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Student Research Report

A Climate Suitability Analysis for Western Hemlock

Modeling Future Occurrence Probability of *Tsuga heterophylla* at the UBC Vancouver Campus

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A Climate Suitability Analysis for Western Hemlock: Modeling Future Occurrence Probability of *Tsuga heterophylla* at the UBC Vancouver Campus

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Abstract

To manage future green spaces on campus and adopt to the changing climate, the Social Ecological Economic Development Studies (SEEDS) program of the University of British Columbia (UBC) organized a series of projects to predict the climate suitability (occurrence probability) of some common tree species existing at the UBC Vancouver campus by 2100. With a generally low climate suitability, coniferous trees are more vulnerable to the change of precipitation and temperature, and climate change is threatening the growth of coniferous trees in British Columbia, Canada. Western hemlock (*Tsuga heterophylla*) is a common coniferous tree species occurring at UBC Vancouver campus and was chosen to be analyzed in this study. The analysis of climate suitability was done using a MaxEnt model. As a machine-learning algorithm not requiring data about absent points, MaxEnt is considered to be a good tool for predicting the distribution of species. There were 19 bioclimatic variables tested in the analysis, and the precipitation in the coldest quarter of the year was determined to be the most important climatic variable affecting the growth of Western hemlock. The results showed that the occurrence probability of Western hemlock would drop from its current ~87% to ~10% under one of the most likely climate models in 2100. Although this result could not represent the real occurrence probability of Western hemlock by the end of the century due to the limited data and variables considered (climate only), this study provided a reference for future climate suitability analysis at UBC Vancouver campus of other tree species and could potentially help with the protection of existing Western hemlock at the campus.

Key words: *Tsuga heterophylla*, climate suitability, probability of occurrence, MaxEnt model, species distribution prediction, UBC

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1. Introduction

Climate change is threatening forests in British Columbia (BC), Canada, and climate suitability analysis of tree species has become an important part of forest conservation (Hansen and Phillips, 2015). Although due to the difference in assumptions and sample data selections, current future climate projection models give slightly different predictions, the consensus is that the climate in BC will become more extreme by the end of this century: the annual mean temperature is likely to increase rapidly, and the precipitation is likely to increase during winter months, but decrease during summer months (Deser et al., 2014). Currently, 90% of forests in BC are dominated by coniferous trees, which are considered vulnerable to high temperature and the change of precipitation (Ministry of Forests, 2003; Hansen and Phillips, 2015). By impacting the distribution of local tree species in the forests, climate change could affect the local ecosystem of the province. With almost two-thirds of land covered by forests, climate suitability analyses of the common tree species in different scales are necessary for future forest management in the province by determining the probability of occurrence of the species in the selected area (Ministry of Forests, 2003).

Western hemlock (*Tsuga heterophylla*) is a common and ecologically significant tree species in BC, and also a crucial part of the local ecosystem at the University of British Columbia (UBC) Vancouver campus (Kayahara, 1992). As a coniferous tree species, Western hemlock has preference for cool temperature and humid environment. It is relatively vulnerable to the increasing temperature and variability of precipitation (Hansen and Phillips, 2015). In this study, a climate suitability analysis focusing on Western hemlocks at the UBC Vancouver campus was conducted. The objective of this study is to determine the climate suitability of Western hemlock by the end of 21st century at the UBC Vancouver campus. The study could potentially help future campus design and reconstruction of local ecological communities in the coming decades. This project is a part of a series of projects led by the Social Ecological Economic Development Studies (SEEDS) Program and UBC Botanical Garden. Some of the previous relevant research includes general predictions about the possible shifting direction and distance of trees in the next decades due to climate change at the UBC Vancouver campus (Liang, 2021) and the climate suitability analysis of maple trees at the UBC Botanical Garden (Stevens, 2022) as well as Western Red Cedar (Hang, 2022) . This analysis is not only important for studying the effects of climate change to the ecological communities dominated by coniferous trees at UBC Vancouver campus, but also providing reference for small-scaled climate suitability analyses of other species in North America.

