A Climate Change Risk Assessment for the CCF

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BACKGROUND

In the fall of 2024, the Cheakamus Community Forest (hereinafter 'the CCF') contracted Frontera Forest Solutions, Inc (www.fronterasolutions.ca) to complete a climate resilience risk assessment for the entire CCF tenure. The CCF and Whistler's public is witnessing current climate change and climate change impacts. Some examples of this have been overall tree and ecosystem decline as well as a recent western spruce budworm outbreak. It is strongly believed that recent (within the last ten years) climate change is affecting forest ecosystems, and their dynamics across BC[1,2,3]. Rather than assume a 'business as usual' approach to sustainable forest management, the CCF has decided to tackle this problem head-on.

The framework for this work was inspired by work completed by Erik Leslie, RPF, and the Harrop Procter Community Co-Op's 'Climate Change Adaptation Project'[4]. Harrop Procter has been a leader in climate change adaptation, vulnerability and risk assessments, and operational planning and implementation; this is especially true in terms of community forest planning.

This risk assessment is intended to fit within a larger CCF framework of proactively managing the community forest for decades under a climate resilience system. This risk assessment is the first of two major projects, the second project being an operational plan. The operational plan will use the findings from this risk assessment to directly address forest management and silvicultural practices across the CCF. The operational plan project will likely take about 8 months to complete with an expected timeframe of May – December 2025.

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[1] *Robert, J. A., & Srivastava, V. (2023, October). Predicting Forest Insect Outbreaks: Insights for Proactive Forest Management. BC Forest Professional Magazine.*
[2] *https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/climate-risk-summary.pdf*
[3] *Forest health and climate change: A British Columbia perspective (https://www.researchgate.net/profile/Harry-Kope/publication/266568957_Forest_health_and_climate_change_A_British_Columbia_perspective/links/54ec99b00cf27fbfd771197d/Forest-health-and-climate-change-A-British-Columbia-perspective.pdf*
[4] *https://hpcommunityforest.org/climate-change-adaptation-project/)*

PURPOSE AND OBJECTIVES

As stated above, this risk assessment report is the first of two reports, the second being a forthcoming operational plan addressing the risks identified and estimated within this report. Further to these two projects is the CCF's goal of practicing sustainable forest management through the lens of climate change. This process will require not only work on the part of the CCF but a shift in perspective. These changes will be a shift in sustainable forest management goals and objectives as well as intentional adaptive management.

Concepts related to climate resilience and sustainable forest management are not new. Canadian researchers and government staff members have been studying and developing guides to assist practitioners. This has included the BC Government[5] as well as the Canadian Council of Forest Ministers[6]. These resources were referenced as guidelines to this project and will likely be utilized in later stages of the CCF's climate resilience planning and implementation journey.

This risk assessment strives to answer the following questions:

1) How will climate change impact the CCF? What are the risks of these impacts?
2) Where are on the landscape are these risks likely to occur?
3) What are the levels of risk across the landscape.

We attempt to answer all of the questions identified above given the available information, science, and data available at this time. The reader should be aware that climate change assessments, including risk assessments are an approximation and contain various levels of error. The climate is changing, and these changes are unpredictable making predicting their impacts to trees and forest ecosystems ever more difficult.

This report is essentially broken up into three main sections:

1) Background
    a. CCF climate predictions,
    b. Forest inventories and stratification,
    c. Disturbance history,
2) Climate change impacts
    a. Current and projected risks,
    b. Location of risks on the CCF,
    c. Severity of risks across the CCF.
3) Discussion of risks and next steps.

[5] https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/natural-resources-climate-change/natural-resources-climate-change-applied-science
[6] https://www.ccfm.org/wp-content/uploads/2020/08/Climate-change-and-sustainable-forest-management-in-Canada-a-guidebook-for-assessing-vulnerability-and-mainstreaming-adaptation-into-decision-making-Report.pdf

STUDY AREA

To set the stage, the study area for this report is the entire CCF tenure which is depicted in Figure 1. One important step in the risk assessment process is to identify the existing forest ecosystems and forest inventory within the CCF. The CCF is a diverse forested landscape containing many different forest ecosystems and tree species. Figure 2 indicates the BEC zones (Version 12) located within the CCF. A description of every BEC and BGC zone is outside the scope of this report; however, readers can refer to website and references for more information[7].

Within the study area, the authors determined which areas are currently 'forested' and those that are 'non-forested'. Methods on how this was achieved are outlined below. This is an important step as it helps refine the study area. For this report the authors focused the study area on the 'forested' lands within the CCF which represents approximately 85% of the entire CCF area. Much of the 'non-forested' areas are high elevation rocky outcrops or low proportion tree cover areas.

In addition to various forest ecosystems, the CCF contains a mix of forest stand age types. For this report, the authors have utilized the RMOW's Priority Habitat dataset[8] which is likely the foremost dataset for forest stand ages for the study area. Forest stand age is depicted in Figure 4. The CCF 'forested' lands are represented by approximately 25% 'Ancient Forest' (400 years old or more) and approximately 25% 'Old Forest with trees aged 250-399 years old.

Finally, the Whistler area has experienced wildfire events over recorded and pre-recorded history. The authors have depicted wildfire events – both ignitions[9] and wildfire perimeters[10] within recorded history in Figure 5.

[7] https://www.for.gov.bc.ca/hre/becweb/
[8] https://www.whistler.ca/services/environmental-stewardship/biodiversity-and-ecosystem-health/
[9] https://catalogue.data.gov.bc.ca/dataset/bc-wildfire-fire-incident-locations-historical
[10] https://catalogue.data.gov.bc.ca/dataset/bc-wildfire-fire-perimeters-historical

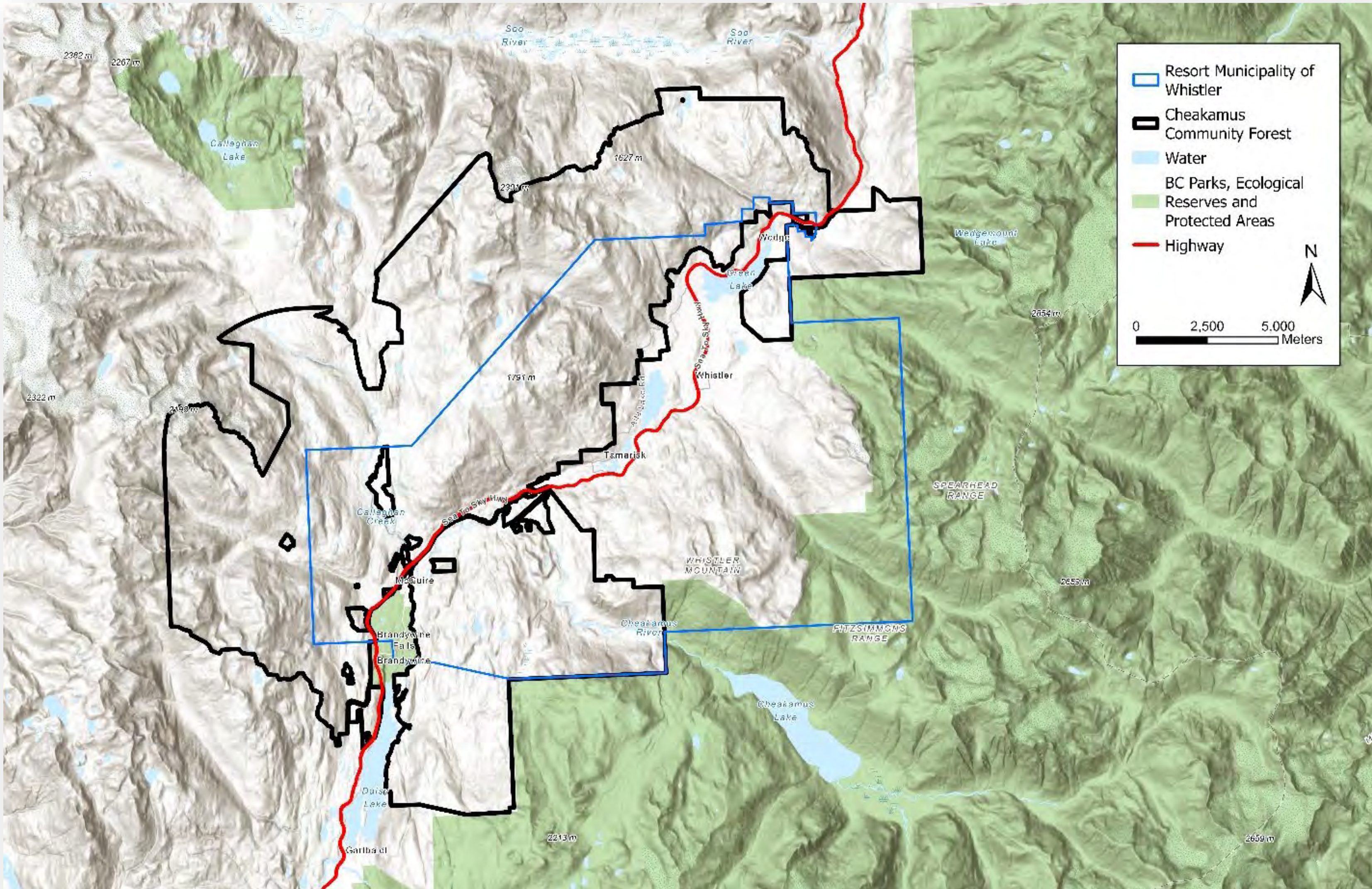

Figure 1: Map of CCF study area.

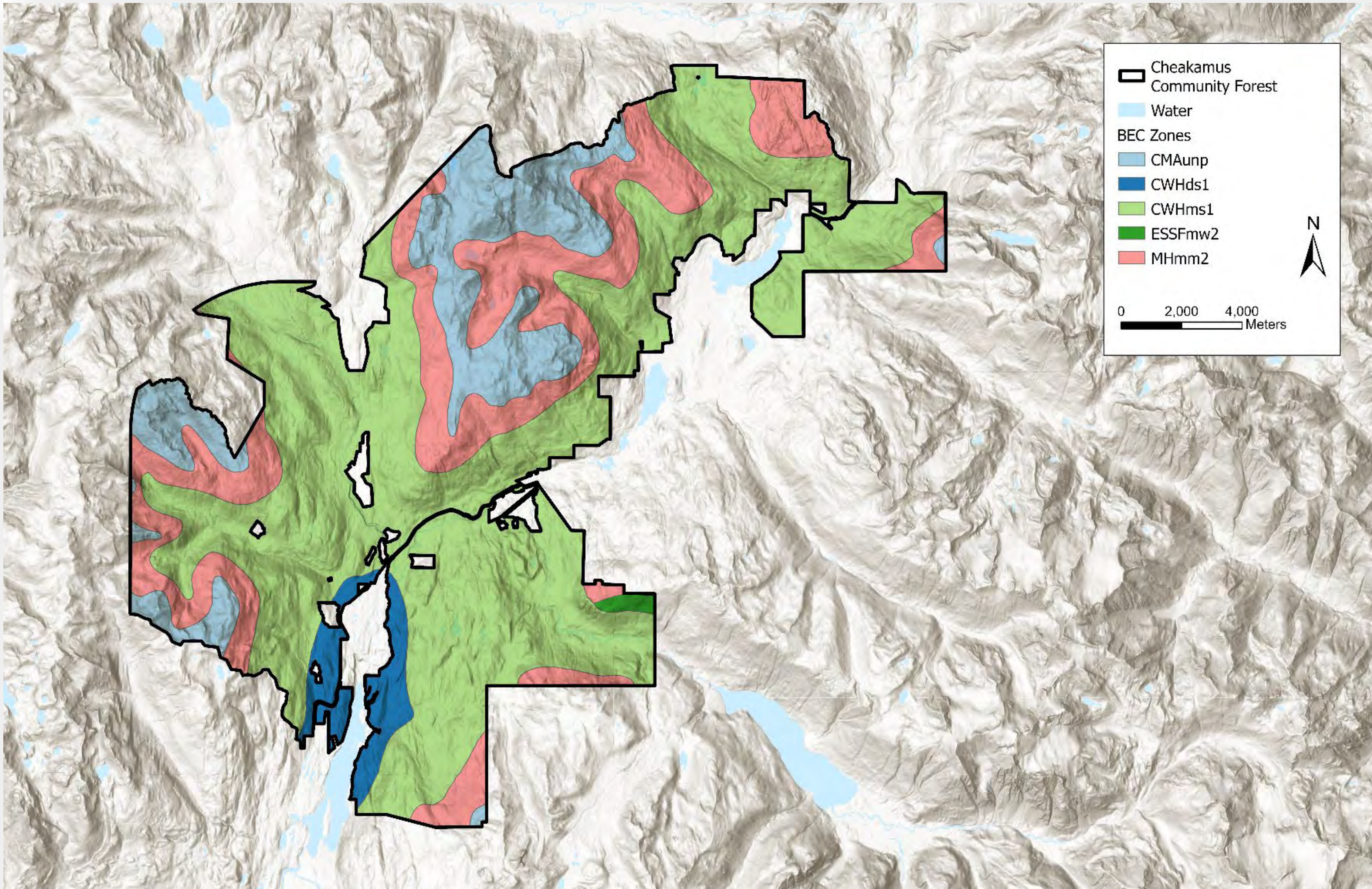

Figure 2: CCF BEC zone map.

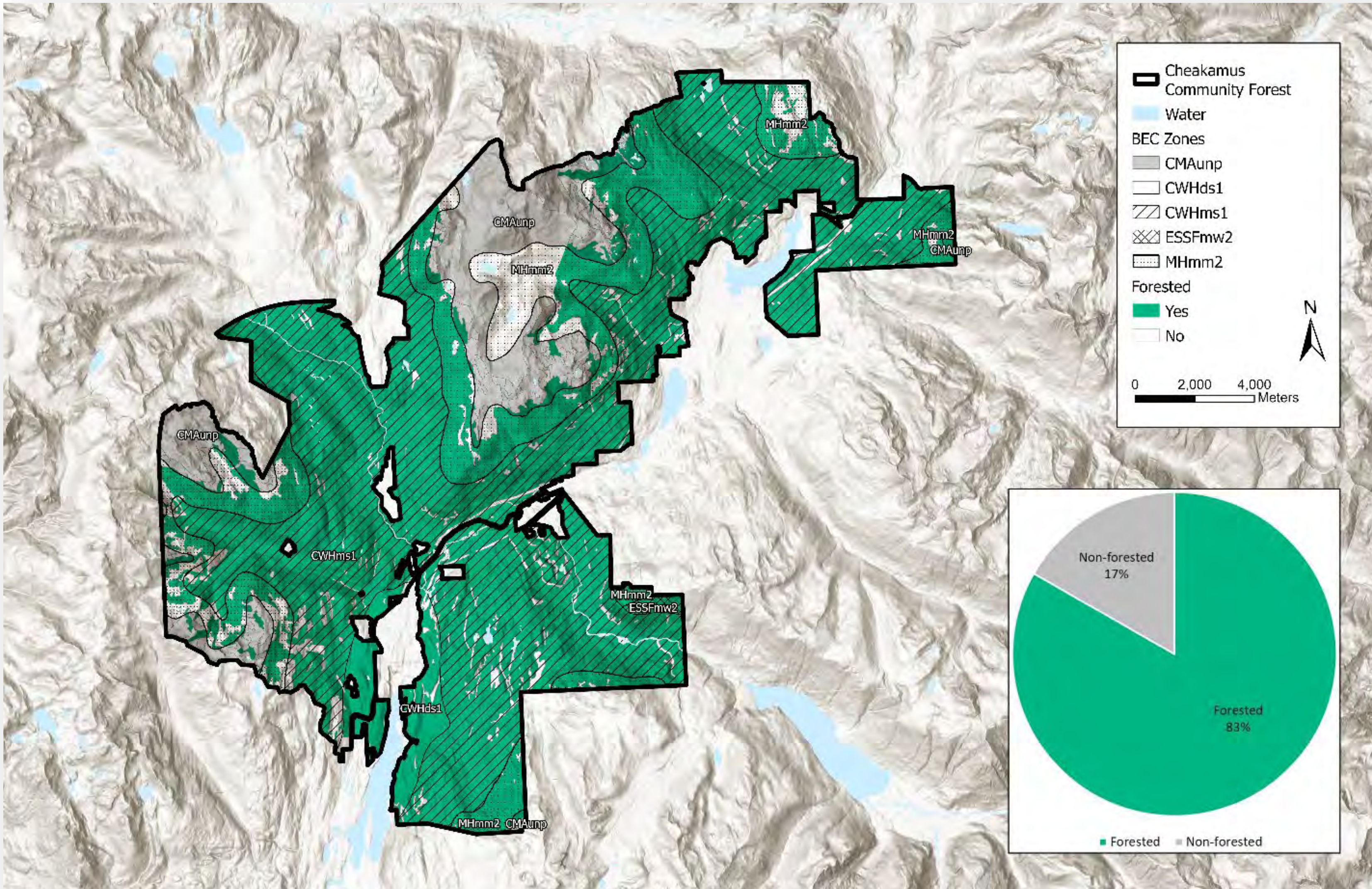

Figure 3: Forest and non-forest areas within the CCF overlaid with BEC zone information.

