Living Breakwaters Study: Plant species composition and structure of the Point Grey Cliffs and potential for slope stabilization

Shaun Yap and Amanda Eliora; Nina Hewitt (Research Supervisor)

University of British Columbia

Theme: Land, Biodiversity, Climate

April 19, 2019

Table of Contents

Executive Summary

The Living Breakwaters project is aimed at stabilizing the cliffs at Point Grey, which are currently susceptible to erosion from wind, rainfall and rising tides. Our research is focused on finding the best canopy and understory flora to stabilize the exposed soil along the cliffs. This is done to inform a cliff stabilizing strategy, without the need to implement costly man-made solutions.

In response to the slope failure on October 12, 2013, we conducted field research to determine the best candidates. We sampled five transects perpendicular to the Point Grey cliffs that were representative of the various slope profiles that it featured. From these data, we judged the likelihood of each species being dominant in the local ecosystem by looking at their densities and frequencies for canopy and understory species, respectively. We also separated the data based on species' position on the cliff, ranging from cliff top, cliff slope and cliff base.

We found that Bigleaf Maple and Red alder may be prospective, native, canopy species for slope stabilization, while Sword fern and native *Rubus* species are viable understory candidates to stabilize the soil along the Point Grey cliffs. Consideration was also taken into the nativity of the flora species as we favored native species over non-native invasive flora. This data will be used to spearhead MetroVan's efforts to stabilize the cliffs.

1.0 Introduction

The Point Grey cliffs that surround the University Endowment Lands is at risk of a slope failure. The University Endowment Lands is home to the University of British Columbia (UBC), its faculty and staff, along with several private homes. However, the rising annual sea levels and heavy precipitation is causing the exposed soil along the cliffs of Point Grey to erode, endangering personnel and infrastructure that occupy its vicinity (Leshchinsky, Olsen, Mohney, O'Banion, Bunn, Allan, & McClung, 2019). A slope failure has occurred in the past at Trail 5 on October 12, 2013 (Landslide near UBC campus leaves sheer cliff; no one hurt, 2013). While there were no causalities as a result of this slope failure, it has raised concerns regarding the safety and the stability of the Point Grey Cliffs in the face of climate change (Pemberton, 1999).

The Point Grey cliffs are currently not stabilized by any man-made structures, but instead are stabilized by native and non-native flora species (Point grey cliffs heading out to sea: 4th edition, 1987).

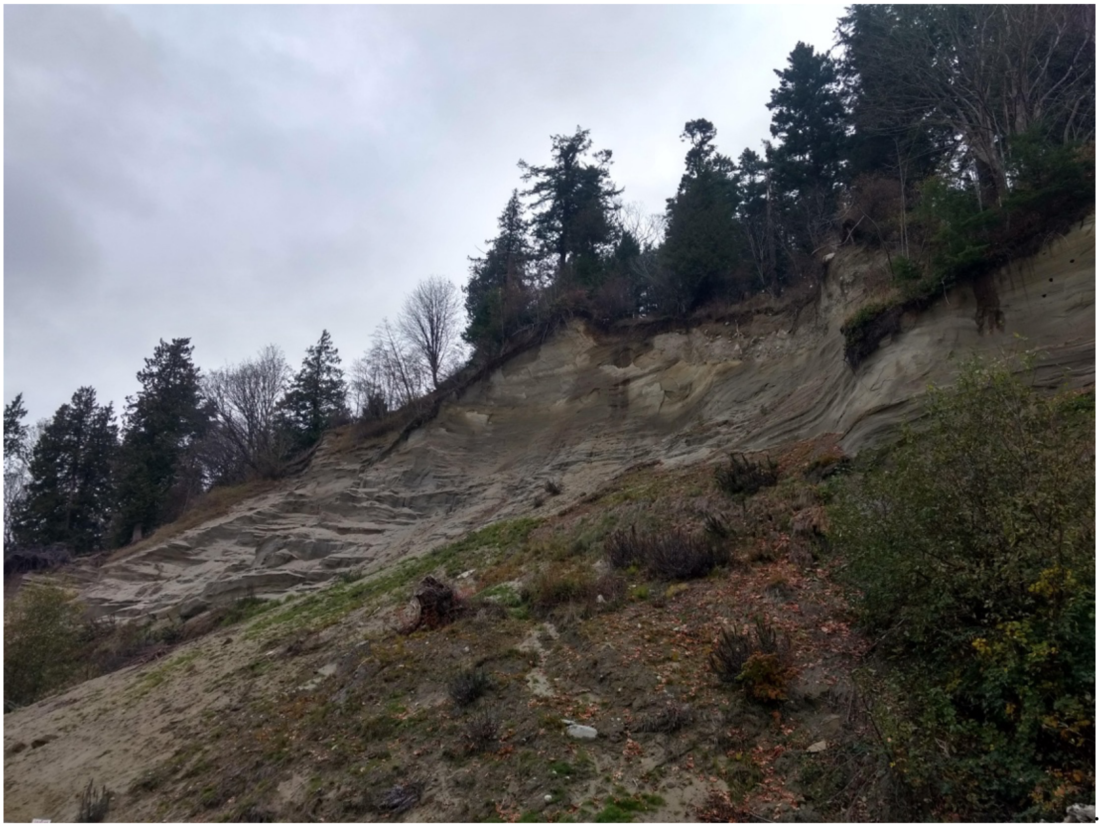


Figure 1. Cliff face at Transect 1, just above the slope base, where a large eroded area occurs in the Quaternary sands.

While flora, both native and non-native, is known to be soil stabilizers, maintaining the ecosystem is a priority for our study as well. Non-Native Invasive plants will threaten the local ecosystem by outcompeting native species, thereby impacting both native flora and fauna species (Vilà et al., 2011). Additionally, de Groot et al. And Gerber et al. Found that the invasion of non-native plants would impact higher trophic levels through the loss of natural food resources (as cited in Vilà et al., 2011, p. 706). The destruction of the native ecosystem will drive out local fauna that depend on it, such as the Barred owl we sighted within the vegetation at Transect 2, plot 1, which is known to prefer native forests (Irwin, D. Rock, & S. Rock, 2018). Our concern is that by overlooking this, there will be unforeseen and irreversible repercussions in the future.

Figure 2. Barred Owl seen at Transect 2, plot 1, in a grove of planted Himalayan spruce (*Picea smithiani*). This species of native fauna usually nests in Old Growth forests. It is not considered endangered.

This study will therefore conclude our recommendation of several potential best canopy and understory flora species to stabilize the cliffs. We will make these recommendations based on two criteria: the potential for the floral species to be maintained in relatively high abundance in the local environment and ecosystem, and their native species status. Factors such as rooting depth and canopy structure will only be considered anecdotally. Through conducting field research, we will summarize our findings on the local flora population at the Point Grey cliffs. We will then analyze the data to obtain stem size distributions and density for the canopy flora species, as well as the frequency per location and percent cover of the understory flora species. We will also address recommendations and concerns that were raised to us regarding the viability of using flora and soil stabilizers, alternative solutions, and potential oversights we made throughout the course of this research.

1.1 Project Objectives

The objective of this research is to inform a climate adaptation cliff erosion strategy that involves valuable cliff stabilizing plant species, with respect to ecosystem properties. Through the gathering of understory and canopy species composition, we considered the flora's relative abundance, nativity to British Columbia, position on the cliff, soil type, and life history to determine its compatibility with cliff stabilization. Due to the 2013 landslide at trail 5 and the increases in relative sea levels as a result of global warming, the research that we conducted was the first of its kind at the Point Grey cliffs. As such, this research acts as a baseline for future recurring studies, in addition to adding to the literature on the role of flora and fauna as soil stabilizers and may inform future studies on erosion and the role of vegetation in similar environments.