In this study, the current distribution map of Western hemlock in west North America was combined with the historical climate data sets (from 1970 to 2000) to run a climate suitability analysis. During the analysis, a bootstrap model was run, and the biological variables impacting the most to the growth of Western hemlock were identified by the model. By the end of the analysis, a current occurrence probability map of Western hemlock in North America was created. Then, using the projected future (from 2040 to 2100) climate data sets under the most likely climate scenario, a future occurrence probability map of Western hemlock in North America was produced in comparison to the current one. The hypothesis was that the probability of Western hemlock's occurrence would gradually decrease in the following 80 years at the UBC Vancouver campus along with the change of climate.

2. Study Area and Data Description

2.1 Study Site: the UBC Vancouver Campus

The study site of this project is the UBC Vancouver campus, BC, Canada. Vancouver is located in the west of Canada, has a latitude of 49.25 and longitude of -123.12. Climate in Vancouver is warm and moderate. Summers are usually cool and dry, with the average daily temperature usually staying under 23 °C. Winter is moderate and wet, with high precipitation and an average minimum temperature slightly below 0 °C (WeatherSpark, 2022). The UBC campus covers more than 400 hectares of land, and around 20,000 trees are distributed in this area (UBC Campus and Community Planning, 2015). Currently, there are approximately 36 Western hemlocks growing at the UBC Vancouver campus (UBC Tree Inventory, 2022). Most of the trees distribute close to the cross of Thunderbird Blvd and Westbrook Mall, and there are also Western hemlocks growing close to the coast. Figure 1 shows an imagery map of UBC Vancouver campus, and the dark black border outlines the boundary of the study site. The red points represent the distribution of Western hemlock.