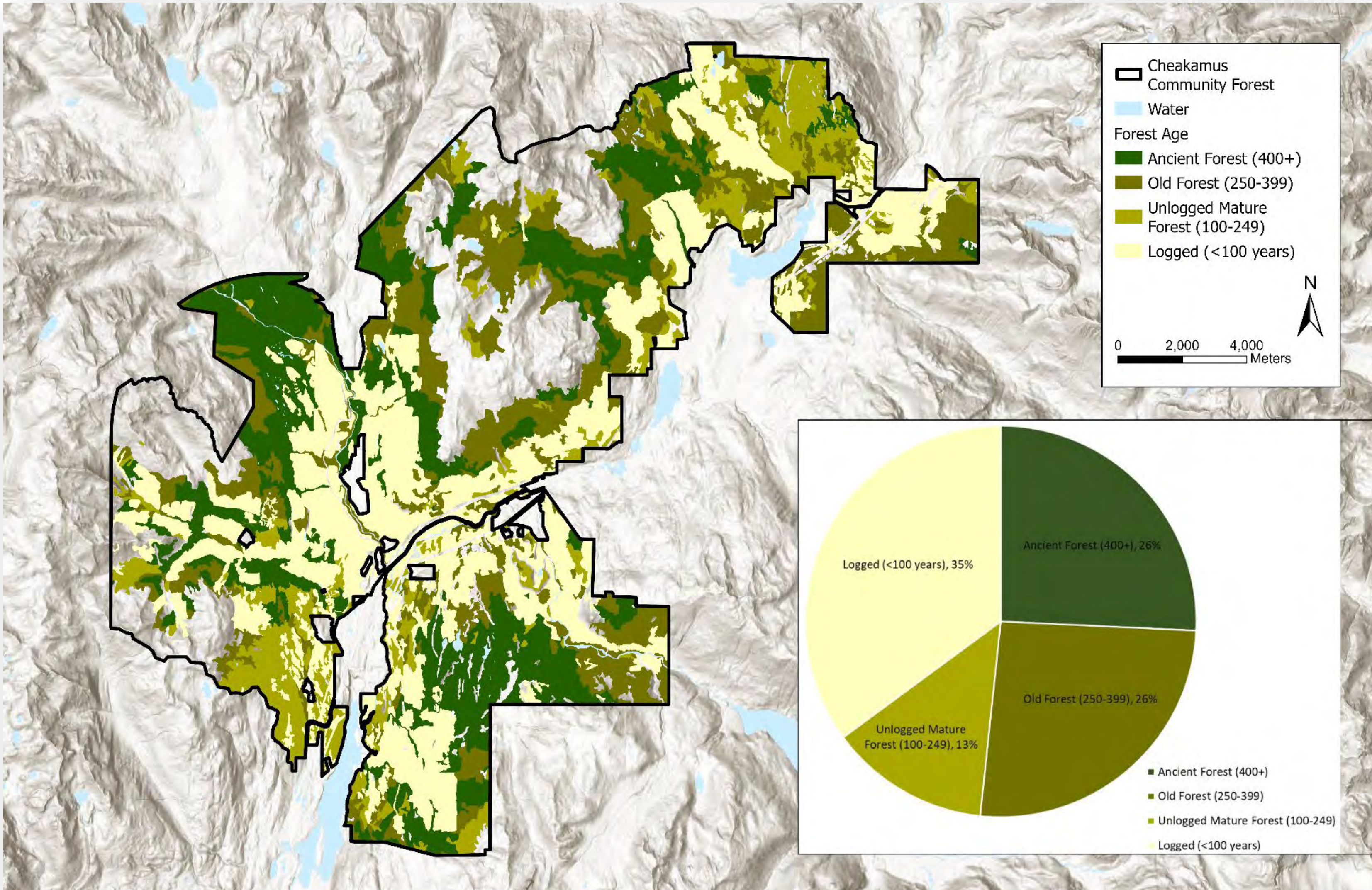

Figure 4: Forest stand age classes across the entire CCF.

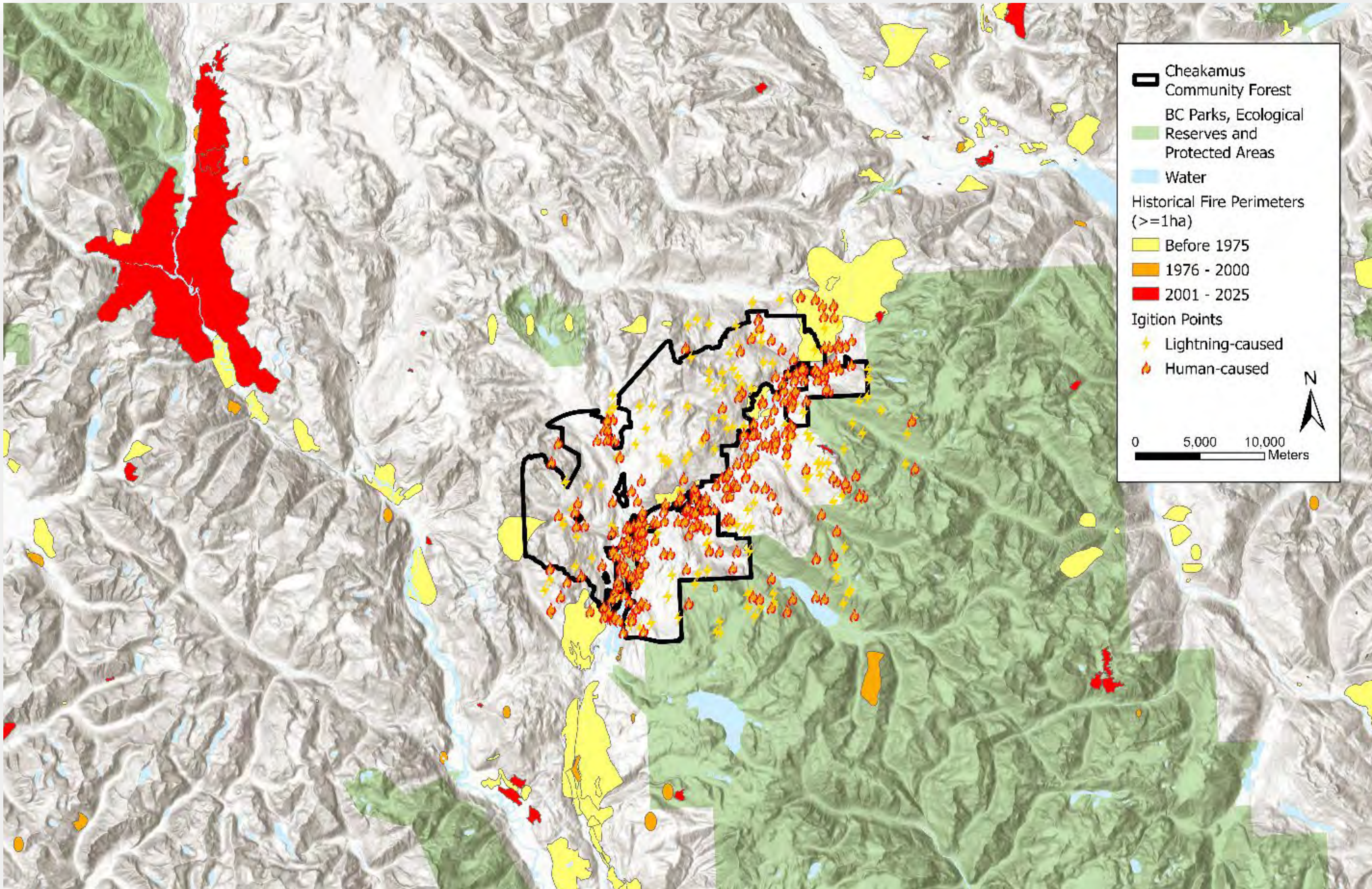

Figure 5: Fire history map for the CCF and surrounding area.

APPROACH

This section outlines the basic approach in performing this climate resilience risk assessment. For the risk assessment the authors used two main approaches to determine and quantify climate impacts and their risks:

1) Conversations with local experts and managers,
    a. In addition, there were conversations and feedback from the Whistler public and forest practitioners,
2) Background research on local and regional climate change impacts to forests, and
3) Modelling of climate impacts.

EXPERT AND PUBLIC DISCUSSIONS AND RESEARCH

Conversations with local experts mainly occurred within the CCF cohort. Initial meetings with the CCF and Chartwell Resource Group Ltd. (CRGL) staff entailed discussions about expert and practitioner informed opinions on current and future climate change impacts to forests. The CCF held a public meeting on this topic on December 3, 2025.

In terms of research, the following documents provided important direction, information, and guidance on local and regional climate change and climate change impacts:

- MOF Forest Health Strategy: 2024-27 Coast Area (unpublished at the time of publishing of this report),
- BGC's Whistler General Climate and Climate Change Assessment (2022)[11], and
- Adapting natural resource management to climate change in the West and South Coast Regions: Considerations for practitioners and Government staff (2016)[12].

The above technical references were used as an initial framework of information and considered in the initial risk assessment findings.

The overall basis for Whistler's current and future climate projections within this risk assessment were based and in-line with the RMOW's 'BGC's Whistler General Climate and Climate Change Assessment' published in 2022. A summary of these climate change effects is outlined in Figure 6. Similar climate effects were reported in 'Adapting natural resource management to climate change in the West and South Coast Regions: Considerations for practitioners and Government staff' and outlined in Figure 7. Figure 8 outlines impact to forests and forest-related ecosystems expected on the Coast, taken from 'Adapting natural resource management to climate change in the West and South Coast Regions: Considerations for practitioners and Government staff'.

[11] https://www.whistler.ca/wp-content/uploads/2022/12/2022_whistler_climate_change_modelling_summary.pdf
[12] https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/regional-extension-notes/coasten160222.pdf

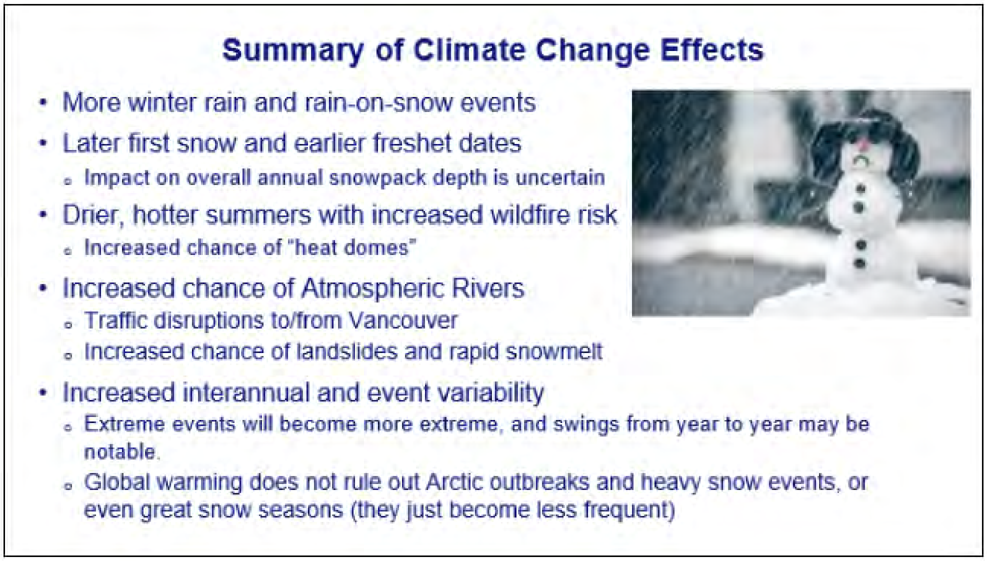

Figure 6: Summary of climate change effects (BGC Whistler General Climate and Climate Change Assessment).

Key Risk	Expected Changes	Impact
Heatwaves	More frequent and intense	Human health and safety; wildfire risk; energy demand; early snowmelt; infrastructure damage
Wildfires	More frequent and widespread	Human health and safety; ecological losses; post-fire landslides and debris flows; infrastructure and built environment damage and disruption
Flash flooding	More frequent and intense	Human health and safety; infrastructure damage; landslides and debris flows
Snowpack	More variable; later onset; earlier melt; less consistent; and, decreased accumulation	Decreased water availability; ecological disruption; winter recreation disruption
Cold snaps	Less frequent	Human health and safety; ecological losses
Freezing level	More variable and increased altitude	Disruption and cost to ski economy; snowpack and flooding; ecological outbreaks
Drought	More frequent, intense, and long lasting	Insufficient water supply; wildfire risk; ecological losses; tourism losses

Figure 7: Climate change impacts outlined in the Adapting natural resource management to climate change in the West and South Coast Regions: Considerations for practitioners and Government staff.

Disturbance	Projected changes
Wind and mechanical damage	• Intense **storm events** may **increase**. • **Windstorms** may **damage** ecosystems along susceptible portions of coast (up to 14% increase in speed of high-wind events projected in spring). Frequency of **catastrophic blowdown** in Northern Vancouver Island, Haida Gwaii, and the central coast may **increase** to approximate the current wind disturbance regime in southeast Alaska. • **Damage** to trees from **ice and snow** may increase with increased storms and increased freeze-thaw events in colder areas.
Fire and drought	• **Fires and drought** may **increase** by the 2080s due to decreased summer precipitation (monthly severity ratings increase by 30 – 60%); the Georgia Basin is predicted to experience the biggest increase in severity.
Hydrogeomorphic (flooding and mass wasting)	• **Increased** winter precipitation may increase the frequency of **slope instability** and mass wasting. Storm-mediated precipitation may increase 40 – 60% in the South Coast. • Maritime watersheds that **shift** from a **hybrid** rain/snow-driven to a **rain-driven** hydrological regime will likely experience the greatest change in flow patterns. • **Increased peak flows** and related sediment delivery may affect aquatic ecosystems and fish habitat as well as damage infrastructure. • **Loss of forest cover** (due to fire or other disturbances) may increase chance of **mass wasting**. • Increased **storm surge** events may affect coastal ecosystems. • **Loss of snow and ice** at high elevation may increase mass wasting from increasing freeze-thaw of exposed rock.
Insects and disease	• **Spruce beetles** may increase as a result of increased adaptive seasonality. • **Swiss needle cast** may increase if seasonal moisture trends continue to change. • Outbreaks of **western hemlock loopers** may increase as a result of the combined effects of more frequent droughts, changes in forest cover, and expanded range of western hemlock.

Figure 8: Climate change projected impacts outlined in Adapting natural resource management to climate change in the West and South Coast Regions: Considerations for practitioners and Government staff.

MODELLING

This section outlines the modelling and prediction systems the authors used to estimate impacts from climate change in the Whistler area. It details the systems, assumptions, and outputs of each model.

CLIMATE PREDICTION MODELLING

Climate prediction modeling is a crucial component of any analysis which aims to better address the future stressors facing both Whistler and the natural environment. To this end, it is vital to best encapsulate the potential ramifications of changes to local and regional climate on Whistler's wildfire environment. These changes could have large implications for fire behaviour, disturbance regimes, and forest structure writ large. There are a few approaches commonly used to address future fire environment conditions when using burn simulation modeling including simulating future weather under different Shared Socioeconomic Pathways (SSP) pathway normals[13], clipping existing weather datasets by future cutoffs, and modifying existing weather datasets with potential future

[13] *Xianli Wang et al., "Future Burn Probability in South-Central British Columbia," International Journal of Wildland Fire 25, no. 2 (2016): 200, https://doi.org/10.1071/WF15091.*

climate normals[14]. In order to do this the authors followed the latter method outlined in Riley and Loehman to project current burn probability simulation modeling on to future climate scenarios.

This approach involves characterizing future climate scenarios by modifying 'Observed' or normal climate data by projected changes under SSP scenarios. Thus, the authors modeled the predicted fire environment under the SSP1-2.6 and SSP3-7.0 pathways, both descriptions of the potential future climate scenario that may exist globally given action, inaction, mitigation, socio-politifcal and socio-economic developments[15]. These represent both an optimistic and pessimistic view of the potential fire environment under climate change. Pathway SSP1-2.6 describes an optimistic view of human mitigation of climate change under which CO2 parts per million levels off and declines starting in 2050 and C02 emissions are cut to zero by 2075. Total radiative forcing, an index which measures the potential climate change impact on Earth, is 2.6 watts per meters squared by 2100. SSP3 7.0 scenario on the other hand involves minimal mitigation techniques and predicts a mean radiative forcing of 7.0 watts per meters squared by 2100 under which CO2 emissions double by 2100[16]. Scenario likelihood modeling is extremely complex but recent analysis of progress on the 2015 Paris Climate Accords agreement has median projected warming at between 2.6 and 3.1 degrees Celsius by 2100 which puts the SSP2- 4.5 scenario (not modeled here) as the most likely, which is between optimistic and pessimistic model runs[17].

Modeling future conditions with burn simulation modeling is very complex and not only requires consideration of future fire weather but also potential changes to fuel structures. The authors opted to not model changes to potential fuel structures to avoid bias that often comes with assumed changes to fuel types[18]. Likewise, by choosing a scenario window of 2041-2060 the authors presumed that fuel type changes and their distributions due to climate change would not be fully realized by the time frame authors selected as ecosystem shifts operate on different timescales than changes to fire weather driven by climate change.

Under these assumptions the authors produced 3 fire weather datasets with which to run a Monte-Carlo simulation-based burn probability model (BurnP3+)[19]. The 3 datasets were the observed fire weather dataset based on local station weather data native to the region of interest and 2 modified datasets that represent the SSP1-2.6 and SSP3-7.0 climate scenarios. Climate scenario datasets were created with the aid of ClimateNA[20] which provides locally specific and statistically downscaled climate surfaces from Regional and Global Climate Models. The authors downloaded observed climate normals for 1991 to 2020 (which correspond roughly to the timeframe for observed fire weather data) and projected future climate normals for 2041 to 2060 for both SSP1-2.6 and SSP3-7.0. Differences between current monthly normals and future normals for all relevant variables (temperature, precipitation, relative humidity) were computed and those differences were applied to observed

[14] *Karin L. Riley and Rachel A. Loehman, "Mid-21st-century Climate Changes Increase Predicted Fire Occurrence and Fire Season Length, Northern Rocky Mountains, United States," Ecosphere 7, no. 11 (November 2016): e01543, https://doi.org/10.1002/ecs2.1543.*
[15] https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/
[16] *Katherine Calvin et al., "IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (Eds.)]. IPCC, Geneva, Switzerland.," First (Intergovernmental Panel on Climate Change (IPCC), July 25, 2023), https://doi.org/10.59327/IPCC/AR6-9789291691647.*
[17] *Joeri Rogelj et al., "Paris Agreement Climate Proposals Need a Boost to Keep Warming Well below 2 °C," Nature 534, no. 7609 (June 30, 2016): 631–39, https://doi.org/10.1038/nature18307.*
[18] *Erin J. Hanan et al., "Missing Climate Feedbacks in Fire Models: Limitations and Uncertainties in Fuel Loadings and the Role of Decomposition in Fine Fuel Accumulation," Journal of Advances in Modeling Earth Systems 14, no. 3 (March 2022): e2021MS002818, https://doi.org/10.1029/2021MS002818.*
[19] *M A Parisien et al., "MAPPING WILDFIRE SUSCEPTIBILITY WITH THE BURN-P3 SIMULATION MODEL," 2005.*
[20] *Tongli Wang et al., "Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America," ed. Inés Álvarez, PLOS ONE 11, no. 6 (June 8, 2016): e0156720, https://doi.org/10.1371/journal.pone.0156720.*

data by variable and by month to model datasets of future daily weather. This approach, as outlined in Riley and Loehman 2016, has advantages for fire weather modeling in that in retains inherent weather variability as opposed to a truncation approach which reduces dataset variability. As well it might offer improvements over simulated weather-based approaches which often underpredict extreme weather events that frequently drive fire behaviour and fire area[21].