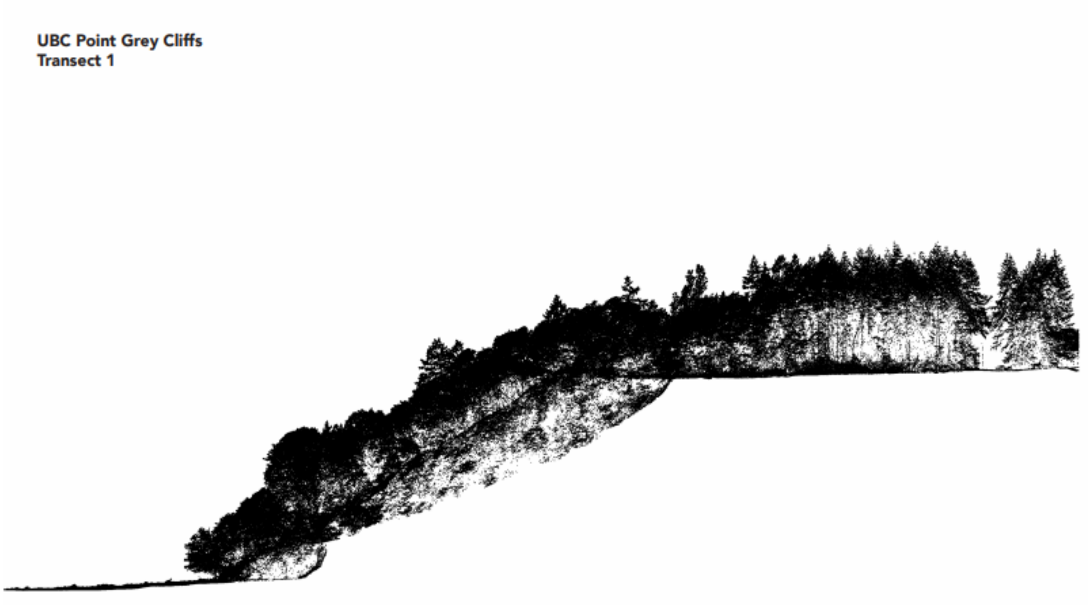
1. Methodology

This research consists of conducting a field survey of the Point Grey cliffs, following a systematic sampling of 5 transects on the Point Grey cliffs, oriented perpendicular to the shoreline. Each transect ran along the beach to the cliff tops to capture various slope profiles which will be important in our consideration of the best flora species to stabilize the soil. The location of the 5 transects are shown in figure 1, followed by the slope profiles and plot locations of each transect shown in figures 2 - 11.

In each transect, we sampled several, 10 m x 15 m, plots along each transect, located at equal intervals, approximately every 75-100 m, along the slope contour. Depending on the length of the slope, more or fewer plots were sampled. For example, Transect 4 is significantly shorter than Transect 5, resulting in 4 plots in the former and 7 plots in the latter (Figs. 8-11). Where topographic complexity occurred, e.g., the ravine along the length of Transect 5, we obtained additional plots along the ravine slope (see plots 1a and 1b, Fig. 11) that were indicative of slope points vulnerable to erosion or failure due to slope position (i.e., near the slope base, e.g., plot 1b, Transect 5) or steepness (1a). In each plot, all woody species stems > 5 cm diameter breast height (dbh) were identified to species, dbh measured, and mapped to the nearest 0.1 meter. Additionally, we measured the percent cover of understory species (herbs and shrubs) within two, 2.5 m x 2.5 m, sub-plots per plot, randomly located in two corners of each plot. Percent cover was estimated visually, and may exceed 100%, since some understory species grew in layers over/under other understory species. We standardized visual cover estimates by having different researchers provide estimates for the first few plots surveyed. We accounted for the presence of any species sited along the transects, along with slope angle, aspect and GPS location for each plot.

Figure 3. Locations on Google earth of each transect

Figure 4a)



b)


UBC Point Grey Cliffs
Transect 2


Transect 2
Museum of Anthropology
Legend
Plot
Plot 1
Plot 2
View Point 2
View Point 1
Google Earth
100 m
N

c)


UBC Point Grey Cliffs
Transect 3


Transect 3
Trail 1
Legend
Plot
Plot 5
Plot 4
Plot 3B
Plot 3
Plot 2
Plot 1
Google Earth
100 m
N

d)


UBC Point Grey Cliffs
Transect 4


Transect 4
NW Marine dr by Westbrook Crescent
Legend
Plot
Plot 2
Plot 3
Plot 1
Plot 4
Google Earth
N
100 m

e)

Figure 4. Google earth images of transects showing GPS located sample plots within each (top images) and Lidar images of slope profiles (bottom images for a) Transect 1; b) Transect 2; c) Transect 3; d) Transect 4; e) Transect 5.

In the case of Transect 2, we had to resort to making visual estimates of slope angle, slope aspect, percent cover, and dbh of flora species within the plot due to difficulties in traversing the terrain. Instead, we visually estimated the species composition and size structures, but did not include those estimates in our numerical summary computations for density and size class.

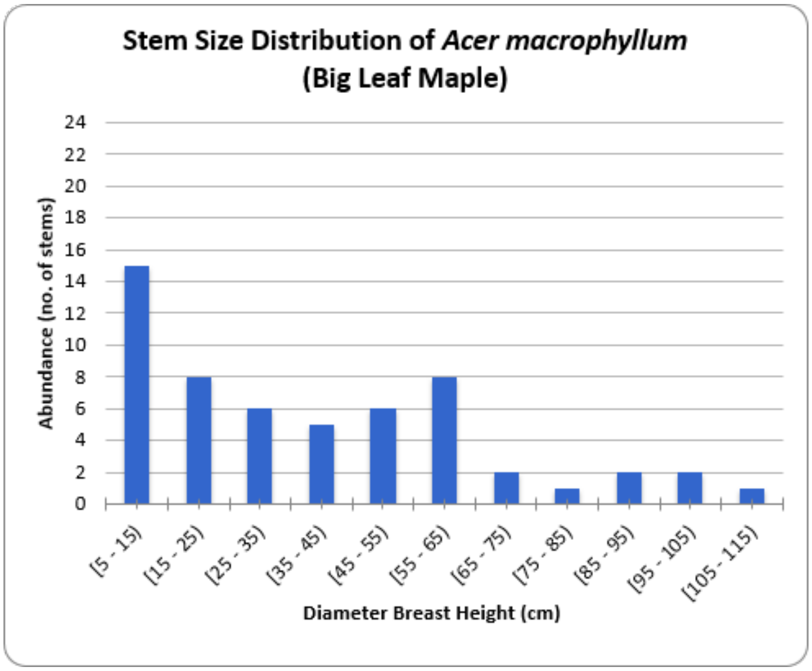
Figure 5. Near vertical cliffs at Transect 2 were difficult to access. Therefore we used viewpoints from a nearby trail to observe and estimate composition and structure of woody and non-woody vegetation. This is a photo taken from Viewpoint 2 (see Fig. 4b).

2. Results and Discussion

We classified the data we collected from the field survey by splitting them into ‘canopy’ and ‘understory’ species. The purpose of doing so is that canopy flora species have different indicators of success from understory species, which needs to be considered by their respective merits to obtain a fair assessment. For canopy species, we will show the stem size distribution, total survey area species density, and cliff top, slope & base density. For understory species, we will show the percent frequency, and the cliff top, slope and base frequency.

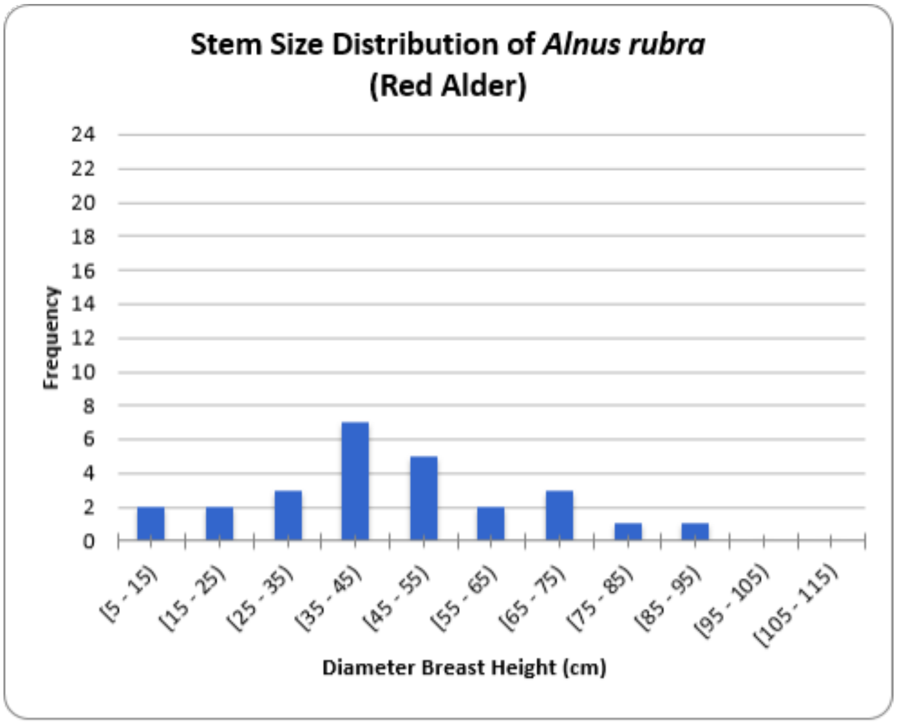
3.1 Canopy stem size distribution

Stem size distribution indicates how well-maintained is a tree population, with inverse, j-shaped distributions (righ-skewed) suggesting a self-maintaining population, that is being replaced by smaller size classes into the future. We grouped canopy species into classes of 10 cm dbh to investigate patterns of size (and age) distribution. We focused on the species that had been intentionally planted, and that tend to dominate the region's coastal forests: Bigleaf maple (*Acer macrophyllum*), Red alder (*Alnus rubra*), Western hemlock (*Tsuga heterophylla*), Douglas fir, (*Pseudotsuga menziesii*), Western red cedar (*Thuja plicata*) (blue bars); as well as those that are non-native and potentially invasive: Sycamore maple (*Acer pseudoplatanus*) & English holly (*Ilex aquifolium*).