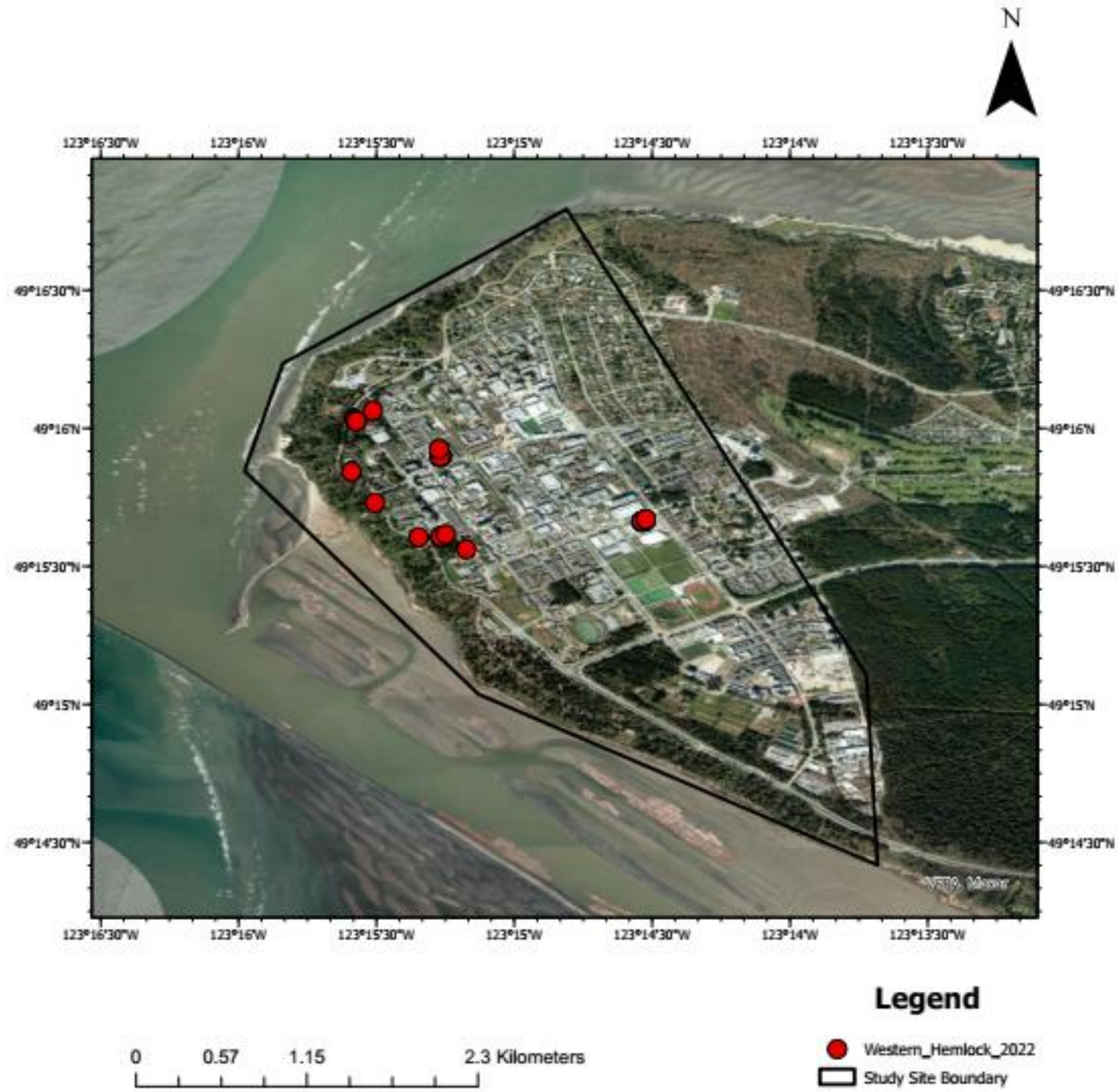

Figure 1: Distribution of Western Hemlock (36 trees) at the UBC Campus. Generated using ArcGIS under the WGS 1984 coordinate system. Base map source: Vancouver Fraser Port Authority, Maxar.

2.2 Data Description

2.2.1 Historical and Future Climate Data

Multiple global climate datasets retrieved from WorldClim were used in this study. The historical climate data collected from 1970 to 2000 was considered to be the climate conditions when the present mature Western hemlock grew, and was used to create the current occurrence probability map of Western hemlock. The projected future climate data sets (2021 – 2040, 2041 – 2060, 2061 – 2080, and 2081 – 2100) created under the MIROC 6 model from Coupled Model Intercomparison Project Phase 6 (CMIP6) was selected to be used as future climate data sets (Fick and Hijmans, 2017). The shared socio-economic pathways (SSP) scenario selected was SSP370. This scenario was considered to be relatively optimistic and one of the most likely scenarios, in which the greenhouse gasses emissions were limited, but fossil fuel was still applied in some industries (Meinshausen et al., 2020). The climate data sets contain 19 bioclimatic variables with a resolution of 2.5 minutes. The bioclimatic variables are the climate factors which are crucial biologically, and have the potential to significantly affect the living of organisms (Fick and Hijmans, 2017). The data sets were downloaded as TIFF files for modeling.

2.2.2 Tree Data

The current global distribution data of Western hemlock was retrieved from the Global Biodiversity Information Facility (GBIF, 2023). Among all the 16,205 records in the database, records distributed between the longitude of -110 to -150 degrees, and latitude between 35 and 65 degrees were rasterized and selected through the Terra package in R (R Core Team, 2022). The selected area covers most of the Western Coast in North America, and the whole BC Province, which is the original habitat of Western hemlock (Pojar et al., 1991). Most of these tree data points are clustered along the Western Coast, and there are also Western hemlock distributions in the Rocky Mountains region.

3. Methodology

Summary

In this study, climate suitability analysis for Western hemlock in North America was conducted to predict Western hemlock's probability of occurrence at the UBC Vancouver campus by 2100. The analysis was completed using the Maximum Entropy algorithm. During the analysis, a current occurrence probability map of Western hemlock in North America was produced and used to test the accuracy of the model. During this process, climatic variables contributing the most to the growth of Western hemlock were identified. With a good area under curve (AUC) score for validation indicating a high accuracy, the model was then applied to predict Western hemlock's probability of occurrence by 2040 to 2100, and a future occurrence probability map was then created. The climate suitability analysis in this study was undergone using R and the maxent package (R Core Team, 2023; Phillips et al., 2006). The detailed analysis process followed the instructions on R Functions (Neto, 2020).