On top of the predicted fire weather datasets, the model parameters that are tuned for the simulation modeling with BurnP3+ can be modified to better predict burned area under climate change. One such parameter is daily burning hours by season which is a preset value or distribution of values that control how long each fire burns during spread event days by season. The authors assumed that diurnal temperature and relative humidity variation best represents the distribution of daily burning hours. After tuning the observed model to best fit the observed fire regime, as outlined in the appendix (Appendix B), the authors then modified existing daily burning hour distributions for both future climate scenarios by the projected percent changes in relative humidity and temperature by season, grouping May normals into spring, June, and July normals into summer, and August and September normals into fall. This resulted in increased daily burning hours for both the SSP1-2.6 and SSP3-7.0 scenario, which leads to larger fire sizes and thus greater burned area.

WILDFIRE MODELLING

Wildfire threat and hazard modeling is a tool often used to summarise key wildfire behaviour parameters that most impact potential threat from wildfire in a given area. Fire behaviour indices such as rate of spread and head fire intensity are both key measures of a fire potential threat. They measure its speed and thus the likelihood and difficulty in suppressive efforts and its intensity as measured which impacts suppression likelihood, spotting potential and damage to the environment, people, and values. Burn probability is another key index which measures the relative probability of a wildfire occurring and/or burning a certain section of a landscape. These three parameters can be combined to gather an assessment of the potential wildfire threat. In this analysis the authors produced 3 wildfire threat assessments; one for observed fire weather environments and two under predicted climate scenarios as outlined by the SSP1-2.6 and SSP3-7.0 pathways mentioned in the section above using the Monte-Carlo based simulation model BurnP3+[22]. Model runs uses the same inputs and static preset ignitions so as to compare fire behaviour driven by changes to weather datasets from projected climate alone.

Results from all three runs were the median or 90th rate of spread, median or 90th head fire intensity, and burn probability for the area of interest for all produced fire simulations and iterations. Given a goal in predicting extreme fire events and to isolate localities that support higher intensity fire behaviour the authors used the 90th percentile level as to include in the threat mapping. All three are integrated into a threat score which is a standardized method for comparing threat from wildfire across a landscape.

Wildfire Threat = (Head Fire Intensity Score*0.3) + (Rate of Spread Score*0.3) + (Probability of Burn Score*0.4)

For more detail see the method outlined in the appendix (Appendix B).

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[21] *Mohamad Alkhalidi et al., "Evaluating the Accuracy of the ERA5 Model in Predicting Wind Speeds Across Coastal and Offshore Regions," Journal of Marine Science and Engineering 13, no. 1 (January 16, 2025): 149, https://doi.org/10.3390/jmse13010149.*
[22] *Parisien et al., "MAPPING WILDFIRE SUSCEPTIBILITY WITH THE BURN-P3 SIMULATION MODEL."*

Fireshed Analysis

On top of a wildfire threat and risk assessment the authors produced a fireshed analysis for each of the modeled climate scenarios for the CCF and Whistler valley. This approach, outlined in Wang et al.[23], involves merging all fire perimeters that intersect the community of interest to create a fireshed processing area. The concept of a fireshed is borrowed from hydrology in which a watershed is a region of interest wherein all streams that would drain into the region are considered within the watershed. This approach is appropriately applied to fire wherein all fire events that could potentially burn into a community or interface with critical values are considered part of the fireshed. From there, firesheds can be thought of as an appropriate management and monitoring domain within which fire threat and risk should be assessed relative to the community.

Following the creation of modeled firesheds for the observed climate, SSP1-2.6, and SS3-7.0 scenarios and using those as a boundary, the approach in Wang et al.[24] and Erni et al.[25] was used to model potential fire spread pathways into the community. Using neighborhoods surrounding CCF and the underlying rate of spread layer as a conductance surface for fire spread, the authors modeled and aggregated potential fire spread pathways or corridors that might enter those critical areas. This method involves igniting fires in every cell within the fireshed and determining the most conducive path for fire spread to different community focal points. This approach uses the maximum rate of spread in every cell and a neighborhood focal statistic to build least cost distance pathways between ignition points and a focal point. For this analysis the authors selected four focal points across Whistler: Cheakamus Crossing, Creekside Centre, Whistler Centre, and the Rainbow Neighborhood as areas of concern. The community focal points are centroid points of Whistler's most populated areas. These focal points are areas of concern and allow us to view an effective spread of potential fire pathways across the CCF to isolate more likely regions of fire spread. The output of this approach is a density analysis of fire pathways that demonstrates where fires, given the right spread direction towards a community, might travel if they head toward values of concern and can aid in management planning, treatment placement, and even treatment effectiveness.

For more detail see the method outlined in the Appendix B: Wildfire Modelling.

MODELLING TREE STRESS AND MORTALITY

Estimating and predicting tree stress and mortality is a challenging prospect anywhere in the world. In order to tackle this and bring it to a local level, the authors decided to use the Climate Change Informed Species Selection tool[26] (CCISS). Within this report the authors used this tool for predicting potential stress on forest ecosystems and CCF's tree species. The authors worked closely with the team from CCISS as this tool is still under development by the BC MOF.

This tool is a Biogeoclimatic Ecosystem Classification-based analysis framework built to anticipate the change climate implications to tree species environmental suitability at a site-specific level. The CCISS tool is a web-based application that makes this analysis accessible to practitioners to help guide climate change adaptation in reforestation decisions.

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[23] *Xianli Wang et al., "Mapping the Distance between Fire Hazard and Disaster for Communities in Canadian Forests," Global Change Biology 30, no. 3 (March 2024): e17221, https://doi.org/10.1111/gcb.17221.*
[24] *Wang et al.*
[25] *Sandy Erni et al., "Mapping Wildfire Hazard, Vulnerability, and Risk to Canadian Communities," International Journal of Disaster Risk Reduction 101 (February 2024): 104221, https://doi.org/10.1016/j.ijdrr.2023.104221.*
[26] https://thebeczone.ca/shiny/cciss/

Understanding climate- and site-level species suitability is one of the foundational pieces of information that practitioners require for the creation of silvicultural prescriptions that will lead to successful reforestation over a rotation period. Climate change will affect this goal by progressively altering environmental conditions and therefore the suitability of tree species established on a site over time. Understanding this aspect is a key objective of the CCF's climate resilience plan in order to improve long term forest management decisions.

CCF FOREST INVENTORY/MAPPING

To identify the current spatial distribution of forests that are within CCF, the authors reviewed Terrestrial Ecosystem Mapping (TEM) datasets from two sources. The provincial TEM dataset is publicly available and was acquired from the BC Data Catalogue[27]. RMOW TEM dataset was obtained from the Resort Municipality of Whistler (RMOW). Both datasets were clipped to the CCF boundary in ArcGIS Pro. To resolve data gaps and overlapping areas, a pairwise erase operation was applied to the provincial TEM dataset using the RMOW TEM geometry. The datasets were then merged into a gap-free, non-overlapping TEM shapefile for CCF. Table 1 describes the retained attributes in the output dataset.

Table 1. Attribute breakdown of merged TEM dataset for CCF.

Source	Attribute Name	Description	Format
RMOW TEM	BGCUNIT	Biogeoclimatic unit (combined BGC zone/subzone/variant)	Alphanumeric codes (e.g., CWHms1, MHmm2)
	ECO1_SS	1st ecosystem component - site series	Two-letter codes or two-digit numbers. E.g. TA, 01
	SG	Site group	Two-letter codes. E.g. RO, ZO
Provincial TEM	BGC_LBL	Biogeoclimatic label	Alphanumeric codes (e.g., CWHms1, MHmm2)
	SITE_S1	Site series number of ecosystem component 1	Two-digit numbers. E.g. 01. 02
	SITEMC_S1	Site series map code of ecosystem component 1	Two-letter codes. E.g. LA, DF

To standardize the merged data, a new attribute "Site Series" was created by concatenating:

- BGCUNIT and ECO1_SS for RMOW TEM polygons.
- BGC_LBL and SITE_S1 for provincial TEM polygons.

The author reviewed Land Management Handbook 25, the Master Ecosystem Code List provided by the provincial ecosystem information team (TEI_Mail@gov.bc.ca), along with TEM documentation, to interpret the ecosystem codes that describe the dominant landscape features of each TEM polygon. Using this information, the author extracted polygons that are predominately forested. In addition, 2018 orthophotos of CCF-RMOW region were cross referenced with the TEM datasets to ensure accurate differentiation of forested from non-forested

[27] https://catalogue.data.gov.bc.ca/dataset/terrestrial-ecosystem-mapping-tem-detailed-polygons-with-short-attribute-table-spatial-view

landscapes. Based on TEM attribute information on site series and moisture regime, forested landscapes were further stratified into the three ecological groups (Table 2).

Table 2. Ecological groups.

Ecological groups	Site Series number
Zonal	01
Drier	02, 03
Wet	04, 05, 06, 07, 08, 09, 10, 11, 22, 23

Following this, the author used Old Ancient Forest Habitat data from RMOW to overlay forest age classification. This dataset categorizes forests into four age classes: ancient forest (400+), old forest (250-399), unlogged mature forest (100-249), and logged (<100). Using the Union operation in ArcGIS Pro, forest age classes were integrated with the forest ecological groups, resulting in 13 distinct strata (Table 3). Areas currently labeled as unknown will be further investigated in the next phase of the project through detailed ecosystem analysis and field verification, where possible.

Table 3. CCF forest strata.

Drier, ancient forest (400+)	Zonal, ancient forest (400+)	Wet, ancient forest (400+)	Unknown
Drier, old forest (250-399)	Zonal, old forest (250-399)	Wet, old forest (250-399)	
Drier, unlogged mature forest (100-249)	Zonal, unlogged mature forest (100-249)	Wet, unlogged mature forest (100-249)	
Drier, logged (<100 years)	Zonal, logged (<100 years)	Wet, logged (<100 years)	

FOREST HEALTH

For this report, the authors worked with various staff from the MOF Forest Health team. In addition, the authors reviewed various literature, particularly the report 'MOF Forest Health Strategy: 2024-27 Coast Area' to both outline historical forest health threats as well as gain information on likely future forest health impacts from climate change. In this section, the authors outline historical forest health impacts and some basic local forest health information.

No forest health modelling was completed for this risk assessment for two main reasons. The first reason is that there are multiple forest health factors that could potentially affect the study area, making modelling all of these extremely time consuming and expensive. The budget and timeframe would therefore not allow it. The second reason is that currently there is no modelling system available for long-term prediction of the multitude of forest health agents on the landscape to properly do this assessment. Therefore, for these two reasons, the authors recommend that this work be done at a later time when models and systems are available to make these predictions.

RESULTS

FUTURE CLIMATE AND OVERALL IMPACTS TO CCF FORESTS

Forests are highly vulnerable to the impacts of climate change, as changes in temperature and precipitation patterns can have significant impacts on forest ecosystems and the plants and animals that depend on them. Some of the key vulnerabilities of forests to climate change include impacts to overall forest health and increased abiotic disturbances such as windthrow and wildfire.

- Wildfire,
- Tree stress and mortality, and
- Forest Health.

WILDFIRE IMPACTS

Wildfire threat to the Cheakamus Community Forest and the greater Whistler Valley region remains an elevated concern. Fast moving wildfires driven by extreme fire weather could be devasting to the community, critical values, forest health, and timber resources. Under concern for this outcome, this report was generated to determine the areas most at risk of extreme fire behaviour and the largest dangers to the CCF from wildfire activity. To this end we produced three major results to demonstrate fire hazard from the analysis of the wildfire risk to the region.

A first key result is the intermediate output of burn probability which highlights areas that are mostly likely to burn in a regular fire season, given the fuels, weather, and climate of the region. The second post-processing result is Frontera's wildfire threat mapping analysis which isolates key areas of concern which integrates high potential for wildfire likelihood (burn probability) and high likelihood of extreme fire behaviour (rate of spread and head fire intensity). Finally, Frontera produced a fireshed pathway and corridor analysis following approaches by Erni et al[28] and Wang et al[29], to isolate pathways of greatest concern to a community given a distribution of randomly seeded ignitions and using the outputs from BurnP3+, Median and 90th rate of spread layers, as a cost layer. This robust approach characterizes the greatest fire movement corridors of all modeled fires that intersected the CCF to best assess where fire risk to the community originates from given the worst-case scenario weather spread patterns. All 3 of these approaches give a detailed understanding of the Cheakamus Community Forest's risk from wildfire currently and under a changing climate.

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[28] *Erni et al., "Mapping Wildfire Hazard, Vulnerability, and Risk to Canadian Communities."*
[29] *Wang et al., "Mapping the Distance between Fire Hazard and Disaster for Communities in Canadian Forests."*

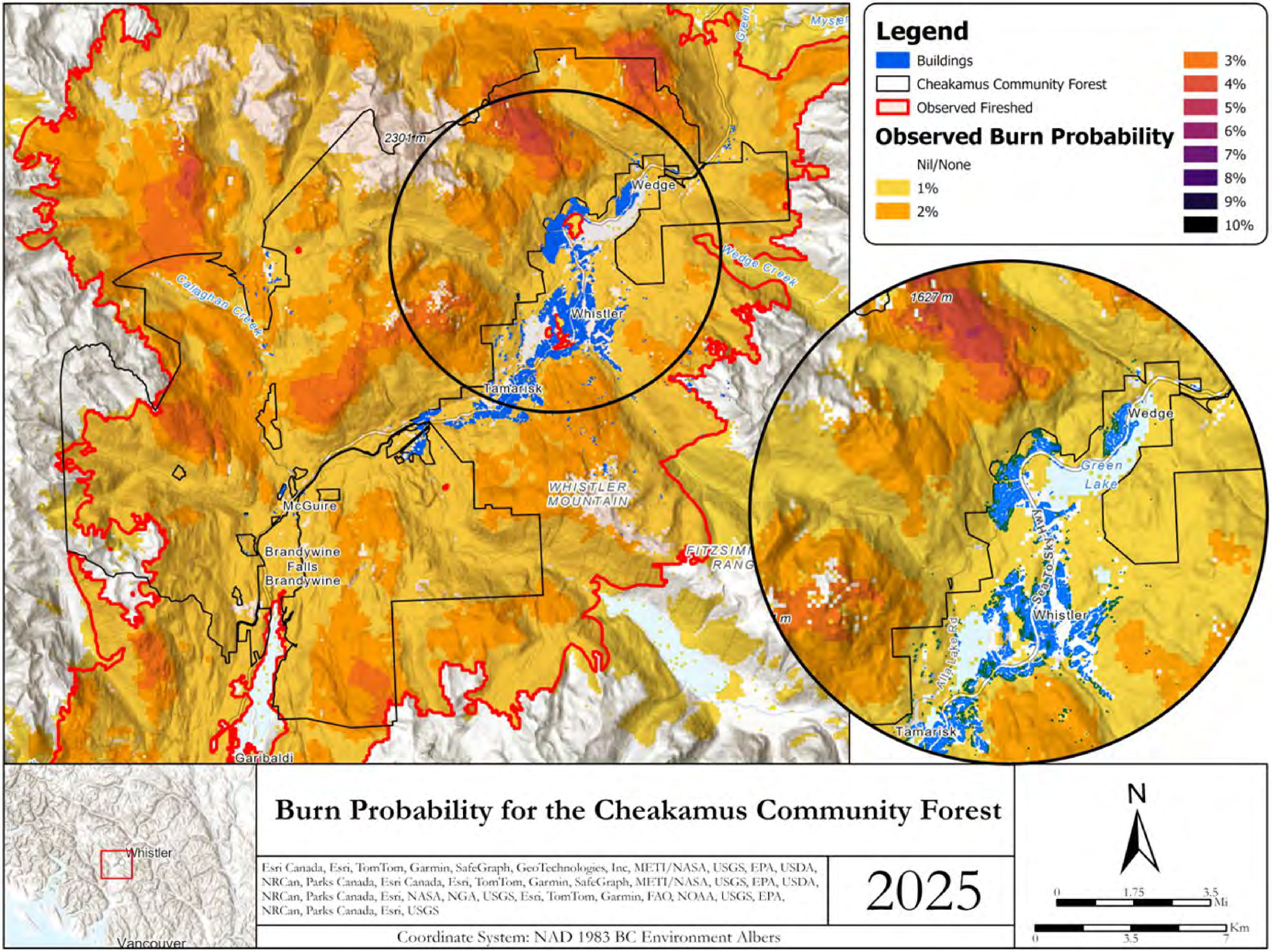


Figure 9: Burn Probability Under Observed Climate for Cheakamus Community Forest and Whistler Valley