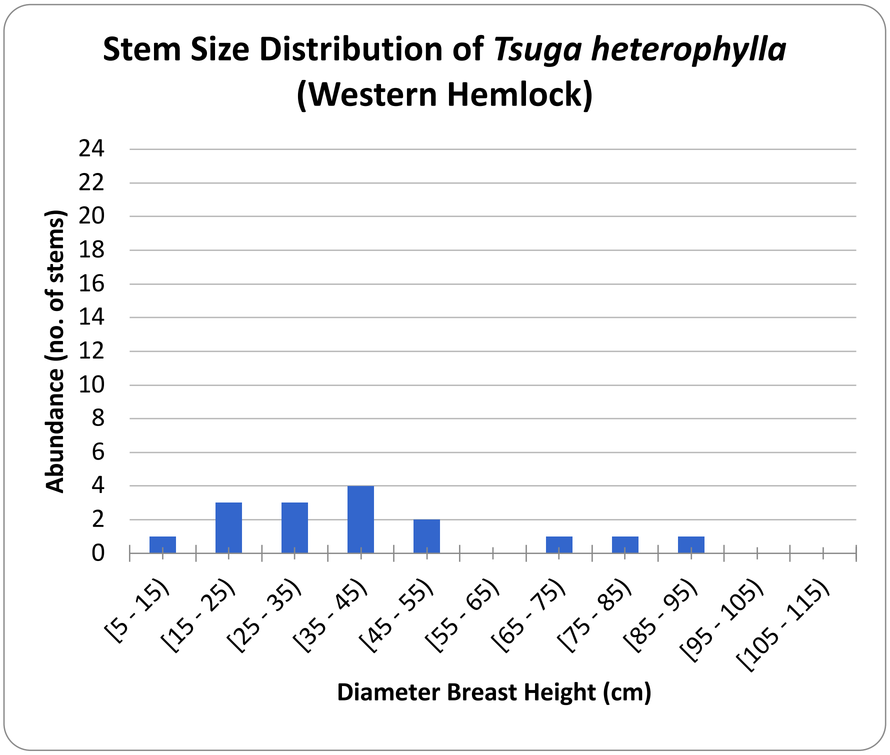
a)

b)



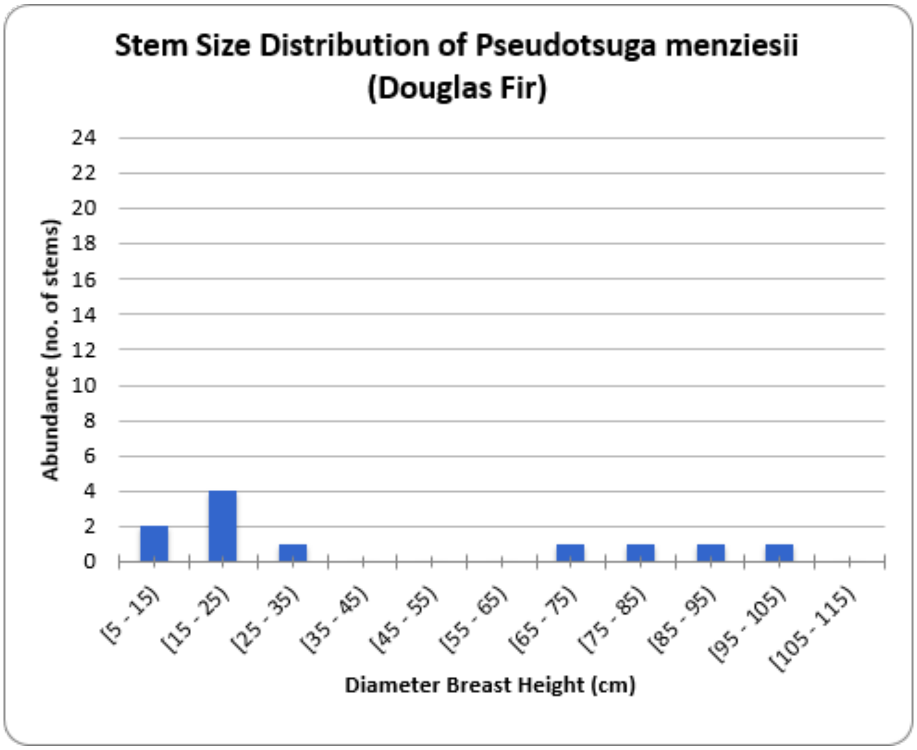
Stem Size Distribution of *Alnus rubra* (Red Alder)
Frequency
0
2
4
6
8
10
12
14
16
18
20
22
24
[5 - 15)
[15 - 25)
[25 - 35)
[35 - 45)
[45 - 55)
[55 - 65)
[65 - 75)
[75 - 85)
[85 - 95)
[95 - 105)
[105 - 115)
Diameter Breast Height (cm)

c)

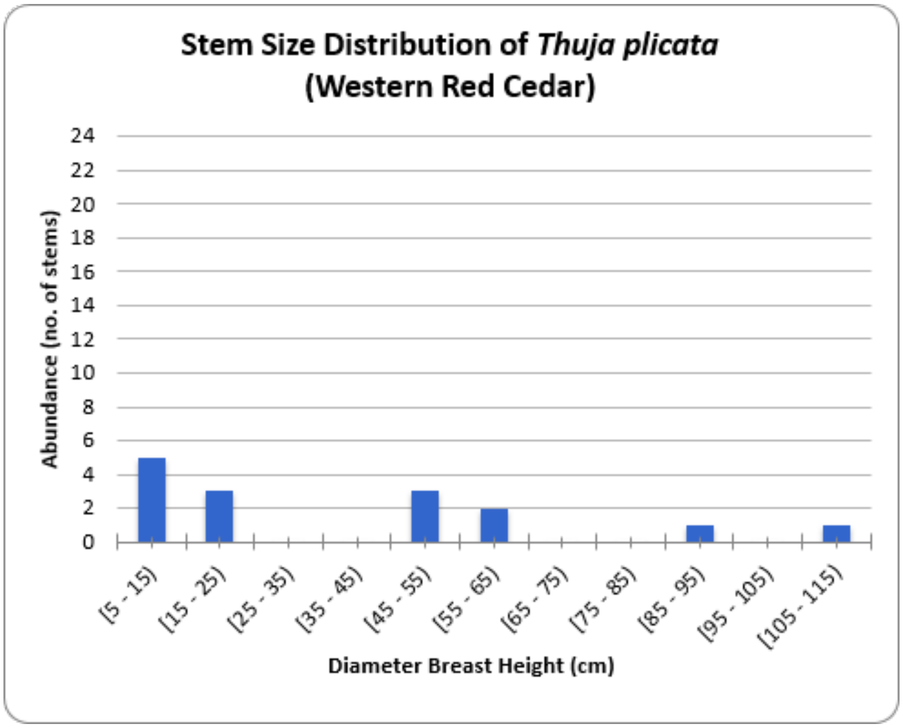


Stem Size Distribution of *Tsuga heterophylla* (Western Hemlock)
Abundance (no. of stems)
0
2
4
6
8
10
12
14
16
18
20
22
24
[5 - 15)
[15 - 25)
[25 - 35)
[35 - 45)
[45 - 55)
[55 - 65)
[65 - 75)
[75 - 85)
[85 - 95)
[95 - 105)
[105 - 115)
Diameter Breast Height (cm)