3.1 MaxEnt Model Setup

Maximum Entropy, or MaxEnt models are common tools being used for species distribution prediction, since it allows researchers to make estimates on the occurrence probability of selected species with only the presented data points but not the absent ones (Kramer-Schadt et al., 2013). Using the pixels with the target species occurrence as samples and selected environmental variables as control variables, the probability of maximum entropy was found, and used for estimating the probability of distribution (Phillips et al., 2006). The current Western hemlock distribution data points in North America were divided into testing and training groups.

3.2 Model Training and Validation

80% of the Western hemlock points were randomly selected and were considered as the training group to be put into the MaxEnt model. The historical climate data from 1970 to 2000 was also input to model the current occurrence probability of Western hemlock in the selected region. With these data sets input in the MaxEnt algorithm, the contribution of each biological important climatic variable included in the WorldClim data sets to the growth of Western hemlock was determined. The other 20% of the Western hemlock points were classified as test group and applied to the model along with 1000 pseudo-absence points (random-selected points which were assumed to have no western hemlock growing) to evaluate the accuracy of the model, which was shown as area under curve (AUC) scores.

3.3 Maps Production

With the relatively accurate model with high AUC scores, the current occurrence probability of Western hemlock in North America was calculated using the predict function of the maxent package in R (R Core Team, 2023; Phillips et al., 2006). Then, future climate data sets for 2021 - 2040, 2041 - 2060, 2061 - 2080 and 2081 - 2100 projecting under the MIROC-6 SSP370 model (Meinshausen et al., 2020) retrieved from WorldClim was then applied to the Maxent model separately along with the Western hemlock distribution data to predict the future occurrence probability of Western hemlock. The results of the predictions were rasterized and output to ArcGIS to create the final maps (ArcGIS, 2021).

4. Results

4.1 The Current Occurrence Probability of Western Hemlock

The MaxEnt model applied to the Western hemlock distribution data had a good accuracy on calculating the current occurrence probability of Western hemlock in west North America with an AUC score of 0.977, indicating that 97.7% of the testing group and the randomly-selected pseudo-absence points were predicted accurately, and the model was considered good. The model also suggested that the climatic variable affecting the growth of Western hemlock the most was the overall precipitation of the coldest quarter of the year, which had a contribution of over 70% for the results. The minimum temperature in the coldest month of the year was the second important climatic variable, but with less than 10% contribution to the results. Figure 2 shows the current occurrence probability of Western hemlock in west North America projected by the model. It suggested the distribution of Western hemlock clusters along the Western Coast, especially in western BC in Canada and Washington State in the US. With a lower probability of occurrence, Western hemlock also distributes in the region close to the Rocky Mountains. At UBC Vancouver campus, the occurrence probability of Western hemlock was about 87% (0.87).