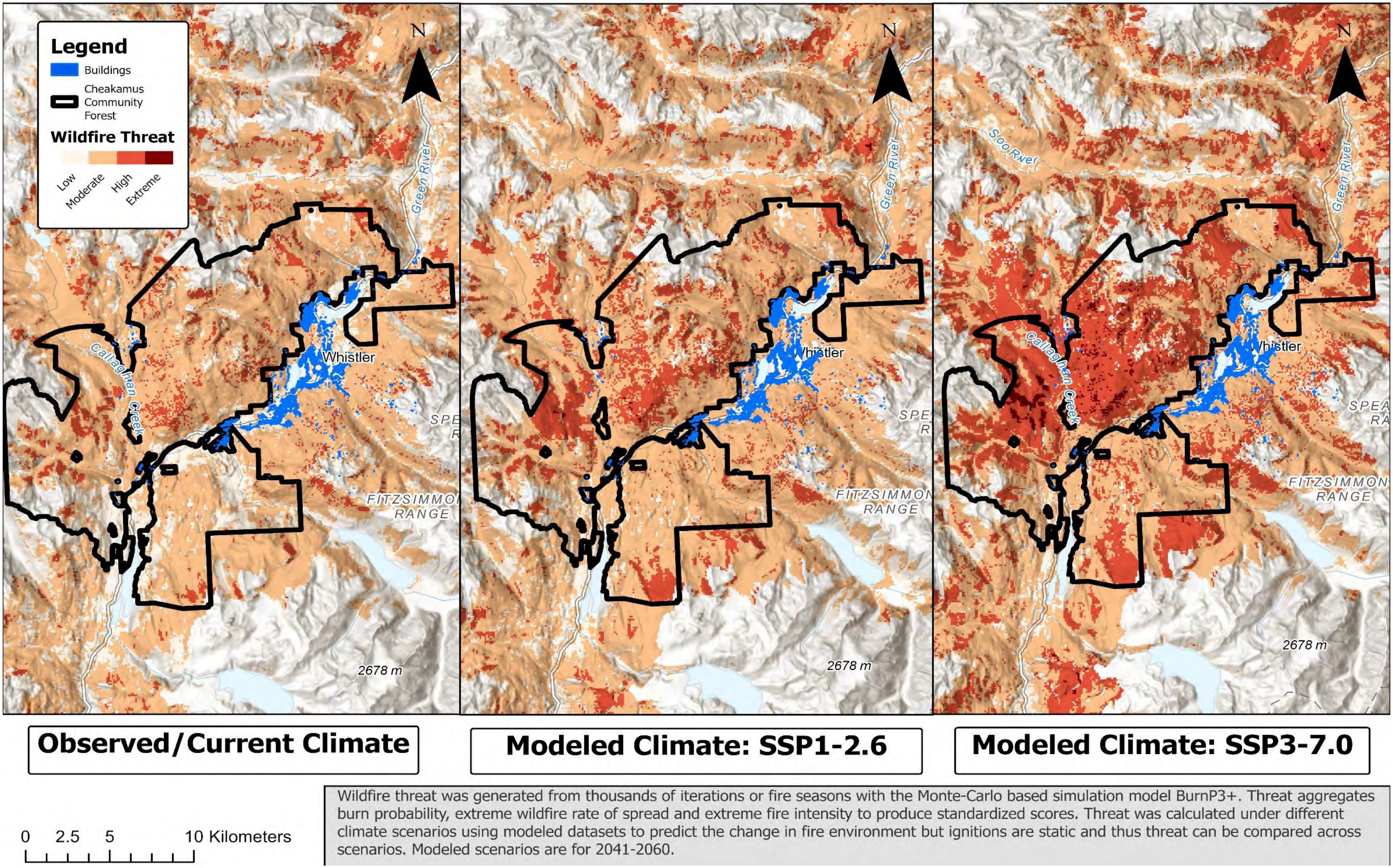
Burn Probability Results

Results from the burn probability mapping through BurnP3+ reveal key trends for the CCF and Whistler valley region (Figure 9). Ignition predictions were based on historical data (human and lightening). Since human ignitions are typically more predictable, the authors utilized a geospatial predictive method that included distance to roads, road network density, distance to railroad, trail density, as well as distance to recreational area as geographic predictors of human ignitions. Through this analysis an ignition hotspot map was created – combining both historical lightening points and human prediction ingitions.

Burn probability mapping is an aggregation of all fire's burning on the landscape through the use of BurnP3+. More simply, it measures how likely an area is to have burned over the average fire season given the right conditions. Burn probability can be produced as either a relative (as was done in Figure 9) or absolute value, and informs analysis as to where both ignitions and fire spread is more likely. Given the analysis, burn probability can be interpreted as the relative likelihood of a fire returning after x number of years. A burn probability of 5% would translate to the likelihood of 1 fire every 20 years, whereas a burn probability of 2.5% would be one fire every 40 years. Caution should be used when interpreting results without experience in the use of fire and burn simulation modeling.

Regions of higher relative burn probability include northern sections of valley north of the Wedge and Rainbow communities and the slopes along Callaghan valley as well as some of the northern facing slopes on Whistler Mountain. While average absolute burn probability in the Whistler valley is low, much less than 1% annual or <1 fire every 100 years, relative burn probability in those regions remains an increased concerned with the Cougar Mountain and Lower Callaghan Valley areas 10-20 times as likely to burn as the regions average. These areas are also of particular concern because fire events in the Whistler region are often driven by outflow wind events wherein dry air from an interior front can cause rapid fire spread southwest and down valley. Potential spotting from fire events on Cougar Mountain or even fire spread into the community itself from the lower Callaghan Valley pose a major concern and should drive management regimes focused on addressing local threats to homes, critical values, and evacuation routes.

Predicted Wildfire Threat under Different Climate Scenarios over 2041-2060 for the Cheakamus Community Forest (CCF) and Whistler Community



Wildfire threat was generated from thousands of iterations or fire seasons with the Monte-Carlo based simulation model BurnP3+. Threat aggregates burn probability, extreme wildfire rate of spread and extreme fire intensity to produce standardized scores. Threat was calculated under different climate scenarios using modeled datasets to predict the change in fire environment but ignitions are static and thus threat can be compared across scenarios. Modeled scenarios are for 2041-2060.

Figure 10: *Wildfire threat for 3 climate scenarios for Cheakamus Community Forest and Whistler Valley. Observed climate represents fire modeled under current (1990-2020) weather conditions (Left). Climate Scenario SSP1-2.6 represents the potential threat from modeled fire events over 2041 to 2060 given an optimistic climate change prediction of 2.6 watts per metre squared of forcing by 2100 (Middle). Climate Scenario SSP3-7.0 represents the potential threat from modeled fire events over 2041 to 2060 given a pessimistic and potentially catastrophic prediction of 7.0 watts per metre squared of forcing by 2100 (Right). Weather datasets for both modeled climate change scenarios were modified as mentioned above to predict potential changes to the fire environment from increased warming. All BurnP-3+ models were run with the same number of ignitions, iterations, and static inputs.*

Threat Mapping Results

Based on the analysis of burn probability mapping, threats to the CCF from wildfire follow similar patterns yet gain additional insights by including fire behaviour metrics like rate of spread and head fire intensity, as well as the potential risk to the valley under climate change (Figure 10). Unlike burn probability, threat mapping includes a combination of measures of burn probability while integrating standardized classes based on the 90th percentile value of head fire intensity and rate of spread. This calculation, for every cell on the landscape, involves calculating the 90th percentile value (both rate of spread and head fire intensity) of all the fires that burn in it. This approach, when coupled with burn probability, reveals not only where fires are more likely but also where they will be more dangerous, move faster, and remain harder to suppress. A threat score of moderate or high implies both higher relative burn probability and a greater propensity to support high intensity crown fires. From Figure 10, current threat to the CCF is primarily moderate to low which is unsurprising given Whistler valley's coastal fire regime and weather conditions. Southern facing slopes along Callaghan Valley and on Cougar Mountain have the highest potential wildfire threat, driven in part by dry aspects and potential rapid fire behaviour upslope. On the other hand, this slope orientation implies a low likelihood of fire spread which exceeds suppression capabilities, downslope and into Whistler communities, but risk of spotting is a concern depending on wind conditions. Under current conditions 24% of the landscape is classified as low risk, 69% is moderate and 7% is high (Figure 11). Despite these results, threats to the CCF increase dramatically with climate change. The valley's particular orientation and vicinity to the dry Interior Douglas-Fir zone of British Columbia make its potential future climate more variable than some of the more coastal regions of BC. That, coupled with the lack of the moderating effect of coastal weather patterns, means the Whistler valley is experiencing more rapid drying than other parts of the Coastal Western Hemlock zone in BC. This creates an increased concern for greater fire risk due to a couple of changes. Greater temperatures and lower relative humidity paired with increasingly variable precipitation increase fire season length, fire behaviour, potential fire spread, and the amount of fuel available to burn. All of these changes are reflected in the threat modeling results for both climate scenarios.

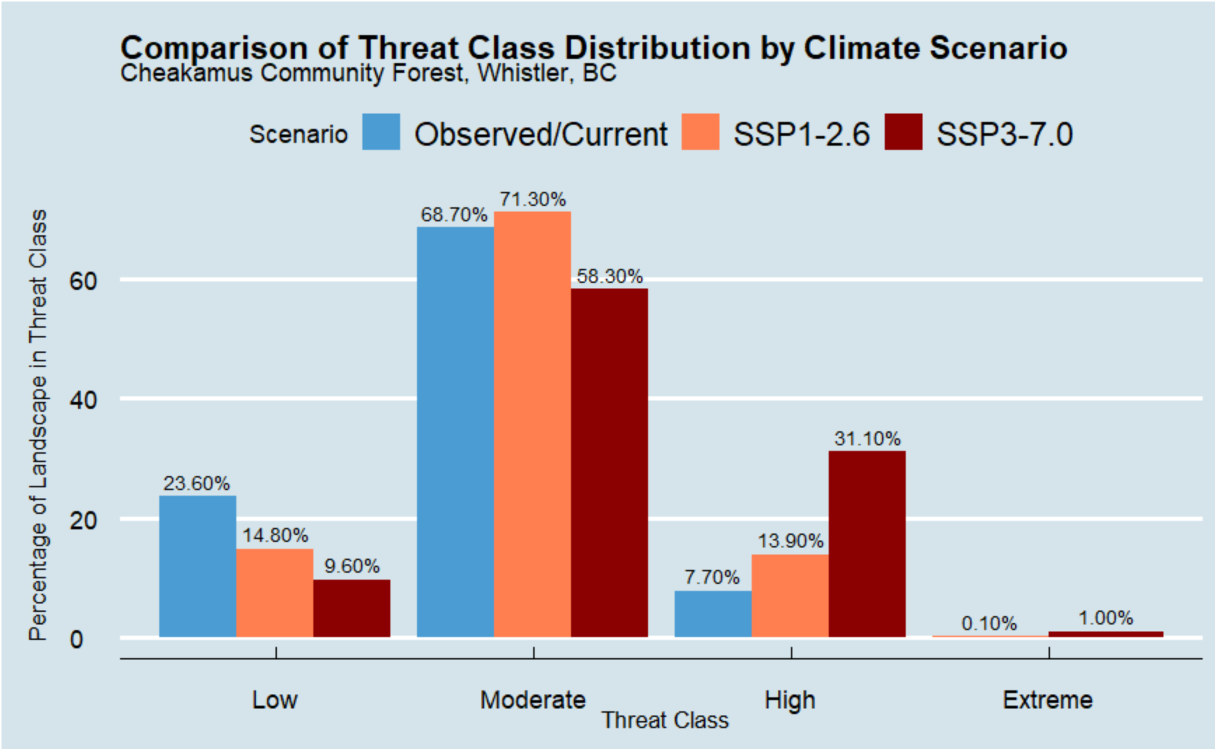


Figure 11: Comparison of threat class distribution by percentage of area occupying each class for the Cheakamus Community Forest and Whistler Valley AOI.

Scenario 1 SSP1-2.6 represents a rather optimistic take on humanity's potential to mitigate the progression and impact of climate change, yet even with that scenario threat to the Whistler Valley increases. The greatest proportionate change is from Moderate to High threat level with greater threat from wildfire along the Western side of the Callaghan Valley, the Southern slopes of Mt. Sproatt along the inlet to the Callaghan Valley and the region to the east of Brandywine above Daisy Lake. (Figure 10) Low threat regions declined to just 15% of the region while moderate threat increased to 71% of the area and high threat also increases dramatically, up to 14% (Figure 11). These increases in threat were driven in the model by increases in burn probability primarily, implying that larger and more dynamic fires have the potential to develop under climate change, particularly in regions that beforehand might have been considered safer, such as northern aspects.

This pattern is exacerbated under the pessimistic SSP3-7.0 Scenario wherein greater burn probability drives an increase in wildfire threat on western and eastern Callaghan Valley slopes and on southern facing slopes above the Rainbow and Wedge neighborhoods on Cougar Valley. (Figure 10) High threat areas increase the most under SSP3-7.0, jumping up to 31% of the landscape while both low and moderate threat percentages decline. Changes to burn probability from climate change are magnified in Callaghan Valley wherein maximum burn probability doubles from 2% to 4% under SSP1-2.6 but quadruples under SSP3-7.0 to over 8%. The same can be said for Cougar Mountain where burn probability under observed climate is 3% at maximum but increases to 5% under SSP1-2.6 and 8.5% under SSP3-7.0. Both these areas represent an elevated risk to the Whistler valley for both the threat of wildfire activity into the community itself and the potential to block off evacuation routes on the Sea to Sky highway in the event of an emergency. Spotting and spread potential into the community is high on the northern edge to due to propensity for dry southern wind events, but the increase in fire size and burn probability in Callaghan valley provides a major fire corridor (Figure 9).

Fireshed Analysis and Fire Corridors

The fireshed analysis revealed further dynamics and changes to wildfire threat for the Whistler Valley and Community Forest under climate change. Results from this method aggregate burn perimeters as a function of whether fire events burn into a region's community area of interest (AOI). For the community forest an AOI was delineated manually as a function of critical values, structures, and housing density. All burn perimeters which intersected this AOI were then extracted and merged to create respective firesheds for each climate scenario. Results from this analysis show expanding firesheds under both climate scenarios (Figure 12). The current or observed fireshed extends 72,000 hectares in a roughly triangular shaped region that covers most of the Whistler and Callaghan valleys. This should be considered the CCF's fireshed and thus its area of concern from both an emergency management and wildfire mitigation perspective. Under climate change the total fireshed areas increased dramatically for both scenarios, although its shape change depended on the scenario. SSP1-2.6 increased to 110,396 hectares while SSP3-7.0 increased to 110,770 hectares; representing a roughly 150% increase in fireshed area under both projections (Figure 13).

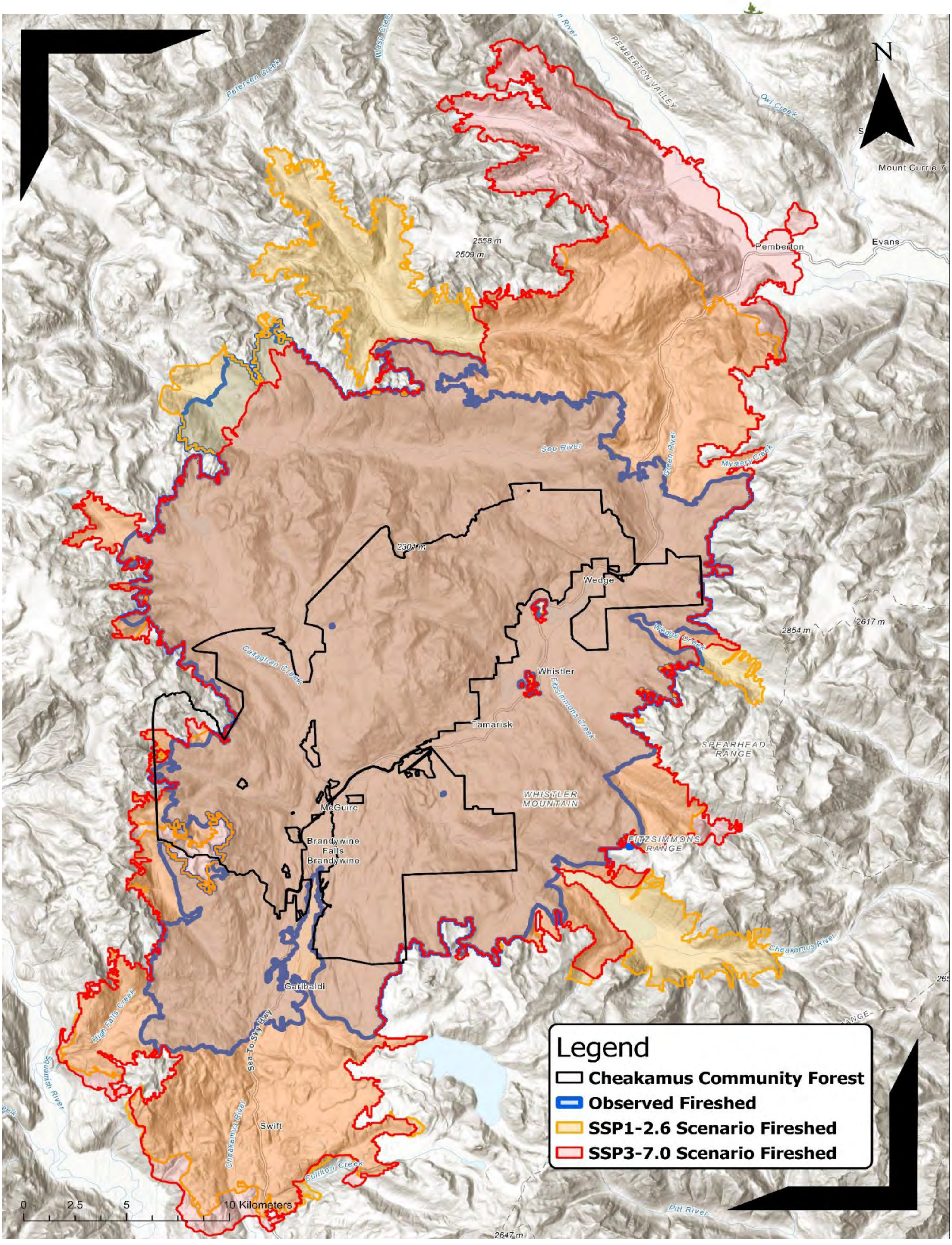


Figure 12: Modeled firesheds for each Burnp3+ scenario. Each fireshed was created with aggregated burn perimeters for all fire events that intersect community areas.

