneumon wasp (Parasitica) (length = 6.5 mm). Note parasitica is a paraphyletic infraorder. I separated this group from other hymenopterans since the parasitoid wasps have very distinct niches.*

Figure 34. *A female parasitoid wasp from the family Proctotrupidae (Parasitica) (length = 3 mm).*

Figure 35. *A parasitoid wasp from the superfamily Ceraphronoidea (Parasitica) (length = 1.3 mm).*


Figure 36. *A parasitoid wasp from the subfamily Scelioninae (Parasitica) (length = 1 mm).*

Appendix E: English ivy Cover and Vegetation Diversity

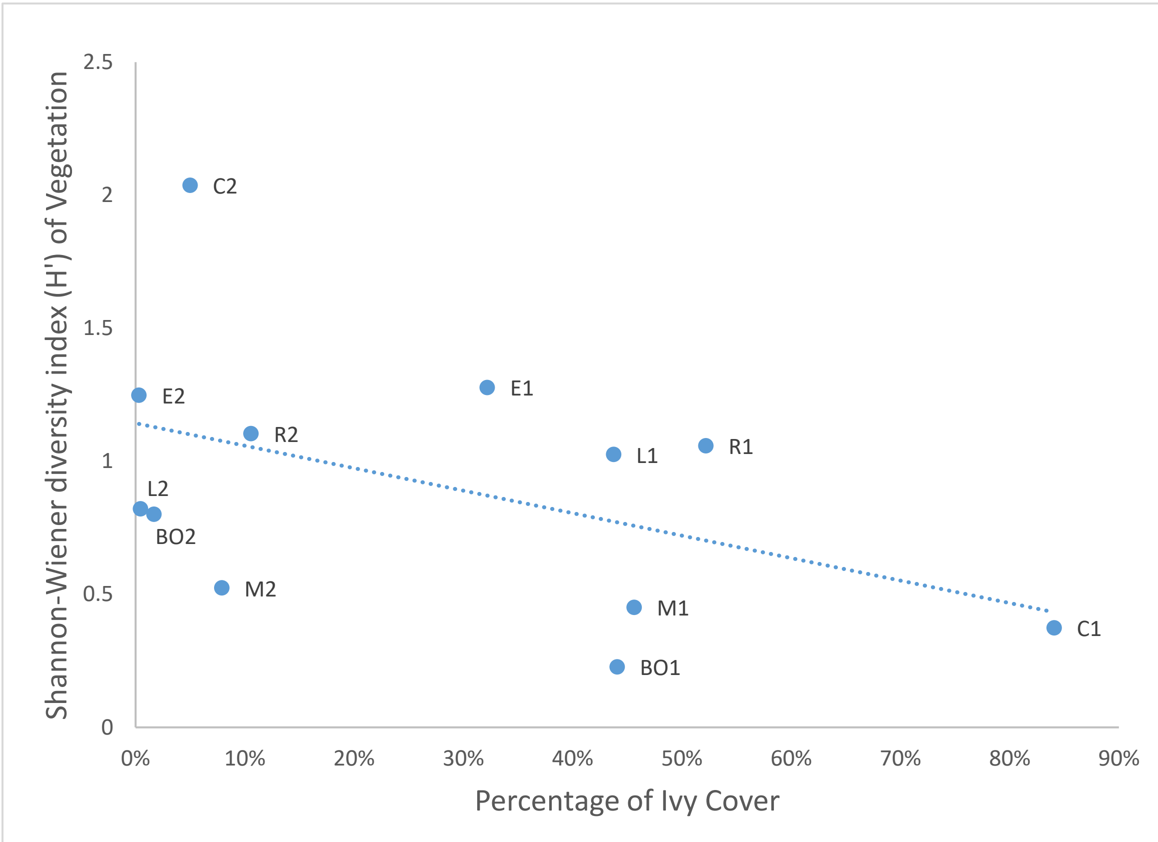

Figure 37. *Linear regression of ivy cover affecting plant diversity at the 12 plots in Stanley Park (R^2 = 0.21). Data was collected via two vegetation surveys on June 5th & 12th, and on July 31st & August 7th, 2019. Ivy cover was negatively influencing the diversity of vegetation and this was consistent with Quinn and Best (2002).*