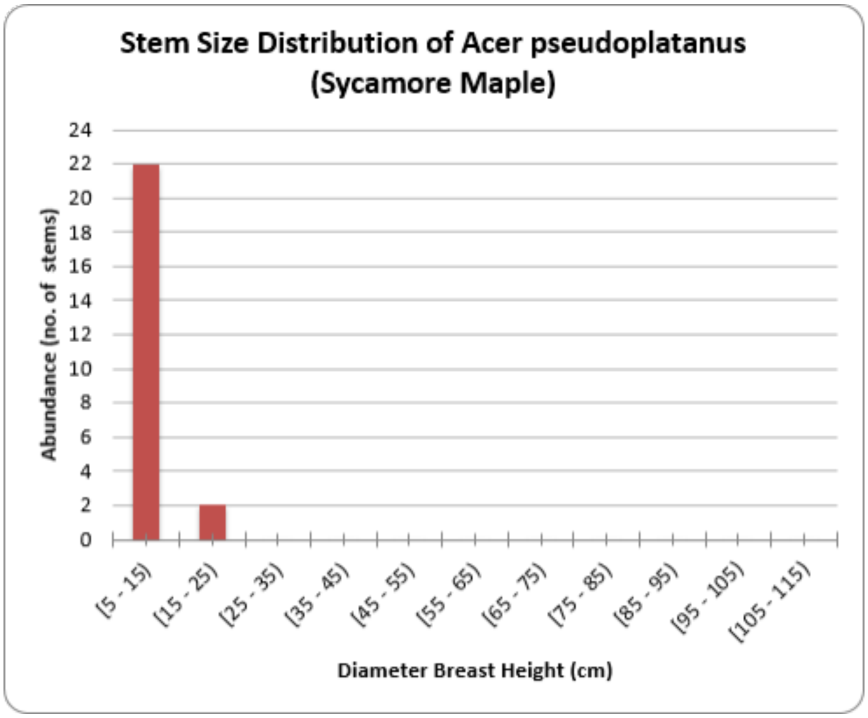
d)


Stem Size Distribution of Pseudotsuga menziesii
(Douglas Fir)
Abundance (no. of stems)
0
2
4
6
8
10
12
14
16
18
20
22
24
[5 - 15)
[15 - 25)
[25 - 35)
[35 - 45)
[45 - 55)
[55 - 65)
[65 - 75)
[75 - 85)
[85 - 95)
[95 - 105)
[105 - 115)
Diameter Breast Height (cm)

e)


Stem Size Distribution of *Thuja plicata*
(Western Red Cedar)
Abundance (no. of stems)
0
2
4
6
8
10
12
14
16
18
20
22
24
[5 - 15)
[15 - 25)
[25 - 35)
[35 - 45)
[45 - 55)
[55 - 65)
[65 - 75)
[75 - 85)
[85 - 95)
[95 - 105)
[105 - 115)
Diameter Breast Height (cm)

f)



g)

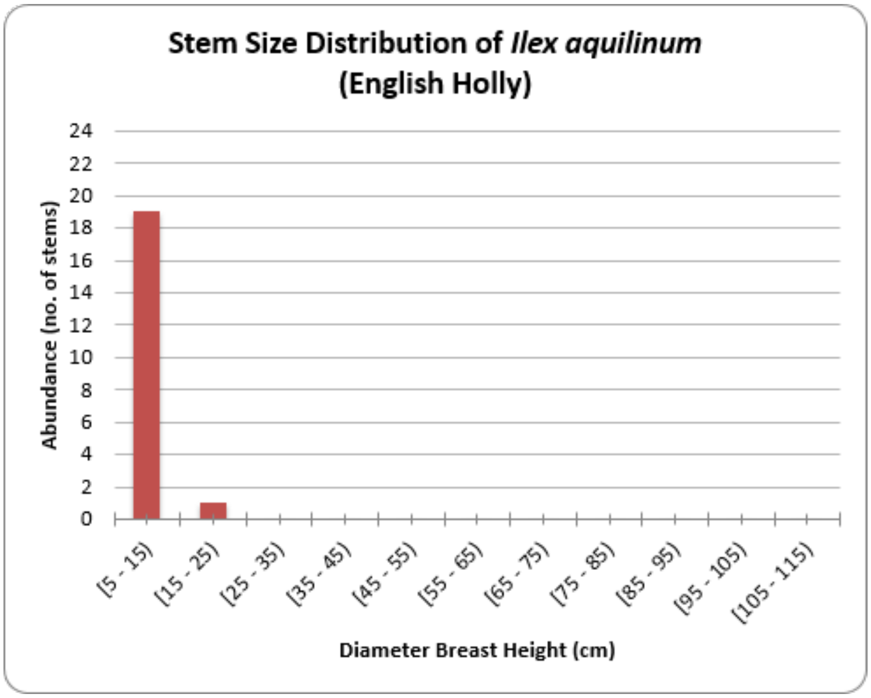


Figure 6. Stem size distributions of a) Bigleaf maple, b) Red alder, c) Western hemlock, d) Douglas fir, e) Western red cedar, and the invasive, non-native species f) Sycamore maple, and g) English holly.

The data shows that the native species, Bigleaf maple, appears to be self-maintaining, indicated with a high abundance at small stems, as well as moderately high numbers of large, mature trees. Red alder populations across the transects are mature with low numbers of young individuals, but this is suggestive of recruitment at a time when light availability was high, during reforestation and planting of the slopes, and that future disturbances or large openings will facilitate additional recruitment pulses of this highly successful, disturbance-adapted species. Western Hemlock, Douglas fir and Western red cedar show relatively low abundance at all age groups, with several years in between when they either failed to establish or failed to reproduce. The non-native species, Sycamore maple and English holly, show that they have a high possibility of establishing in this ecosystem.

3.2 Canopy total survey area species density

The total survey area density provides, at a glance, the total densities of every species per hectare. This data shows us how dominant each tree species is in all of the transects combined.

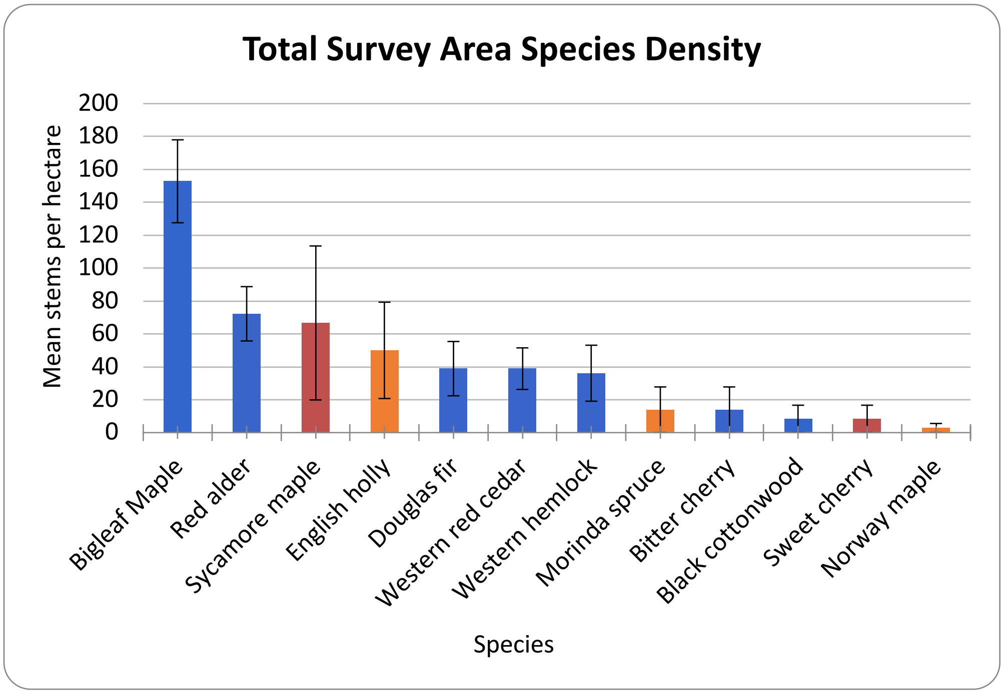


Figure 7. Mean stem density (stems/ha) of woody species across all transects and plots.

Bigleaf maple has a greater density than other woody perennials by a large margin. It is followed by Red alder and Douglas fir, which are about half as dense. However, Sycamore maple and English holly have large densities in smaller size classes and are expected to become more important in future (see Figures 6 and 7).