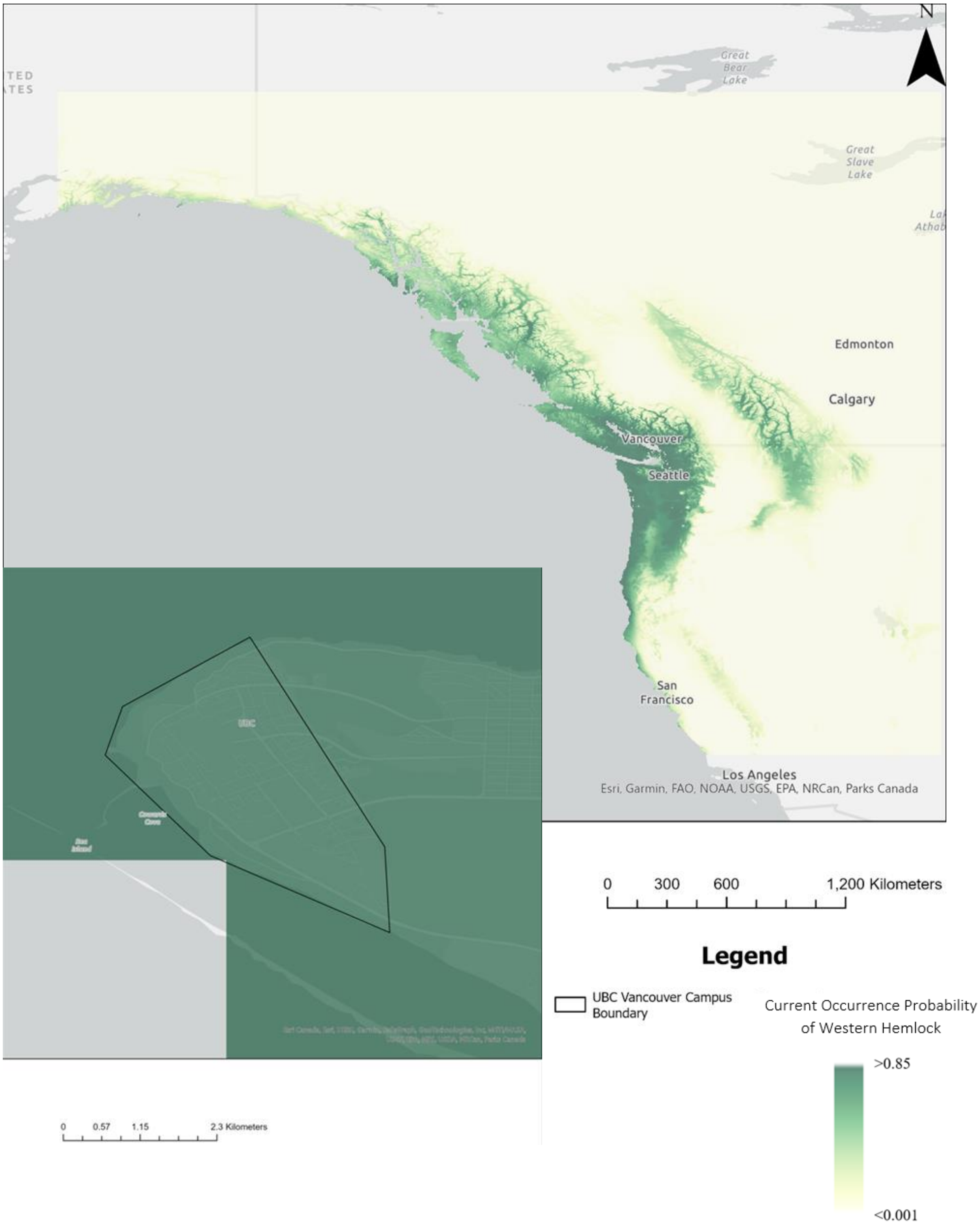

Figure 2: Current Occurrence Probability Map of Western Hemlock in West North America and a zoom-in occurrence probability map at the UBC Vancouver campus (with an occurrence probability of ~0.87). The base maps were provided by Esri et al.

4.2 The Predicted Future Occurrence Probability of Western Hemlock

The overall precipitation of the coldest quarter of the year in Vancouver was projected to increase rapidly from 495 mm to 613 mm in 2040. After 2040, the variance tended to be lower according to the projections made by WorldClim from MIROC-6 SSP370 climate model (Fick and Hijmans, 2017). In 2100, the overall precipitation of the coldest quarter of the year in Vancouver was projected to be 663 mm. The change between the projections of Western hemlock's occurrence probability was very little in 2040, 2060, 2080 and 2100, hence only the prediction for 2100 was selected to be shown in this report. Figure 3 shows the projection for the probability of occurrence in 2100. The projected occurrence probability of Western hemlock in UBC Vancouver campus dropped significantly from over 0.8 to 0.108. Western hemlock also showed a significant decreased occurrence probability in its other original main habitats in BC and Washington State (from 0.7-0.9 to 0.1-0.2) and close to Rocky Mountains (from 0.6-0.7 to 0.05-0.1), but a slight increase (from 0.1-0.2 to 0.2-0.3) in its northern habitats in the north of BC and the south of Alaska.