Despite the similarity in size, the shape of these firesheds also reveals cues as to the nature of climate induced changes to fire dynamics for the landscape. While SSP1-2.6 extends outward and north and southward in a much more proportionate spread, SSP3-7.0 fireshed extends northward more dramatically into the Pemberton valley implying faster moving fires driven by greater fire weather conditions which allow for more linear spread patterns. Larger wind driven and climate change fueled fire spread patterns are of increasing concern in the Whistler valley region with the 2015 Elaho fire being a prime example wherein strong southerly outflow breezes drove unprecedented wildfire spread of 11,500 hectares over a 12-hour period. Under future fire weather conditions, events of that magnitude may be more common and expand the area of concern for CCF mangers to include more northward and drier areas of the Pemberton valley.

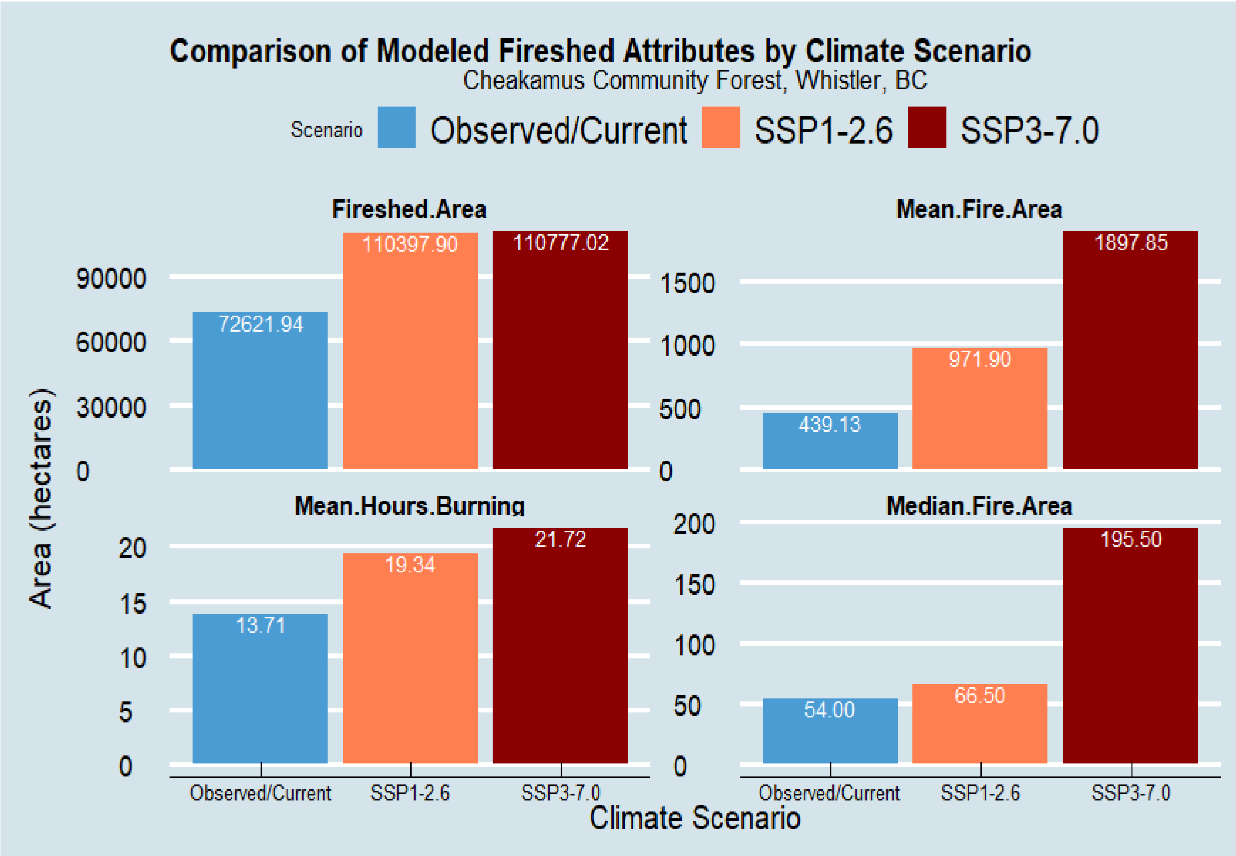


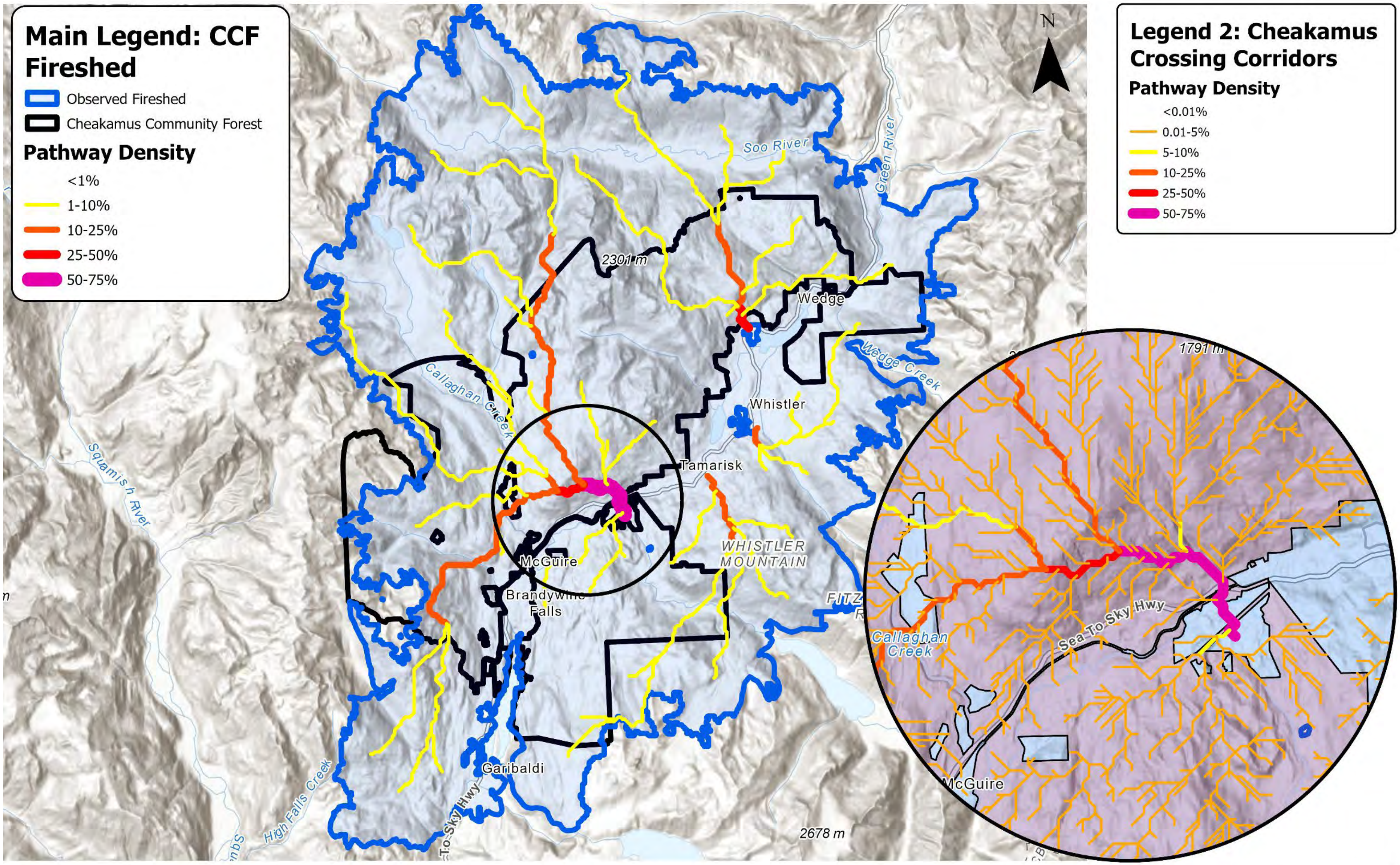
Figure 13: ***Fireshed summary statistic for all climate scenarios. Includes Fireshed total area in hectares (top left), mean fire area of fires in each fireshed (top right), mean hours burning of all fires in each fireshed (bottom left), and the median fire area for fires in each respective fireshed.***

Summary statistics for the fires included in the analysis reveal that fire size drove the large increase in fireshed area under climate change. Mean fire area increased over 200% from the Observed/Current scenario to SSP1-2.6 and over 400% under SSP3-7.0. (Figure 13) Likewise, median fire area, a more appropriate summary statistic for fire distributions, increased disproportionately the most under SSP3-7.0 up from 54 hectares (Observed/Current) to 195 hectares, whereas it only increased to 66 hectares under SSP1-2.6.

Despite this large increase, the jump in hours burning from SSP1-2.6 to SSP3-7.0 was only 2 hours implying that fires were not just burning longer but primarily burning more rapidly to explain the large increase in mean and median fire size between climate change scenarios. Rapid fire spread represents a potent threat to suppression capabilities and evacuation planning as it requires much quicker response and planning on behalf of fire management agencies. This increase in fireshed area and change in fire attributes demonstrates that not only does climate change exacerbate local conditions conducive to more extreme fire behaviour but that communities must concern themselves with fire events much farther afield than before.

Fireshed pathways and fire corridor analysis of 4 key community focus points revealed potential spread patterns for the fastest fires moving into the CCF and Whistler Valley communities. The decision to choose 4 key focus points was to sample enough of the community region to ensure the authors could capture potential spread patterns into any region of the populated section of whistler valley. These points alone do not represent an exhaustive list of threatened communities but instead allow us to interpret patterns of rapid fire spread. Pathways under the Observed conditions demonstrated diffused density with fires somewhat evenly spreading across the 4 community focus points but with greatest density of fire pathways into the Cheakamus crossing point of about 50% of fires intersecting that AOI (Figure 14). As mentioned, above the northern edge of the valley along with the Rainbow and Wedge communities represent another area of increased risk as the second highest density of fire spread pathways, as well as increased potential spotting risk.

Predicted Firesheds and Fire Spread Corridors under Observed/Current Weather for selected neighborhoods in the Cheakamus Community Forest (CCF) and Whistler Valley



Firesheds are generated from thousands of iterations of Monte Carlo based simulation model BurnP3+ under respective weather scenarios and bound all fires which burn the CCF AOI. Fire pathways are then generated as weighted spread patterns of fires seeded in every cell within the fireshed. Pathways are generated from those cells to the closest focus points located at Cheakamus Crossing, Creekside Base, Whistler Centre, and Rainbow Neighborhood using a least cost distance algorithm based on focal statistics. Pathways are aggregated to form fire spread corridors for density analysis and represent the potential spread vectors of fires into the community.

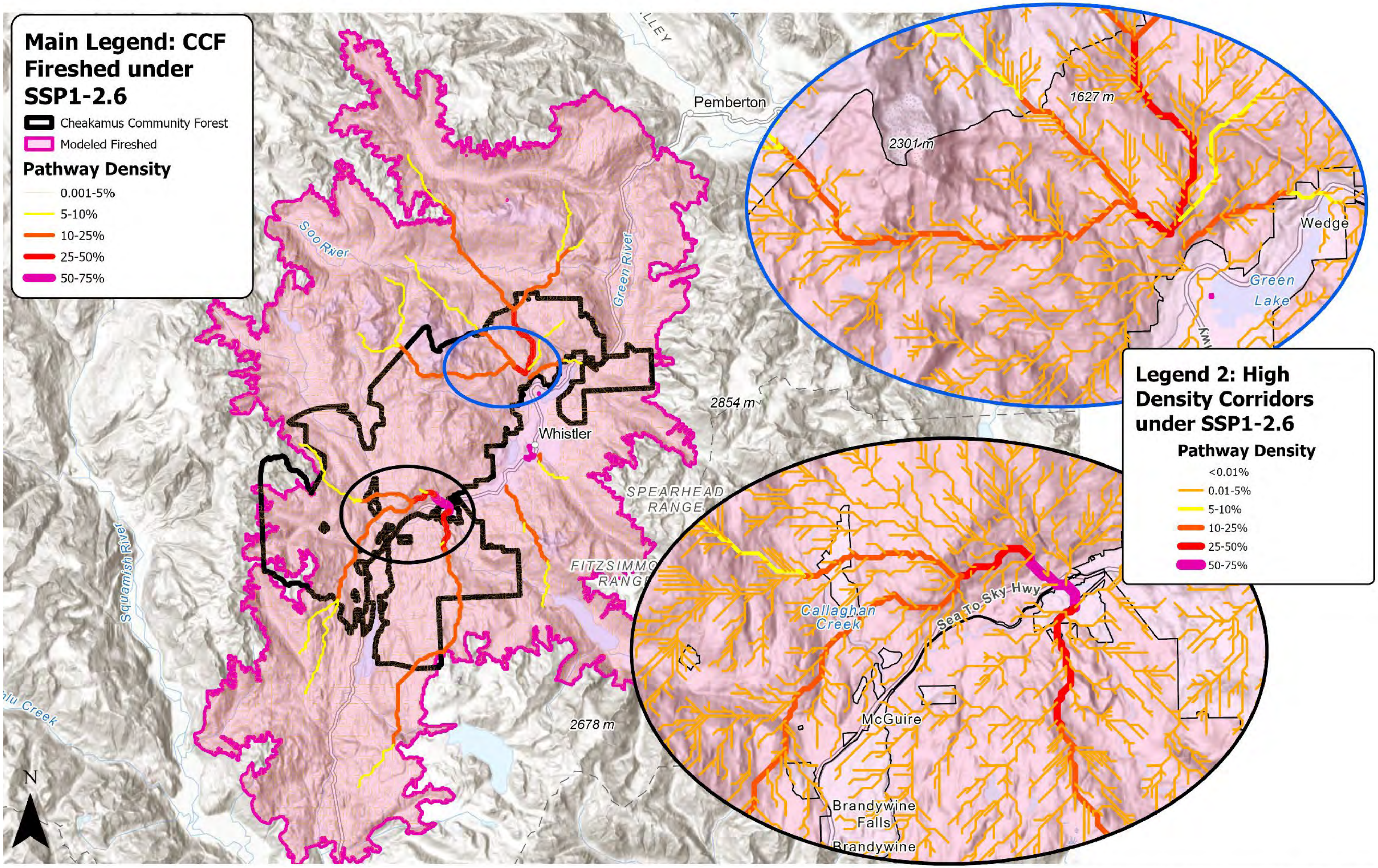
Figure 14: Predicted Firesheds and Fire Spread Corridors under Observed/Current Weather for selected neighborhoods in the Cheakamus Community Forest (CCF) and Whistler Valley.

Fire corridors under SSP1-2.6 revealed a more binary distribution of fire pathways, with a greater proportion of fire spread patterns intersecting mainly the southern community focus point of Cheakamus crossing and a somewhat less minority to the northern point of Rainbow/Wedge neighborhoods.(Figure 15) Fires spreading into either Whistler Centre or Creekside Centre made up less than 20% of total fire pathways, with the large majority intersecting the other two focus points. This outcome was largely driven by greater burn probability north of Green Lake and along the inlet of the Callaghan Valley which means ignitions were much more likely to travel to the Rainbow/Wedge communities or Cheakamus crossing point than to either Whistler or Creekside.

Corridors under the extreme scenario SSP3-7.0 reflected a widening of this trend. (Figure 16) Absolute change in pathway density between this scenario and SSP1-2.6 did not change as dramatically as between the observed conditions and both climate change scenarios. This was in part due to the relative similarity in fireshed area between both climate change scenarios, despite the change in the shape and arrangement of the fireshed. The authors found that greater ignitions north of the CCF, driven by an expanded fireshed and larger fire sizes meant that distributions of pathways were more evenly split between Rainbow/Wedge and Cheakamus crossing. As well, the expanded north and southward fireshed shape allowed for ignitions farther in those directions, which tend to travel up and down valley, to be included in the analysis, thus biasing the southern and northern points rather than the Whistler and Creekside centres.

Pathway and corridor analysis under all scenarios reveal the largest threats to CCF and Whistler valley communities remain from northward moving fires and those initiating in the Callaghan canyon or from southward moving fires initiating on in the Cougar Mountain region with particular concern for fast moving fires and spotting during outflow wind events. Flammable C-3 fuels coupled with favorable slopes represent an extreme fire risk to the CCF and provide for consistent spread corridors which threaten critical values and Whistler communities. While fire spread downslope on northern slopes of the valley is lower risk, risk of spotting from firebrands in those conditions would still be elevated and mitigation techniques to address that should be employed.