3.3 Woody Species Densities at different slope positions: cliff top

A comparison of woody species densities at different slope positions is instructive. The cliff top densities matter for stabilization where development is currently occurring and where failure will be catastrophic in the near term. Soil stabilization and canopy cover at the top of the cliff edge is important as it prevents material runoff through rain splash erosion. Due to variation in plot characteristics between the five transects, such as the distance from the shore/ slope top, and slope steepness, we are unable to obtain a precise classification of plot position. Therefore, we classified plot positions based on drainage, exposure to shoreline and edge conditions. Using this, we selected plots that were on the cliff top based on them being well drained, far away from the coastline, and having minimal edge effects due to the lack of light, wind and wave action. Additionally, note that the error bars indicate the variance between plots due to the nature of calculating averages, not all plots reflect the same number of individuals in a species (see Graphs 8 - 14).

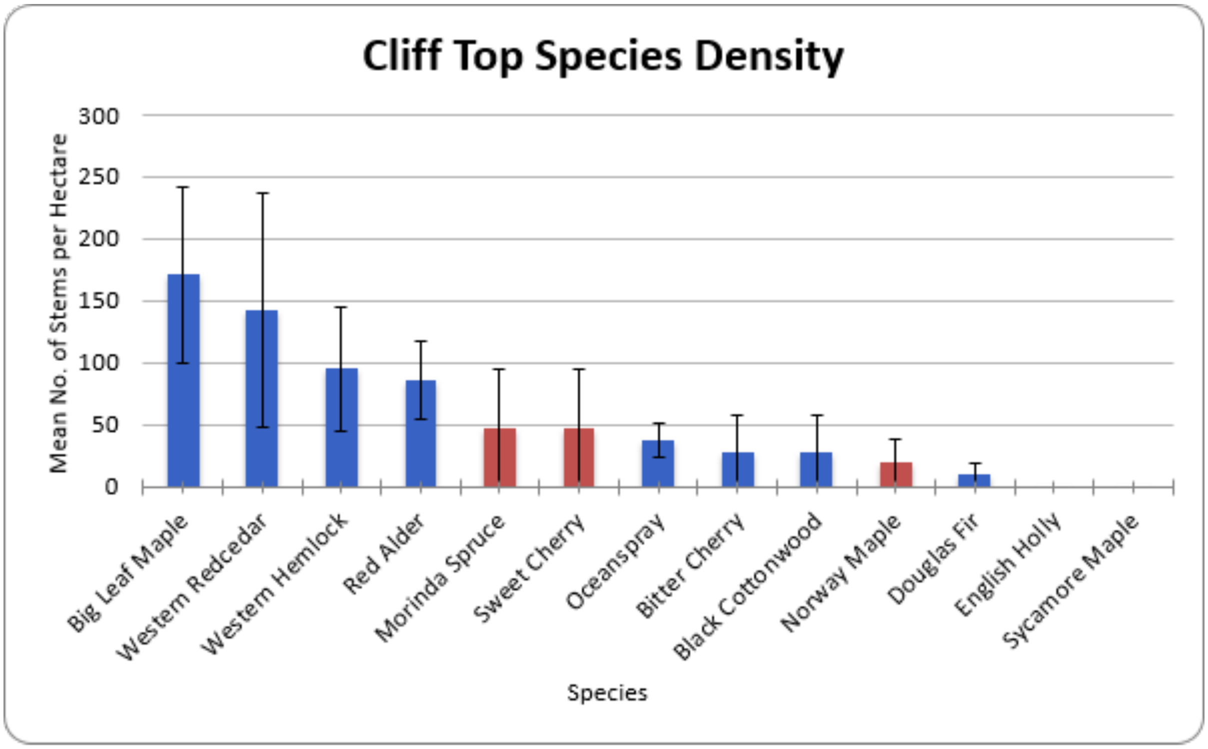


Figure 8. Mean stem densities (and standard deviation) of woody species in the cliff top plots, averaged across all transects.

Based on the data on the graph, Bigleaf Maple dominates the top of the cliff, with Western red cedar following close behind.

3.4 Woody Species Densities at different slope positions: Intermediate slope positions (Cliff slope)

Densities at intermediate slope positions, along the cliff slope are important for slope stabilization as this study aims to find a canopy species that can grow on slopes well, to stabilize the soil and shield the ground from rain splash erosion. We classified plots that represented a cliff slope as intervening plots between the cliff top and the cliff base.

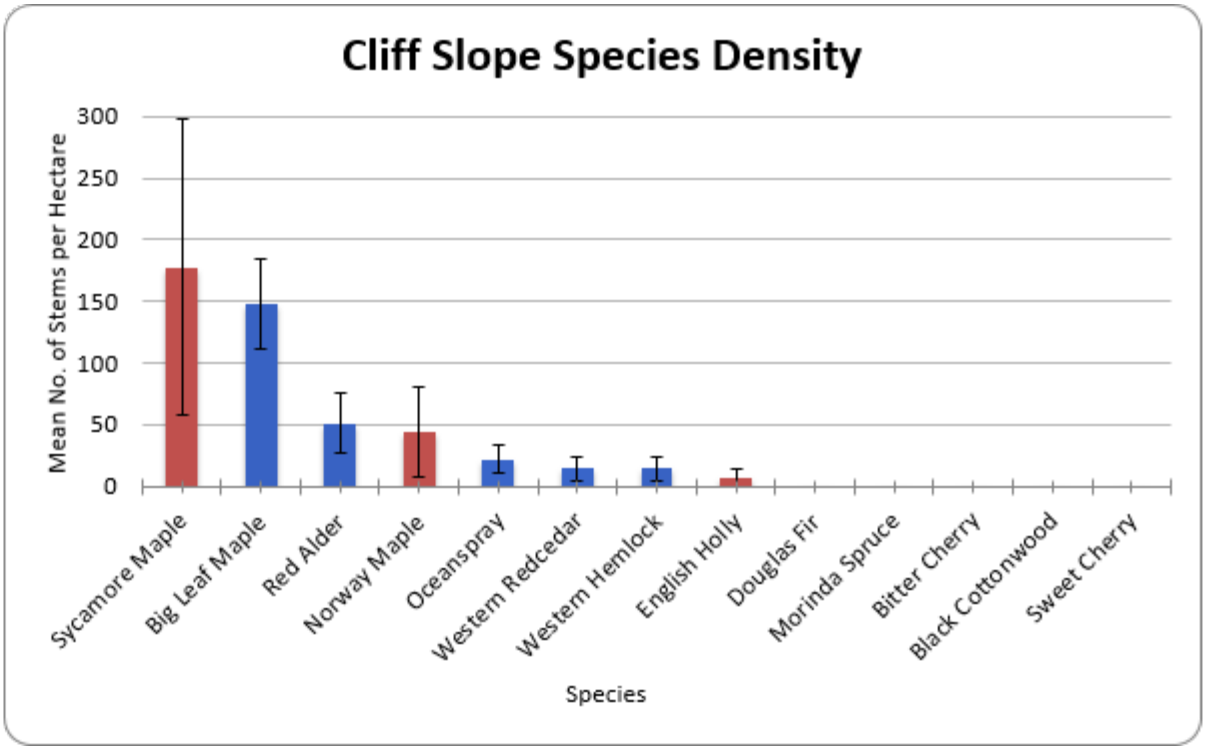


Figure 9. Mean stem densities (and standard deviation) of woody species in the plots sampled along the slope, in the transect portions below the cliff top and slope base, averaged across all transects.

Densities were generally high for Sycamore maple, but were quite variable from site to site, as indicated by the large error bars. It occurred in dense concentrations in a small number of plots, mainly along Transect 3, while it was completely absent in majority of the plots. This would suggests a young invasive species. Native Bigleaf maple follows closely behind as a successful species in terms of numbers, and was less variable over space, with many mature (and likely planted) individuals, along with some recent recruitment (see Fig. 6a).

3.5 Canopy cliff base density

The base of the cliff is where the cliff toe is, and if the toe of the cliff is destabilized enough, the slope will fail. In addition to rain splash erosion, the cliff toe is also threatened by the rising sea levels. Therefore, the findings of species density at the base of the cliff will be important in our consideration. We classified plots at the base of the cliff by their close proximity to the coastline, poor drainage, and large edge effect.