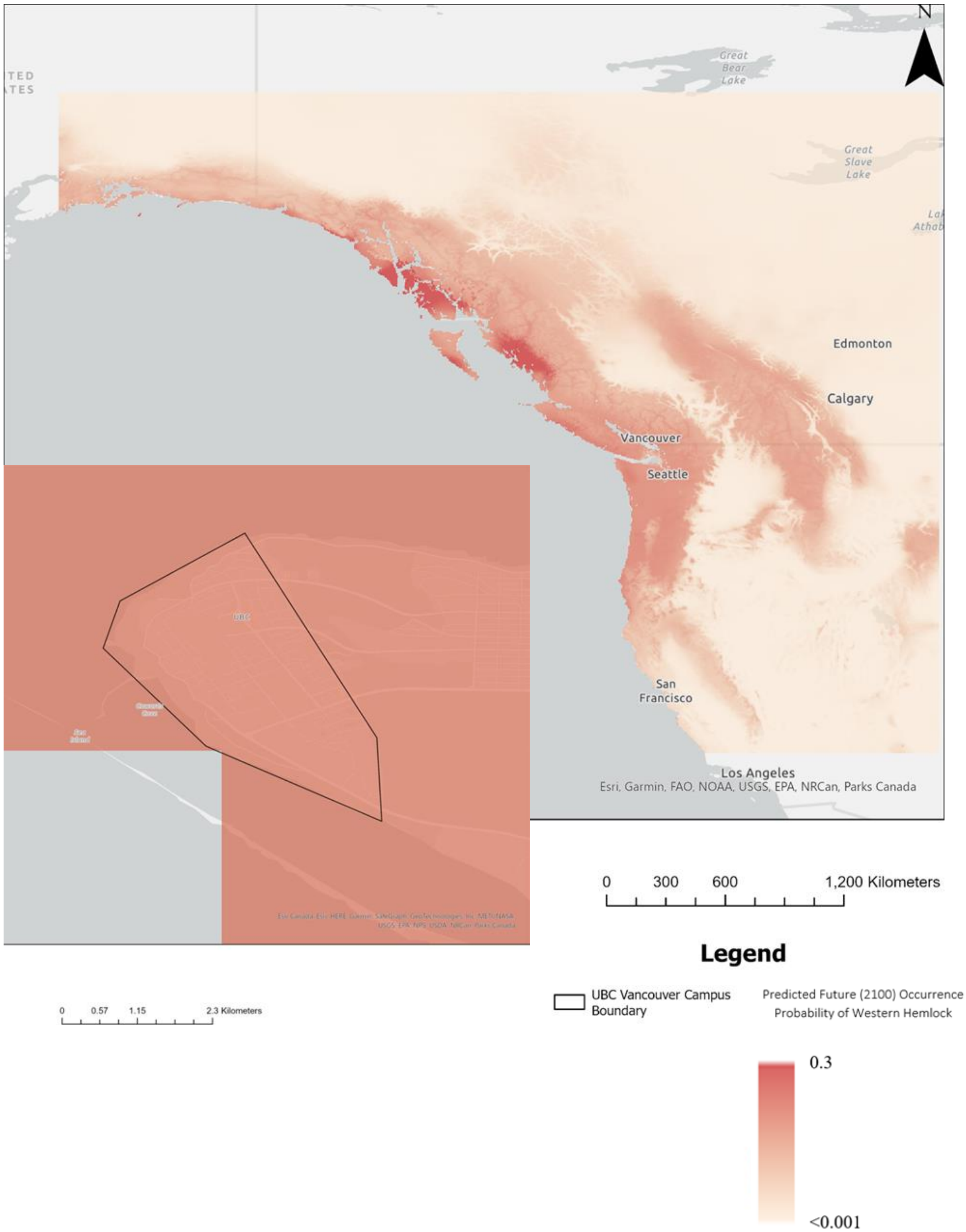

Figure 3: Projected Occurrence Probability Map of Western Hemlock in West North America in 2100 and a zoom-in occurrence probability map at the UBC Vancouver campus (with an occurrence probability of ~0.11). The base maps were provided by Esri et al.