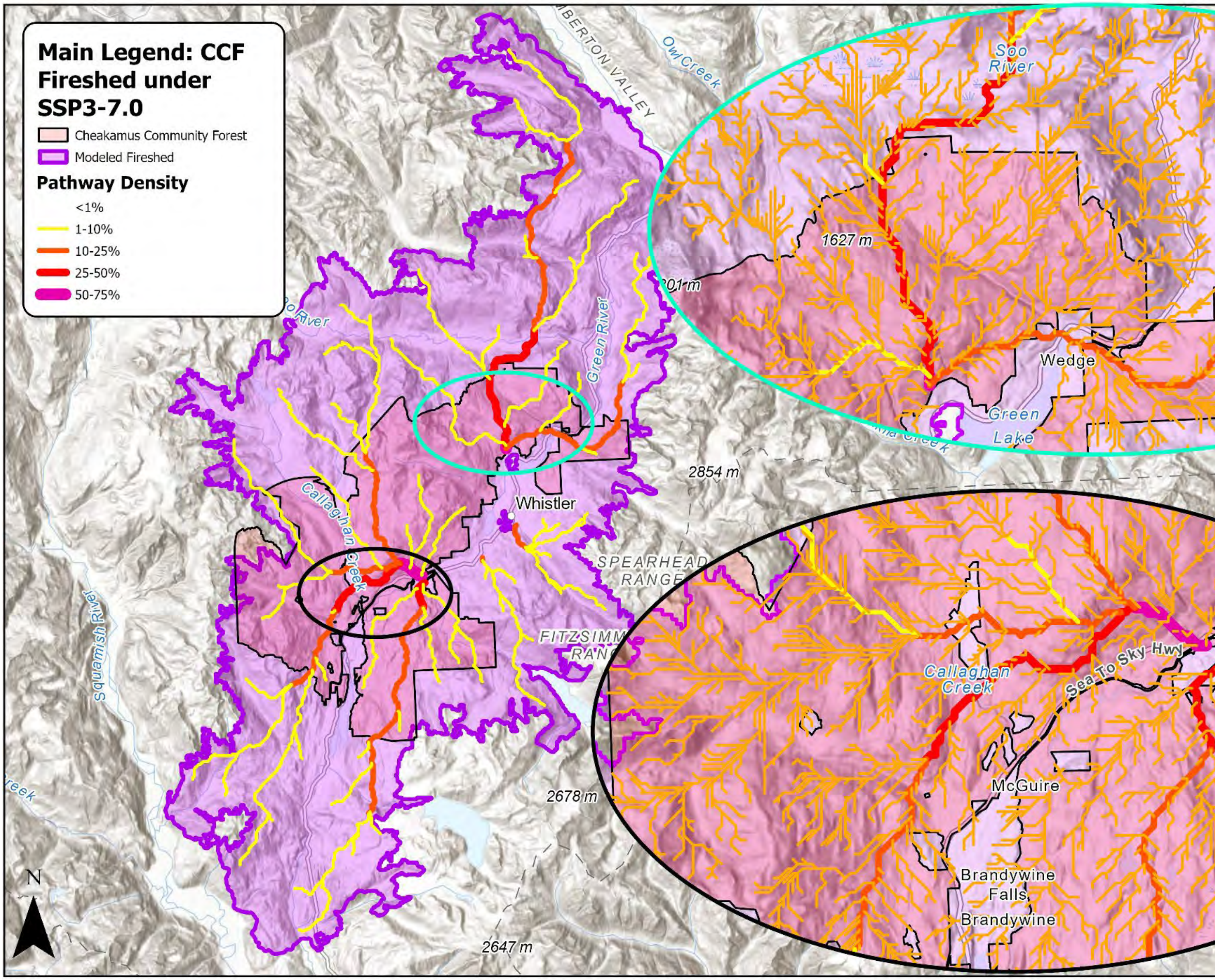
Predicted Firesheds and Fire Spread Corridors under Climate Scenario SSP1-2.6 over 2041-2060 for selected neighborhoods in the Cheakamus Community Forest (CCF) and Whistler Valley



Firesheds are generated from thousands of iterations of Monte Carlo based simulation model BurnP3+ under the modeled weather scenario and bound all fires which burn the CCF AOI. Fire pathways are then generated as weighted spread patterns of fires seeded in every cell within the fireshed. Pathways are generated from those cells to the closest focus points located at Cheakamus Crossing, Creekside Base, Whistler Centre, and Rainbow Neighborhood using a least cost distance algorithm based on maximum fire spread. Pathways are aggregated to form fire spread corridors for density analysis and represent the potential spread vectors of fires into the community under climate change.

Figure 15: Predicted Firesheds and Fire Spread Corridors under Climate Scenario SSP1-2.6 over 2041-2060 for selected neighborhoods in the Cheakamus Community Forest (CCF) and Whistler Valley.

Predicted Firesheds and Fire Spread Corridors under Climate Scenario SSP3-7.0 over 2041-2060 for selected neighborhoods in the Cheakamus Community Forest (CCF) and Whistler Valley



Firesheds are generated from thousands of iterations of Monte Carlo based simulation model BurnP3+ under the modeled weather scenario and bound all fires which burn the CCF AOI. Fire pathways are then generated as weighted spread patterns of fires seeded in every cell within the fireshed. Pathways are generated from those cells to the closest focus points located at Cheakamus Crossing, Creekside Base, Whistler Centre, and Rainbow Neighborhood using a least cost distance algorithm based on maximum fire spread. Pathways are aggregated to form fire spread corridors for density analysis and represent the potential spread vectors of fires into the community under climate change.

Figure 16: Predicted Firesheds and Fire Spread Corridors under Climate Scenario SSP3-7.0 over 2041-2060 for selected neighborhoods in the Cheakamus Community Forest (CCF) and Whistler Valley.

TREE STRESS & MORTALITY

The first related step for this impact, as outlined in the methods, was to stratify the CCF landscape by forest ecological units.

The TEM analysis produced the following map and area (ha) proportion information found in Figure 17. From this, the authors then produced an ecological grouping map of three groups (zonal, drier, and wet strata) and area (ha) proportion information found in Figure 18.

The ultimate goal of this work was to produce a map dataset that can be used in the future operational mapping exercise. Figure 19 indicates which group overlap ‘Ancient Forest’ and ‘Old Forest’ classes within the CCF. Pie charts depicting these areas (ha) are illustrated below Figure 19.

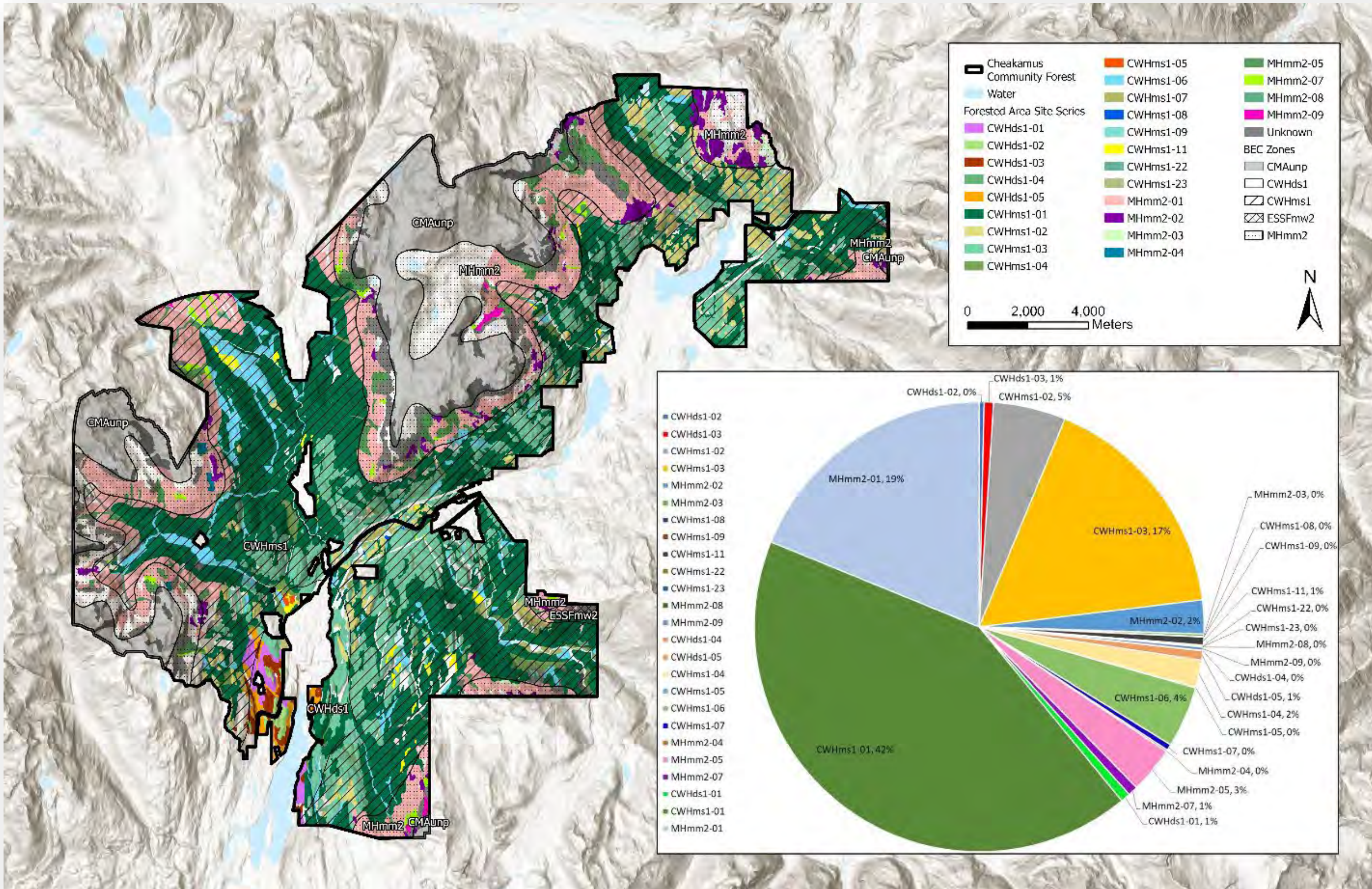


Figure 17: Forest site series from TEM within the CCF.

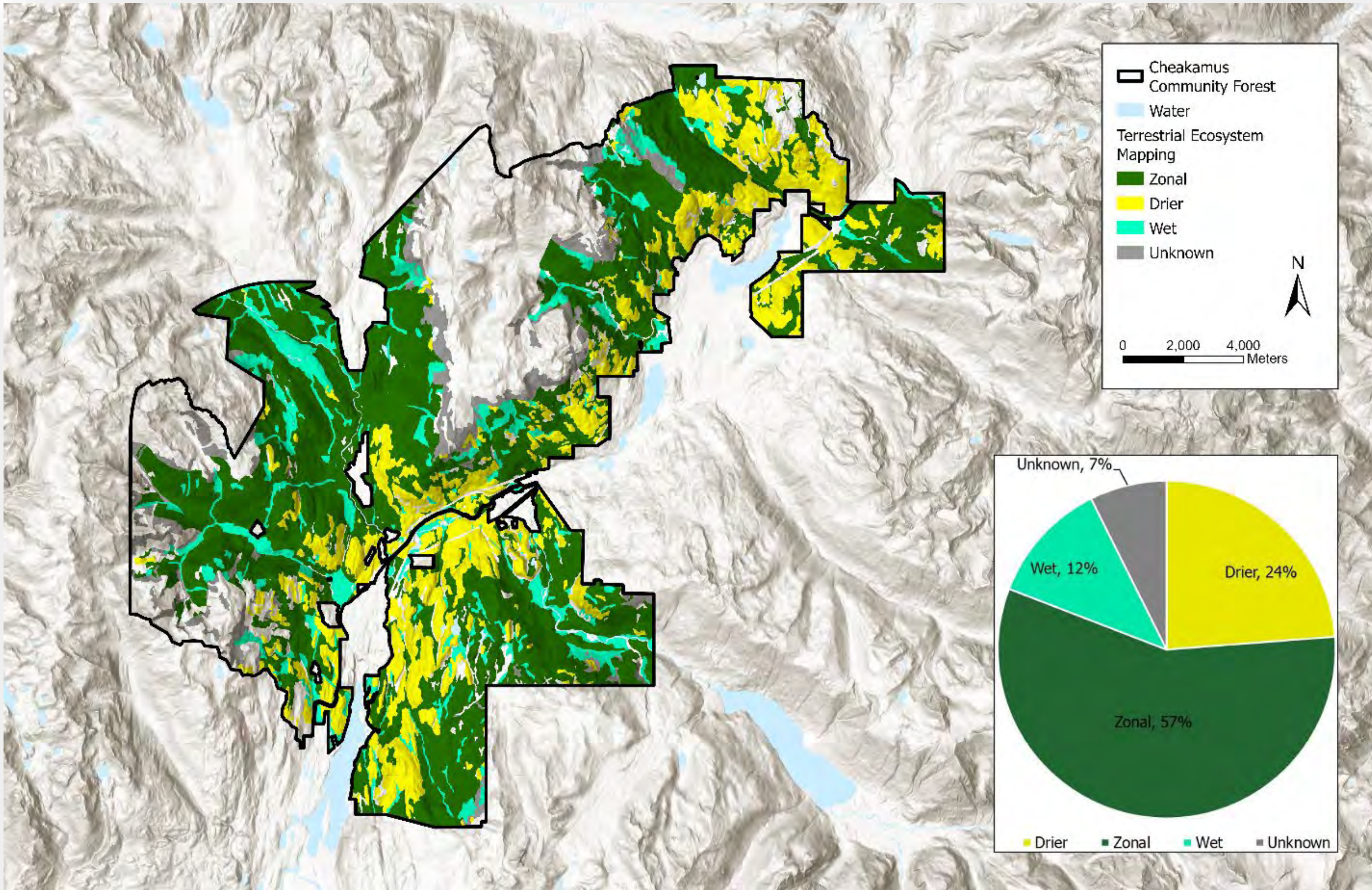


Figure 18: Forest ecological groups

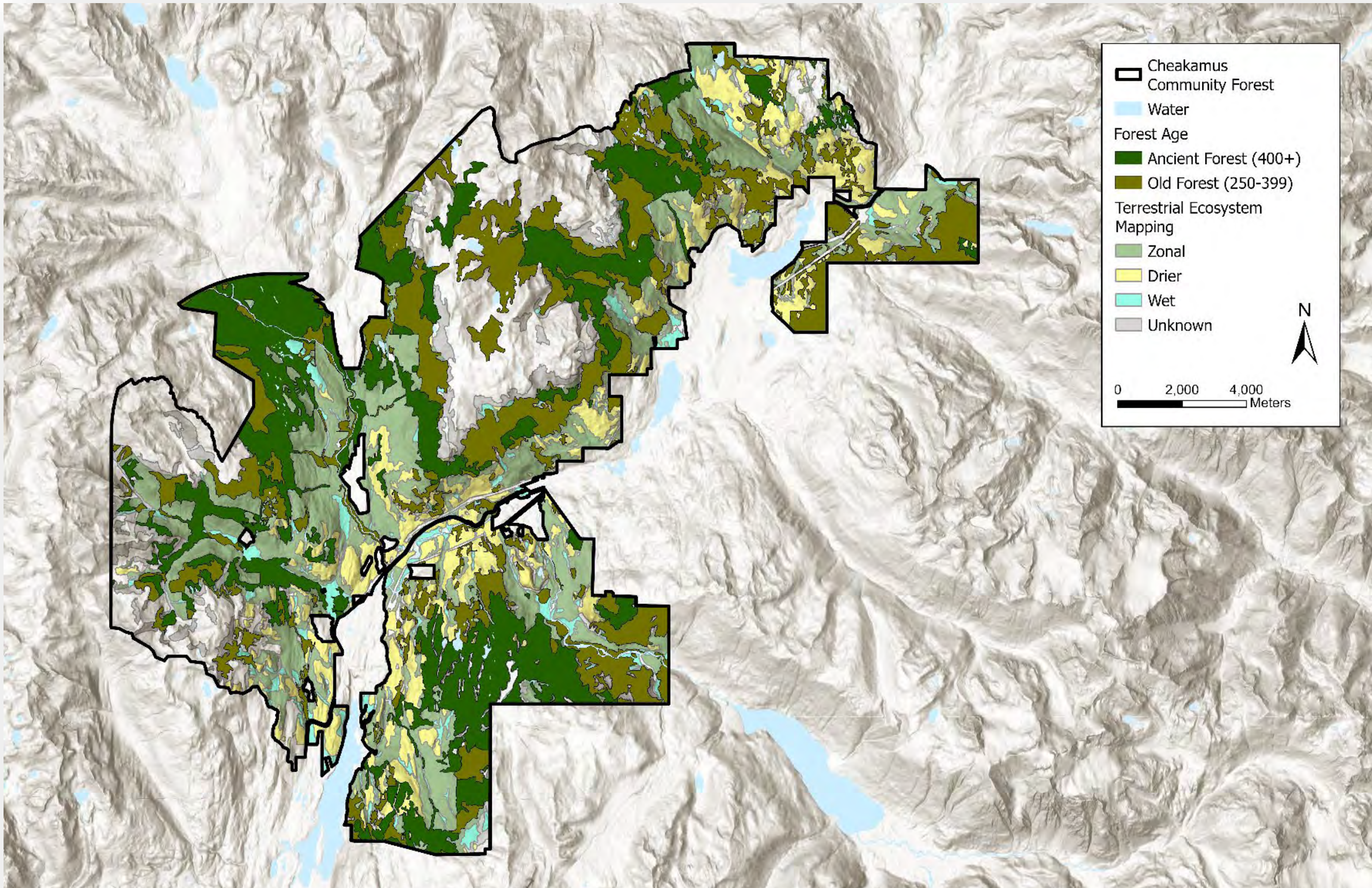
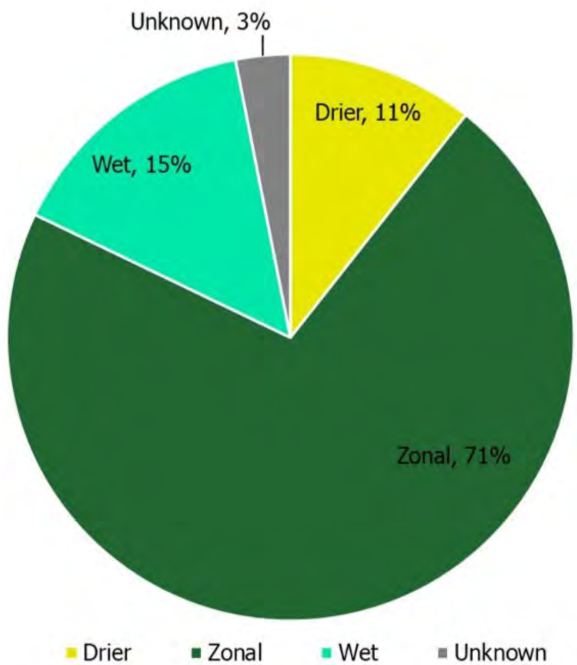
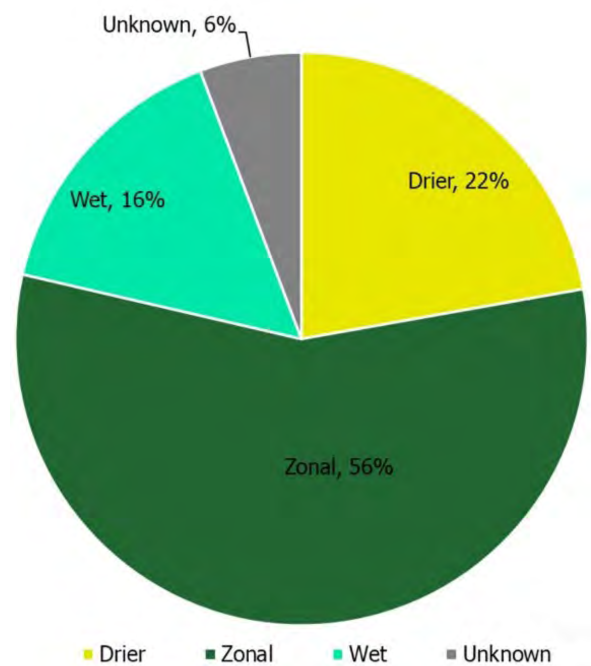


Figure 19: Grouping and forest age classes 'Ancient Forest' and 'Old Forest'.