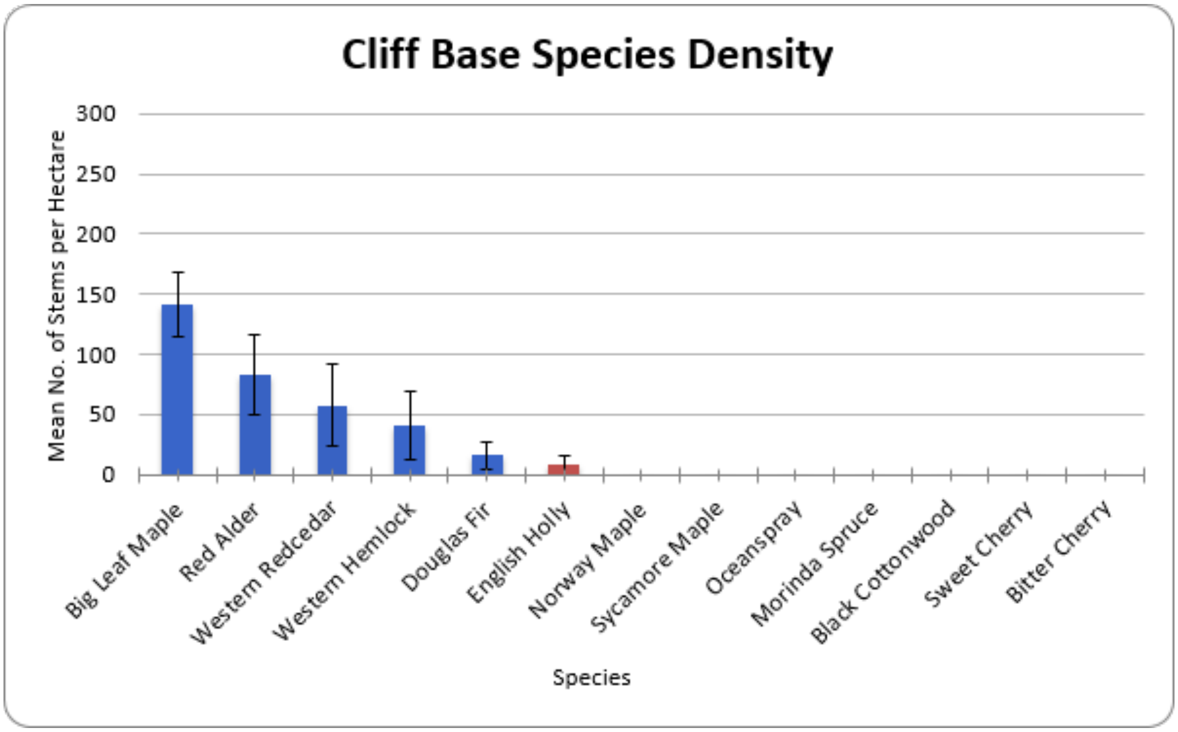


Figure 10. Mean stem densities (and standard deviation) of woody species sampled in plots at the base of each slope/cliff, averaged across all transects.

The data shows that Bigleaf maple and Red alder dominate the base of the cliffs, with Western red cedar following closely behind. The small error bar also indicates that Bigleaf Maple is found in the majority of the sampled plots.

3.6 Understory percent frequency

Understory species are vastly different from canopy flora as their dominance and health in the ecosystem is measured by looking at their percent frequency. This indicates the chances of seeing that species when visiting the research survey area.

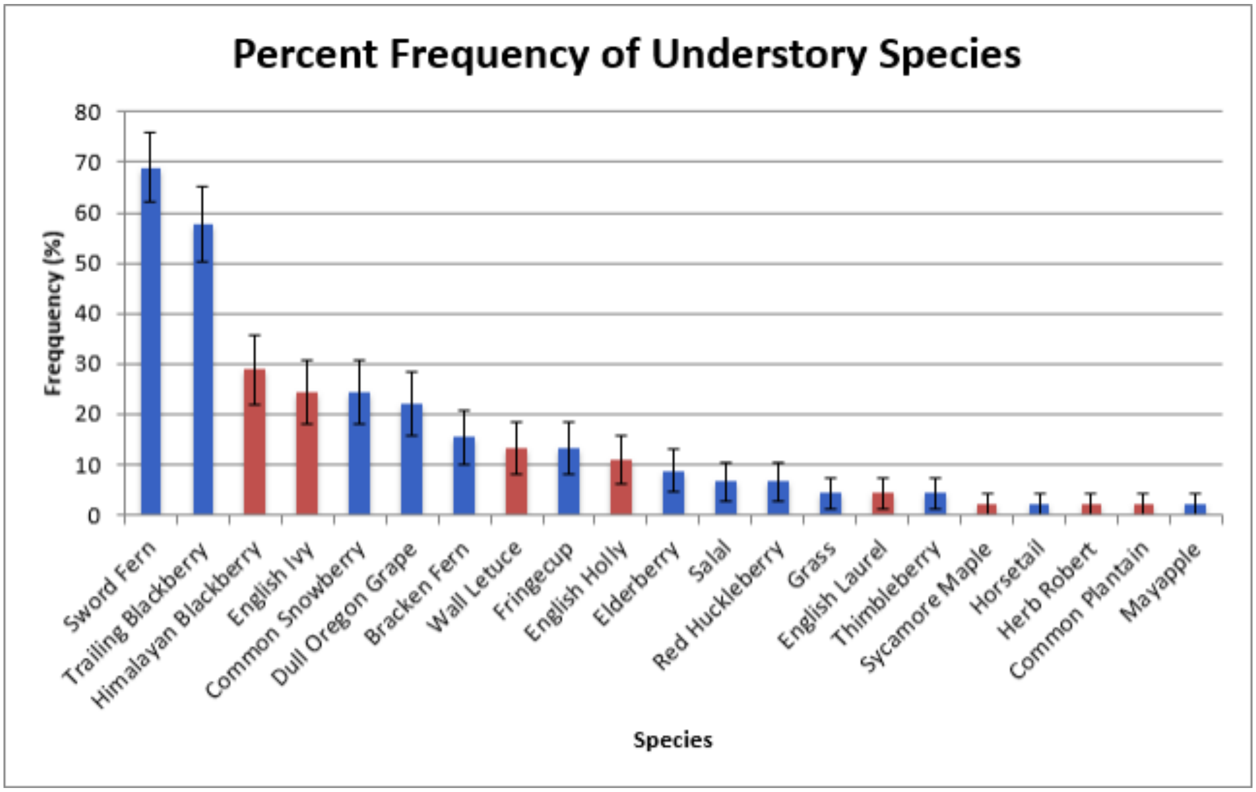


Figure 11. Percent frequency of understory species sampled in plots across all transects.

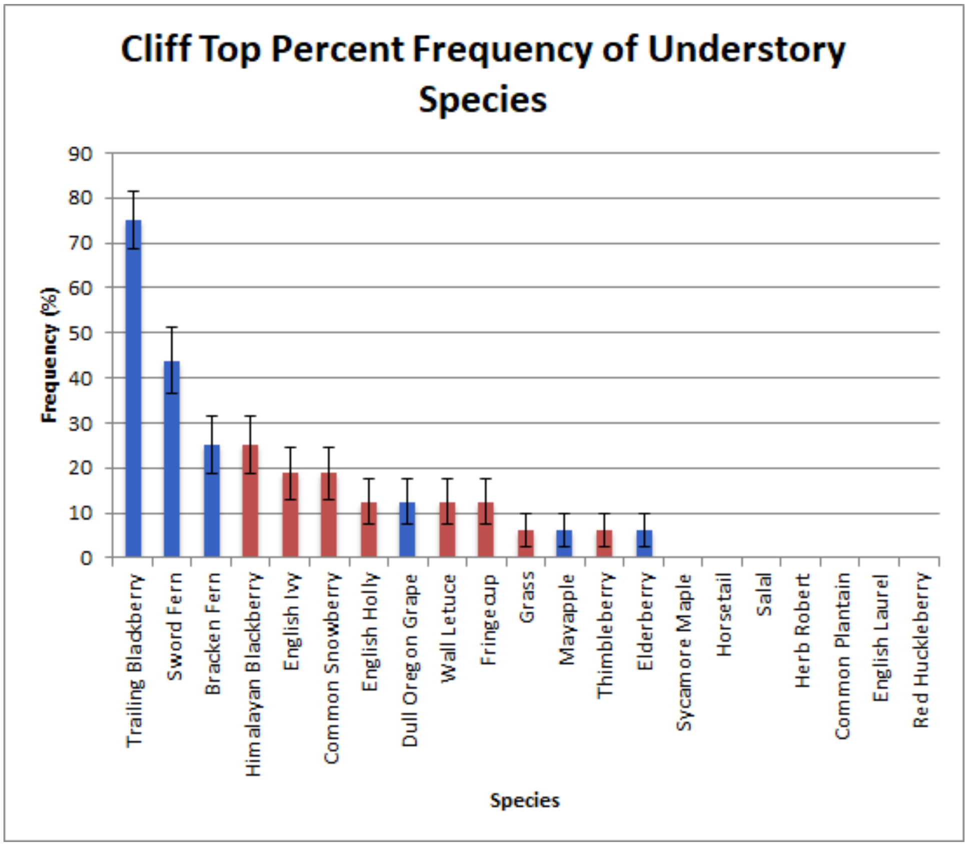
The graph shows that Sword fern (*Polystichum munitum*) is the most commonly recurring understory flora species, followed by Pacific, or Trailing blackberry (*Rubus ursinus*) and Himalayan blackberry (*Rubus discolor; syn., R. armeniacus*). While Trailing blackberry is currently out performing Himalayan blackberry, the latter is a known invasive species that is infamously hard to control according to Soll et al. (cited in Gaire et al., 2015, p. 559). This is of concern as Himalayan blackberry tended to dominate and grow densely where it occurs, and its presence results in a decrease in plant biodiversity (Gaire et al., 2015). There is a concern that this the species is displacing Trailing blackberry, which occupies a similar niche, but is not as pre-emptive of light and other resources, in its growth form (Caplan & Yeakley, 2013).