5. Discussion

In this study, the climate suitability of Western hemlock was analyzed, and the probability of its occurrence at the UBC Vancouver campus at present and by the end of the 21st century was modeled. The future occurrence probability of Western hemlock in North America was also determined. Although the study site was limited to the UBC Vancouver campus, the study also provided a reference for Western hemlock protection against climate change in North America.

5.1 The Predicted Change of Western Hemlock Distribution at the UBC Vancouver Campus and in North America

The increase of precipitation in the coldest quarter of the year in Vancouver region was projected to be significant (~20%) from the historical climate (1970 – 2000) to the climate between 2020 – 2040, but with a much lower variance at about 10% between 2040 – 2100 (Fick and Hijmans, 2017). According to the results, this climatic variable contributed to over 70% of the occurrence probability of Western hemlock. This factor could potentially explain why the maps of projected occurrence probability from 2040 to 2100 have such a high similarity. The results also suggested that the rapid decrease of Western hemlock's occurrence probability at the UBC Vancouver campus (from >80% to 10 - 15%) is likely to occur between 2000 to 2040. Although due to the limitation of the data source, more detailed prediction was not able to be made, the decrease of natural-growing Western hemlock numbers is possible to start in the near future.

Overall, as a coniferous tree species, the climate suitability of Western hemlock is relatively low as expected (Hansen and Phillips, 2015). Under the MIROC-6 SSP370 climate projection, by the end of the century, some outliers of Western hemlock might survive in their original habitats along the West Coast in North America, but most projected habitats would not be suitable for Western hemlock after the climate change. The Western hemlocks at UBC Vancouver campus have a chance to survive under extra protections (i.e., appropriate coverage of the trees to reduce the received precipitation in winter) from humans. The most suitable habitat of Western hemlock moves from the west of British Columbia to the south of Alaska, where the winter precipitation is projected to be less, but the probability of occurrence is still low (~25%) compared to its current occurrence probability in Vancouver (~87%).

5.2 Limitations of the MaxEnt Climate Suitability Analysis Applied

The analysis was conducted on a relatively large scale in comparison to the study site. With a climate data set having resolution of 2.5 minutes in latitude and longitude (~4.5km at equator), UBC Vancouver campus was represented by only three pixels, and the precision of the study was relatively low. Also, only climatic variables were considered in the analysis and other variables such as elevation, soil types and local eco-community could also impact the growth of Western hemlock (Kayahara, 1992). The results of this analysis should not be considered as a reliable prediction of Western hemlock's future distribution in Vancouver, but an evaluation of potential climate suitability of Western hemlock only.

5.3 Significance of the Analysis and Future Study Directions

Being different from another SEEDS project testing the climate suitability of broadleaf trees (maples) at the Botanical Garden last year (Stevens, 2022), Western hemlock was analyzed as a typical coniferous tree at UBC Vancouver campus in this study. This project provides another climate suitability analysis for a common tree species on the UBC Vancouver campus. With a similar methodology applied as the previous project, Western hemlock was found not to be as resistant to climate change as most of the maples at the UBC Vancouver campus (Stevens, 2022).

In future studies, the climate suitability of other tree species is worth evaluating under smaller resolution using alternative climate data. Besides, since the distribution of Western hemlock at UBC Vancouver campus is likely to be impacted significantly by future climate, adaptation strategies for existing Western hemlocks on campus could be taken into consideration for future conservation planning.

With the prediction of future occurrence probability, the tree species most threatened and needing further attention could be identified. In order to protect the genetic diversity of Western hemlock under the rapidly and significantly changing climate conditions in the 21st century, climate suitability analyses of selected tree species are necessary for global forest conservation and prioritized adaptation strategies are required (Hansen and Phillips, 2015).

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