(From above Figure 19: Proportion of groupings overlapping 'Ancient forests'



From above Figure 19: Proportion of groupings overlapping 'old forests'

The authors produced CCISS BGC outputs for two timeframes: 2000-2021 and 2021-2040 (Figure 20). These are projections of Version 13 BGCs using the algorithms within the CCISS tool.

In addition to using the BGC projection tool, the authors also utilized the CCISS climate species suitability tool. For this tool, the authors simply used a time series projection of 2021-2040 and four common Whistler tree species:

- Western red cedar (Figure 21),
- Douglas-fir (Figure 22),
- Western hemlock (Figure 23), and
- Subalpine fir (Figure 24).

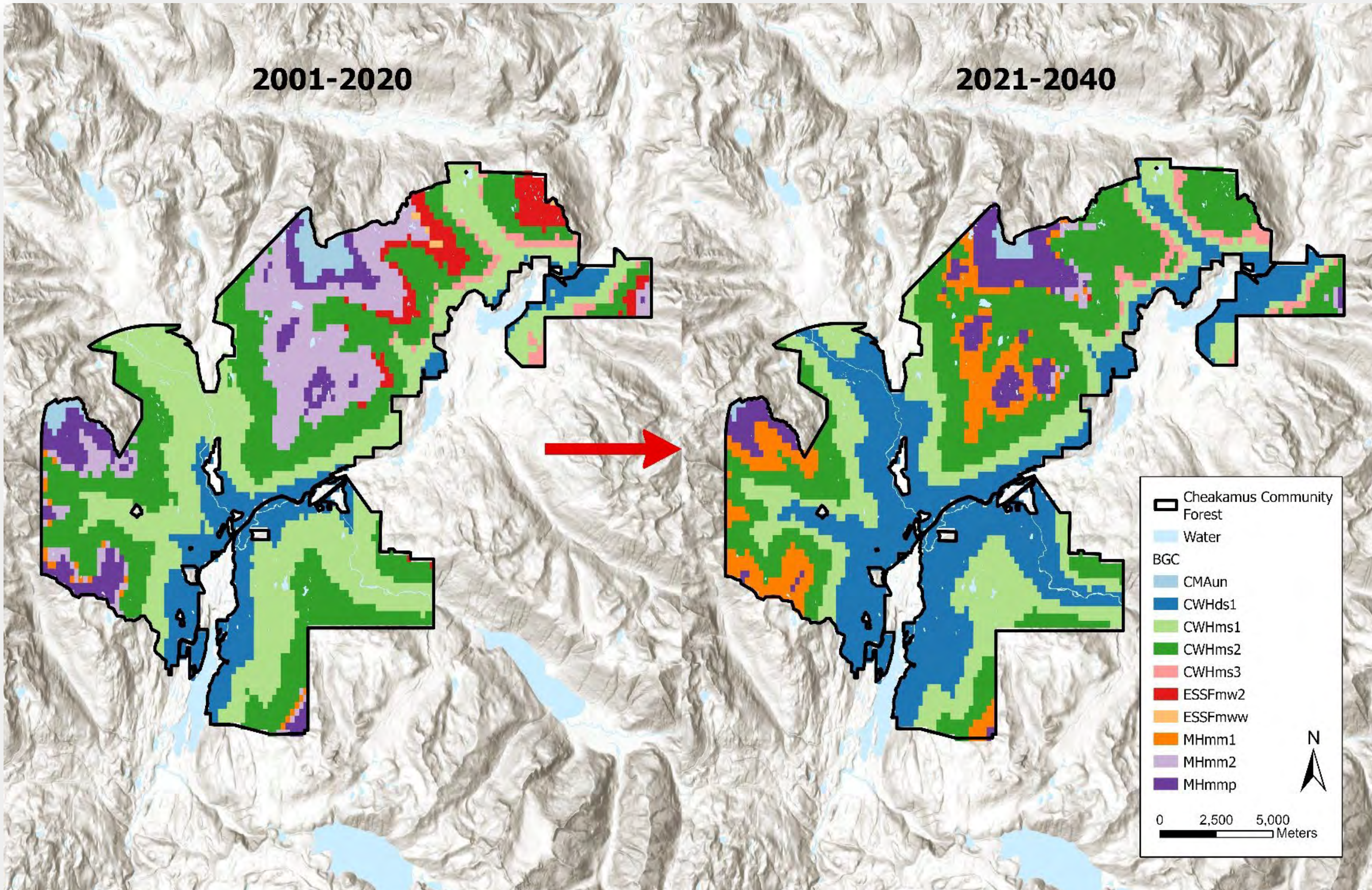


Figure 20: Model predictions of BGC changes.

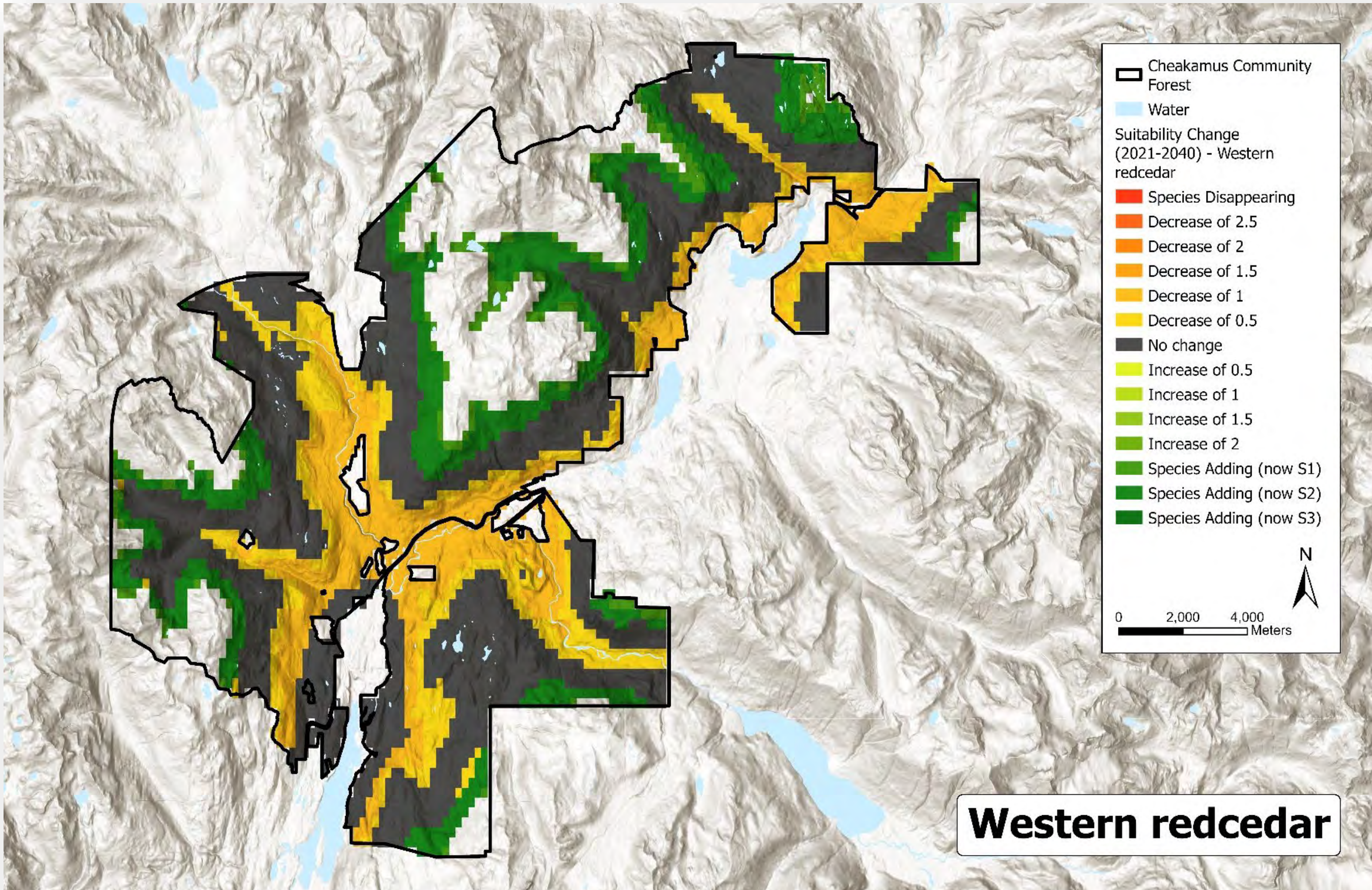


Figure 21: Projected suitability change (2021-2040) of Western redcedar.

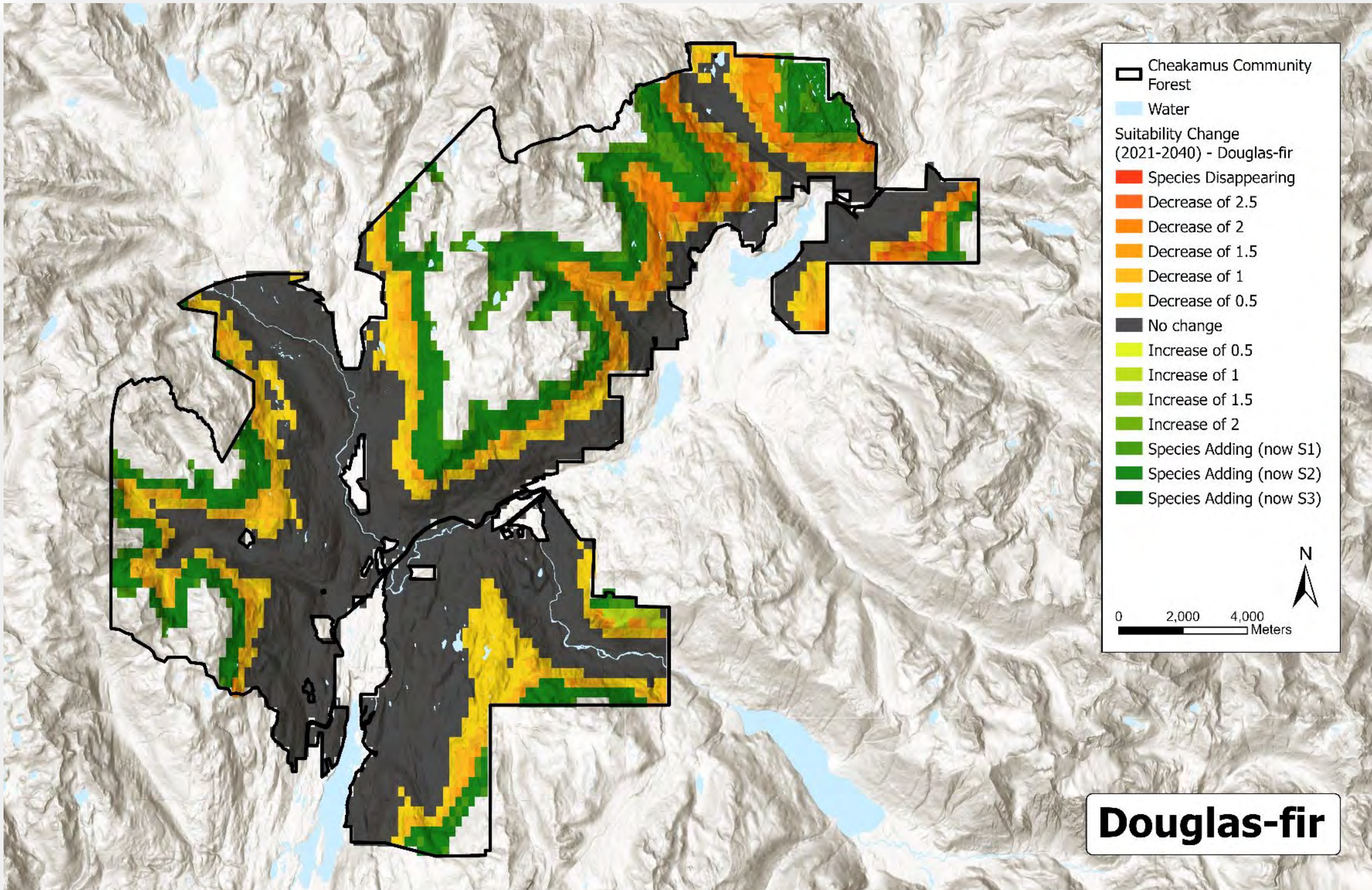


Figure 22: Projected suitability change (2021-2040) of Douglas-fir.

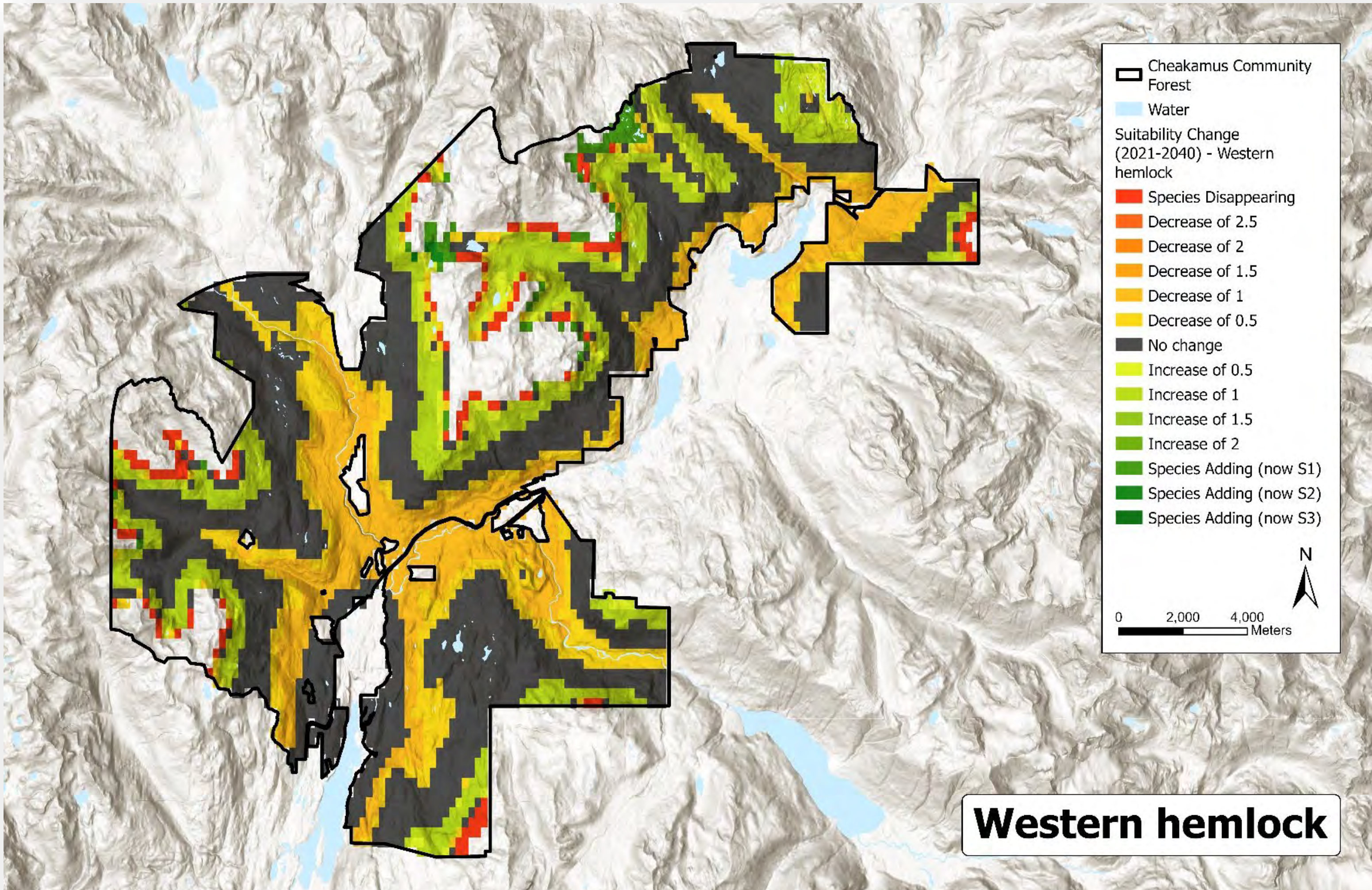


Figure 23: Projected suitability change (2021-2040) of Western hemlock.