Figure 12. Himalayan blackberry invades a slope that is otherwise dominated by Trailing blackberry along the slope in Transect 3. These two species of the *Rubus* genus (the former, an introduced species; the latter, a native blackberry) occupy a similar niche, but Himalayan blackberry grows taller and denser, and potentially outcompetes the native *Rubus*, invading along the cliffs.

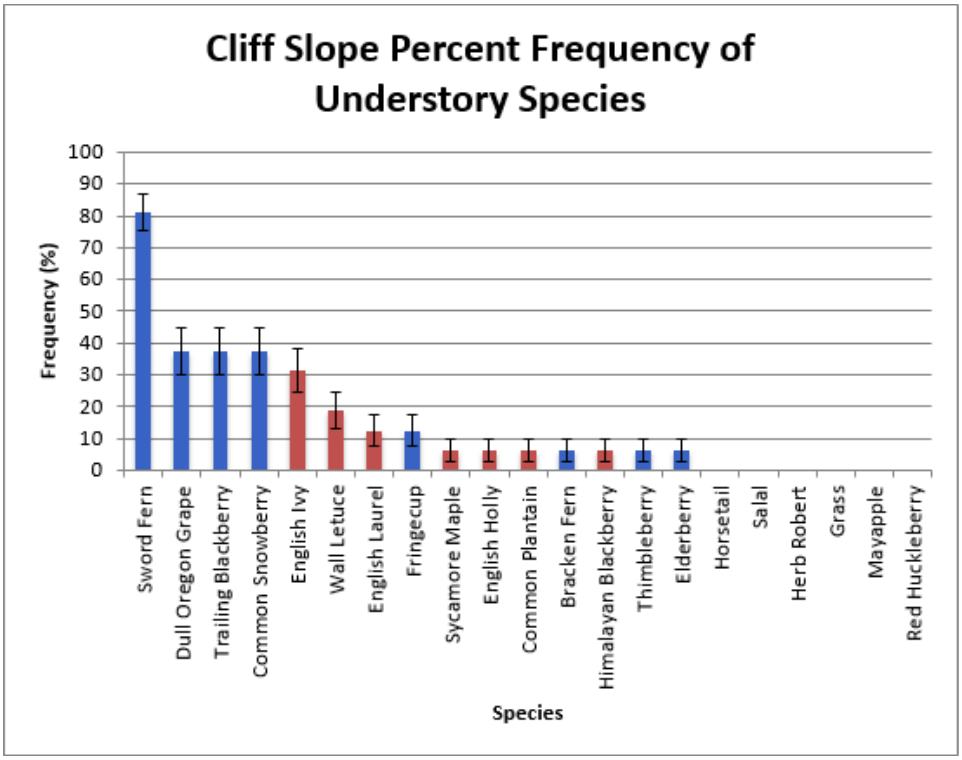
3.7 Understory cliff top percent frequency

We further classified the data based on the position of the plot on the cliff it was found. Using the similar criteria as the canopy cliff classification, we grouped cliff top plots based on their proximity to the coastline, drainage, and edge conditions.

a)


Cliff Top Percent Frequency of Understory Species
Frequency (%)
90
80
70
60
50
40
30
20
10
0
Trailing Blackberry
Sword Fern
Bracken Fern
Himalayan Blackberry
English Ivy
Common Snowberry
English Holly
Dull Oregon Grape
Wall Letuce
Fringecup
Grass
Mayapple
Thimbleberry
Elderberry
Sycamore Maple
Horsetail
Salal
Herb Robert
Common Plantain
English Laurel
Red Huckleberry
Species

b)


Cliff Slope Percent Frequency of Understory Species
Frequency (%)
100
90
80
70
60
50
40
30
20
10
0
Sword Fern
Dull Oregon Grape
Trailing Blackberry
Common Snowberry
English Ivy
Wall Letuce
English Laurel
Fringecup
Sycamore Maple
English Holly
Common Plantain
Bracken Fern
Himalayan Blackberry
Thimbleberry
Elderberry
Horsetail
Salal
Herb Robert
Grass
Mayapple
Red Huckleberry
Species

c)

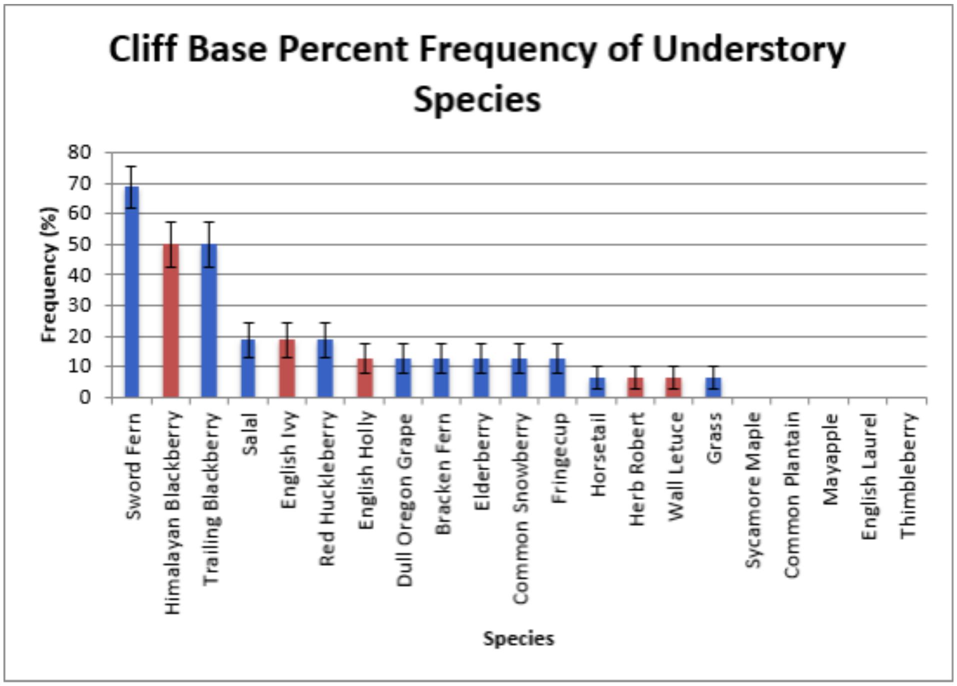


Figure 13. Percent frequency of Understory species in plots located at the a) the cliff tops, b) cliff slopes, and c) cliff bases.

Trailing blackberry is the most frequent understory species by a large margin. This species would be an asset to slope stabilization if planted at the cliff tops and slopes as it would deter human traffic.

3.8 Understory cliff slope percent frequency

Similar to the canopy cliff slope, the understory cliff slope percent frequency is a major consideration to our recommendation of the best candidate to stabilize soil on the cliffs. Our findings show that Sword fern is the most frequent understory species on cliff slopes by an enormous margin, followed by Dull Oregon grape (*Mahonia nervosa)*, Trailing blackberry, and Common Snowberry (*Symphoricarpus albus*). Based on field observations, we found that Sword fern provided incredible support when traversing the slopes along the transects.

Figure 14. Steep slopes at Transect 5, plot 5, were only accessible thanks to the strength and abundance of Sword fern that we used to pull ourselves up the slope.

This could possibly indicate that Sword fern possesses a complex and strong root structure, which provided a habitat for soil stabilizing arbuscular mycorrhizal fungi to grow in (Daynes et al., 2013). However, we did not conduct field research into this and thus recommend further study on the species' rooting habit with respect to the soil type and Sword fern root traits at the Point Grey cliffs.

3.9 Understory cliff base percent frequency

The role of understory flora species at the cliff toe is important as it stabilizes the soil there, considering the high stress conditions like light, wind, and wave action playing a prevalent role. Sword fern is the most frequent understory species at the base of the cliff, followed by Himalayan blackberry and Trailing blackberry. The percent frequency of Himalayan blackberry and Trailing blackberry are similar, which signals that they are currently fighting for dominance over the same niche (See Appendix 4). Therefore, controlling the non-native invasive Himalayan blackberry population will cause native Trailing blackberry population to rise at the cliff base.

3. 0 Summary and Further Research

The findings suggest that a number of native species are abundant and self-maintaining along the cliffs, particularly at vulnerable cliff bases. These include Bigleaf maple, Red alder and Western red cedar in the canopy, and Sword fern in the understory species. Being native to North America, these species do not present risks to ecosystem stability. However, our findings on canopy densities indicate an impending invasion of Sycamore maple and English holly, both highly invasive non-native species (Shouman et al., 2017; Stokes et al., 2014). For the understory species, Himalayan blackberry along with juveniles of English holly are abundant and potentially increasing. We believe that by planting additional members of less numerous species such as Douglas fir and Western red cedar, and maintaining populations of Bigleaf maple & Sword fern would help with slope stabilization and suppression of populations of Sycamore maple, Himalayan blackberry and English holly. However, some level of invasive species control may also be required to prevent English holly and Sycamore maple from invasion. Such efforts are in play in neighboring Pacific Spirit Forest, and need to be applied along the cliffs as well (Law et al., 2017; Jon, 2018).

Further Research:

1. Our study is focused on the health and the succession of flora species as indicators of good candidates to stabilize the soil at the Point Grey cliffs. While it is accepted that flora are soil stabilizers, our study does not consider the physical attributes of the species that may cause its effectiveness as a soil stabilizer to vary.
2. While we took an ecological solution to the issue of cliff stabilization, more research can be conducted regarding the hybridization of both man-made solutions and ecological solutions acting in concert to stabilize the Point Grey cliffs.
3. In conducting future recurring research under the Living Breakwaters Project, the utilization of drones or climbing equipment would aid in the gathering of data. This would result in obtaining valuable data on steeper slopes that are too unsafe for personnel to traverse.

Appendix: Photos of Field Site

Young Western red cedars at Transect 1, Plot 2, with mature W red cedar and Sword fern in the background. The scenery is reminiscent of plots at the top of the cliffs we studied.

Canopy cover at Transect 1, Plot 2. Some of the dominant trees occupying the canopy are Douglas fir and Western hemlock.

Picture taken at the edge of the cliff at Transect 1. The leaning trunks of the trees indicate gradual soil creep over the tree's growth.

Sword fern dominated the understory, along with Trailing blackberry at this steep, ravine slope along Transect 1.

Picture taken at the beach at Transect 1. Apart from it being a nice photo, it captures the scale of erosion that has occurred in these Quaternary sands, very close to the slope base where rising sea levels and wave action may soon further de-stabilize slopes.

Forest behind the Museum of Anthropology at Transect 2, plot 1. This is also the area where we spotted the Barred owl roosting in Himalayan spruce.

Using the designated trail to get down Transect 2 due to the sheer cliffs at both flanks. Note the Bigleaf maples in the background.

High concentration of Sycamore maple at Transect 3, and close up of leaf and stem. This invasive species formed a monoculture in this section of the forest, in what appeared to have been an opening at the time they established.

View from the top of Transect 4, where a Bitter cherry grew among larger stemmed Western red cedars and Douglas firs.

Demarcating the 10 meters by 15 meters survey area at Transect 5, Plot 5. Notable Fauna in this picture is Sword fern, Western red cedar, and common Snowberry.

Acknowledgments

We would like to extend our sincere gratitude to everyone involved in making this research possible, and providing us with valuable insight and constructive feedback throughout the six months spent working on the Living Breakwaters project. We would also like to give Dr. Nina Hewitt, our project supervisor, a special thanks for her outstanding contribution to the entire research, which would not have been possible without her guidance. Additionally, we want to thank Professor Kees Lokman for making this work possible through his "Living Breakwaters" project grant, and for his important insights during our presentation. A special thanks Kelly Hurley (UBC WorkLearn Undergraduate Research Assistant) and Irene Cantoni, Camilla Gaido, Tessa Jonker, & Laura van Gijzen (Visiting Masters students, Technical University of Delft, Netherlands), their field assistance. We thank Dr. Tugce Conger for her guidance and co-ordination during all stages of the work. Finally, we extend our gratitude to David Gill (SEEDS Sustainability Office and Campus and Community Planning) and Doug Doyle (Associate Director, Municipal Engineering, UBC) for their invaluable support in supporting and coordinating, and providing advice and feedback, on all aspects of the field research. This research was funded by an NRCAN Research Grant to Dr. Lokman (Principal Investigator) and a WorkLearn grant to Nina Hewitt.

References

Caplan, J. S., & Yeakley, J. A. (2013). Functional morphology underlies performance differences among invasive and non-invasive ruderal *Rubus* species. *Oecologia*, 173(2), 363-374. doi:10.1007/s00442-013-2639-2

Daynes, C. N., Field, D. J., Saleeba, J. A., Cole, M. A., & McGee, P. A. (2013). Development and stabilisation of soil structure via interactions between organic matter, arbuscular mycorrhizal fungi and plant roots. *Soil Biology and Biochemistry, 57*, 683694. doi:10.1016/j.soilbio.2012.09.020

Pojar, J. and MacKinnon, A. (eds.) (2014). Plants of Coastal British Columbia. Lone Pine Publishing.

The Canadian Press (2013) Landslide near UBC campus leaves sheer cliff; no one hurt, CTV News, Oct. 13. Retrieved from https://bc.ctvnews.ca/landslide-near-ubc-campus-leaves-sheer-cliff-no-one-hurt-1.1496772

Gaire, R., Astley, C., Upadhyaya, M. K., Clements, D. R., & Bargen, M. (2015). The biology of Canadian weeds. 154. Himalayan blackberry. *Canadian Journal of Plant Science, 95*(3), 557-570. doi:10.4141/cjps-2014-402

Irwin, L. L., Rock, D. F., & Rock, S. C. (2018). Barred owl habitat selection in west coast forests: Barred owl habitat selection. *The Journal of Wildlife Management, 82*(1), 202-216. doi:10.1002/jwmg.21339

Jon, H. (2018). Trails in Pacific Spirit park closed after landslides Retrieved May 21, 2019, from https://www.cbc.ca/news/canada/british-columbia/trails-pacific-spirit-park-closed-1.4526151

Law, A., Chookolingo, B., Soria, C., & Nathania, L. (2017). Comparing herbicide application methods for controlling *Ilex aquifolium* (English holly) in pacific spirit regional park

Leshchinsky, B., Olsen, M. J., Mohney, C., O'Banion, M., Bunn, M., Allan, J., & McClung, R. (2019). Quantifying the sensitivity of progressive landslide movements to failure geometry, undercutting processes and hydrological changes. *Journal of Geophysical Research: Earth Surface, 124*(2), 616-638. doi:10.1029/2018JF004833

Pemberton, K. (1999). Cliff erosion threatening university buildings [Final edition]. *The Vancouver Sun.* Retrieved May 21, 2019, from http://ezproxy.library.ubc.ca/login?url=https://search-proquest-com.ezproxy.library.ubc.ca/docview/242750996?accountid=14656

Point grey cliffs heading out to sea: 4th edition. (1987). The Vancouver Sun

Shouman, S., Mason, N., Kichey, T., Closset-Kopp, D., Heberling, J. M., Kobeissi, A., & Decocq, G. (2017). Functional shift of Sycamore maple (*Acer pseudoplatanus*) towards greater plasticity and shade tolerance in its invasive range. *Perspectives in Plant Ecology, Evolution and Systematics, 29*, 30-40. doi:10.1016/j.ppees.2017.11.001

Stokes, D. L., Church, E. D., Cronkright, D. M., & Lopez, S. (2014). Pictures of an invasion: English holly (*Ilex aquifolium*) in a semi-natural pacific northwest forest. *Northwest Science, 88*(2), 75-93. doi:10.3955/046.088.0204

Vilà, M. et al. (2011). Ecological impacts of invasive alien plants: A meta-analysis of their effects on species, communities and ecosystems. *Ecology Letters, 14*(7), 702-708. doi:10.1111/j.1461-0248.2011.01628.x