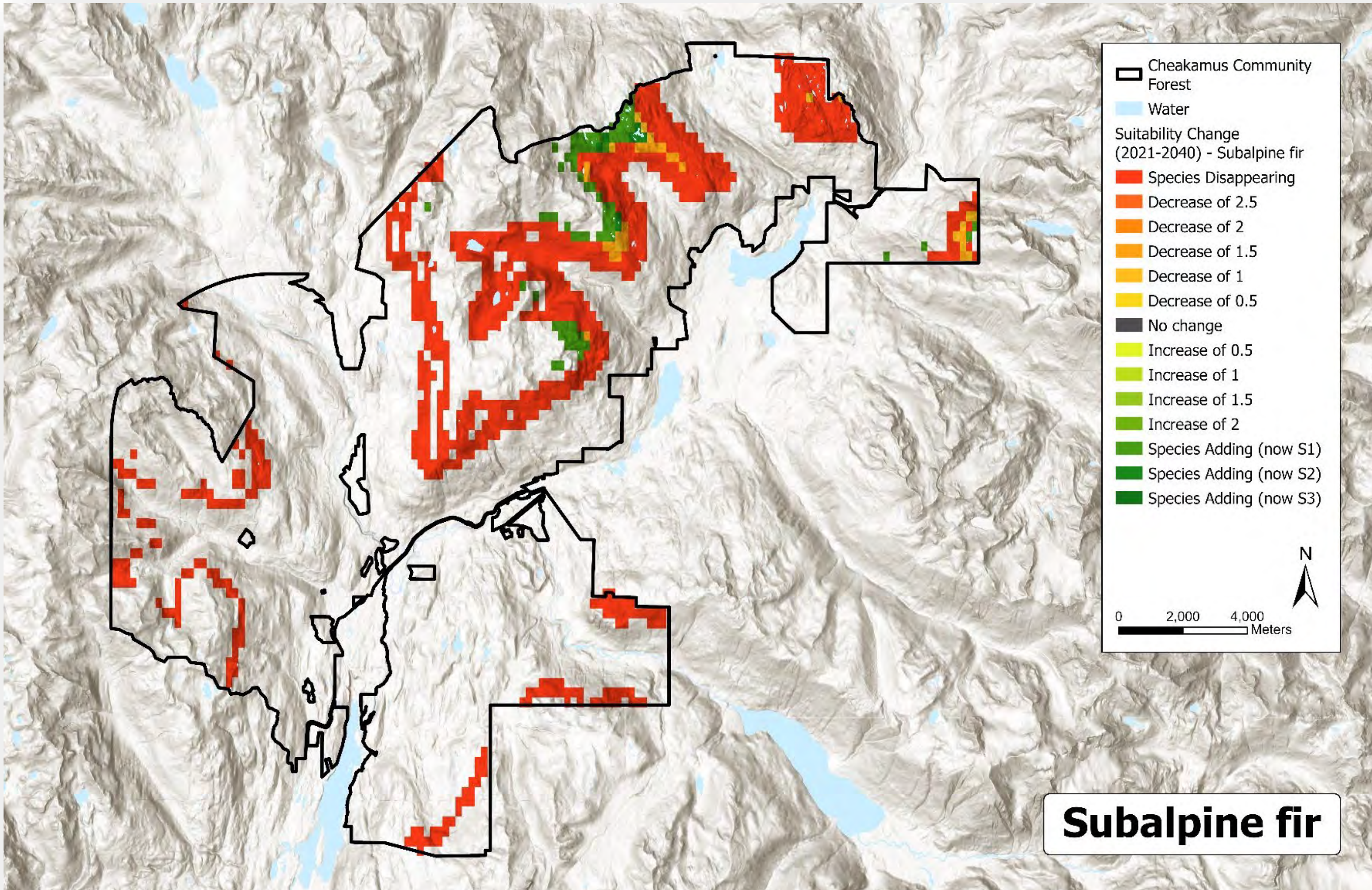


Figure 24: Projected suitability change (2021-2040) of Subalpine fir.

FOREST HEALTH IMPACTS

Historically, the Coast has not been affected to the same degree by forest health compared to the rest of the province. Within the Coast Area, some of the largest forest health impacts have been in the Coast-Interior transition area. Climate change is having a growing effect on forest health and will be a major driver when it comes to forest health in the future. The most visible immediate impacts are the increase in fires and drought mapped in the AOS. The CCF and surroundings areas are located within the Soo TSA of the MOF's Sea to Sky District. The following forest health factors were identified to be historical threats to local forests within the CWHms1 BEC variant:

- Dothistroma Needle Blight,
- Hemlock Dwarf Mistletoe,
- Armillaria,
- Rhizina Root Disease,
- White Pine Blister Rust,
- Swiss Needle cast,
- Douglas-fir Beetle,
- Western Spruce Budworm,
- Spruce Terminal Weevil, and
- Mountain Pine Beetle.

Of particular concern in the Whistler area includes bark beetles such as Douglas-fir beetle following fire and wind, increased drought mortality of trees with root disease (Armillaria), tree declines, and increases in secondary insects and disease following periods of drought. Of additional note is growing and spreading Swiss needle cast which has not appeared in the Whistler Valley but is growing in incidence in the Coastal region.

The Whistler area is currently experiencing a significant Western Spruce Budworm attack. Given it is an immediate issue, the authors decided to complete a full assessment, historical analysis, and recommendation report. This can be found in Appendix A: Western Spruce Budworm Report.

DISCUSSION

This section touches on various overall findings from each risk assessment section and highlights particular findings of note.

WILDFIRE IMPACTS

Burn Probability, Threat Mapping, and fireshed analysis reveal that the wildfire impacts to the CCF and Whistler Valley region give cause for concern. Current and historical weather conditions create fire regimes which include many small fires with relatively low burn probability across the landscape but the size and potential damage from large disruptive events, while rare, means the risk is too great to avoid mitigation. On top of the current threat, the analysis of the potential future fire regimes produced under climate change scenarios reveal increasing wildfire threat under even the most optimistic SSP scenario, SSP1-2.6, implying increasing aridity and precipitation variability will exacerbate the wildfire threat. Modeled burn probability and threat mapping reveal key risk areas in the southern CCF near the entrance to the Callaghan valley and to the north of CCF by Cougar Mountain above Green Lake. Risk of wildfire spread into the community is elevated in the south while spotting is the greater concern to the north.

The approach characterized potential changes to burn patterns for this region did not account for fuel type changes or changes to patterns of ignitions which could introduce greater variability to effects of climate change of wildfire threat. Pathway and corridor analysis under all scenarios reveal the largest threats to CCF and Whistler valley communities are and will be from the north and eastward moving fires near the Callaghan Valley and southwest moving fires from the Rainbow/Cougar Mountain region.

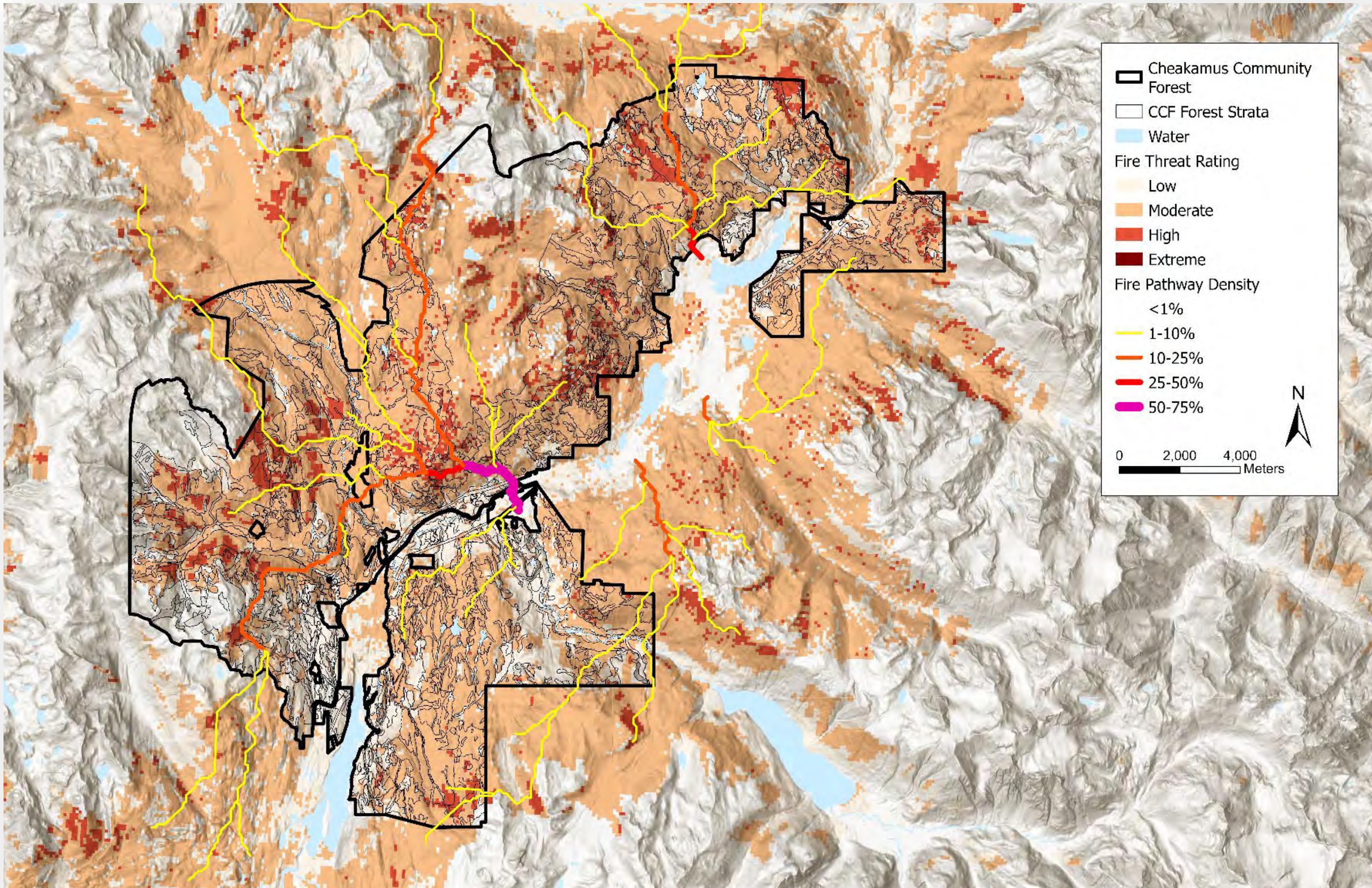


Figure 25: Fire pathway density and fire threat map.

TREE STRESS AND MORTALITY IMPACTS

Tree stress and mortality impacts are complex and will require more work and discussion with the project team. Furthermore, the MOF Forest Ecology team will be coming out with a Version 13 BEC system in the spring of 2025 which will assist in overall better understanding of the CCISS results presented within this report.

Initial findings of changes projected up until 2040 indicate the following in the CCF's most dominant BGCs:

- A significant increase in area and likelihood that climate change will benefit (expand) the CWHds1[30] (from 12% to 32%, as longer, hotter, drier weather patterns emerge,
- A reduction in size (and thus likely stress and tree mortality) within CWHms1 (from 31% to 22%), and
- A relatively stable (neutral) state for CWHms2 (from 29% to 28%).

For individual tree species (Figure 21- Figure 24) the following overall results were determined:

- Western red cedar appears to be declining at a relatively moderate rate according to the CCISS 'suitability change metric' (decrease of ~1.5) at lower elevations and neutral mid slope (when compared to the other three tree species). Potential expansion on upper slopes.
- Douglas-fir appears to be neutral on the lower and mid slopes, a band on upper midslopes that is in some decline and then an expansion upper slope.
- Hw appears to be declining appears to be declining at a relatively moderate rate according to the CCISS 'suitability change metric' (decrease of ~1.5) with mid slopes neutral and some expansion at upper slopes.
    - Some localized disappearance at highest elevation slopes.
- Subalpine fir exists on upper slopes and it appears to disappear almost entirely from the CCF landscape.

One important question relates to whether or not 'Ancient Forests' and 'Old Forests' will be more or less resistant to climate change than younger forests. In order to delve into this question specifically, the authors researched this question separately. The overall findings and conclusions from this research are outlined in Appendix C: PNW Old Growth Forests & Climate Change.

[30] *This was mapped using BEC V13 – a forthcoming BEC V13 references along with a Vancouver Forest District Land Management Handbook forthcoming in spring/summer 2025.*

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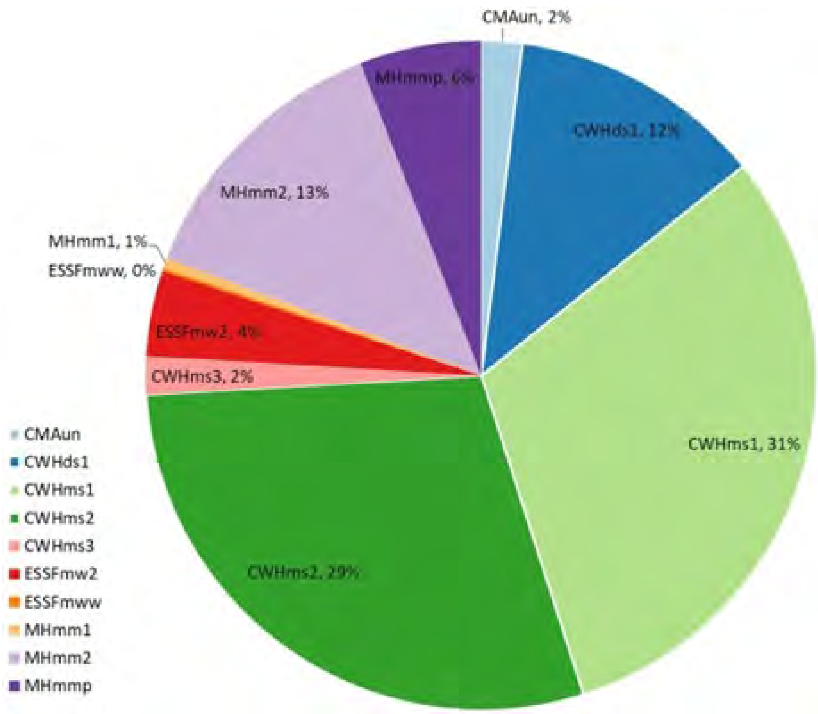
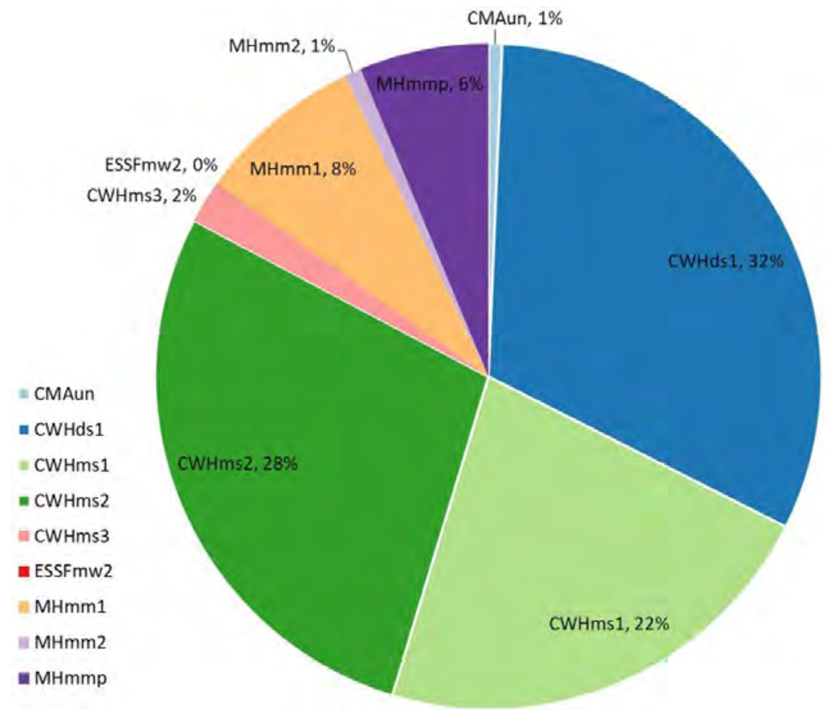


From Figure 20: 2000-2021



From Figure 20: 2021-2040

Figure 26: CCISS tool outputs for CCF BGCs.

NEXT STEPS

It is recommended that the risk assessment findings be used to develop a forest management operational plan as the next phase of the CCF's climate resilience program. These risk findings can be used as a foundation in determining management recommendations for the stratification outputs developed within this report. There are three broad management options for responding to and adapting to climate change (Figure 26). More detail regarding each type of management option is further provided in Table 4.

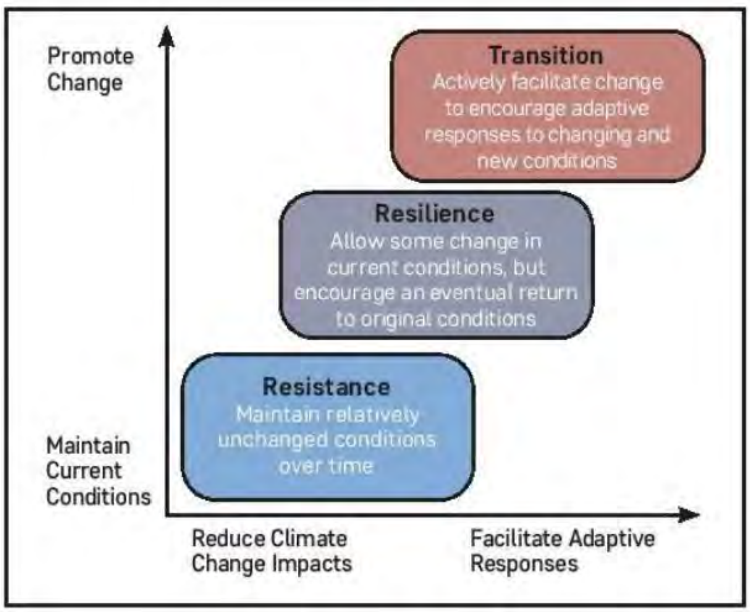


FIGURE 2. *Adaptation options, from Nagel et al 2017.*[7]

Figure 26: Resistance, resilience and transition concepts in graphic format.

Table 4. Adaptation Management options and some examples.

Table 1. Adaptation Options (adapted from Nagel 2017)

Adaptation Strategy	Definition	Operation Treatment Examples
RESISTANCE	Act defensively to maintain current conditions and resist undesirable change	Locate landscape-level fuel breaks, protect rare habitats
RESILIENCE	Accommodate some change and promote resilience	Thin to lower stand densities, diversify forest structure
TRANSITION	Current stand conditions are incompatible with future changes	Convert maladapted stands, introduce new species

APPENDIX A: WESTERN SPRUCE BUDWORM REPORT

INTRODUCTION

In BC, The Western Spruce Budworm (WSB) is an early-season defoliator that partially or entirely consumes flushing foliage and new buds, causing the remaining needles to redden (Maclauchlan et al., 2018). WSB's primary food source is Douglas-fir, but the insect can also feed on true firs, Engelmann spruce and western larch (Senf et al., 2017). Successive seasons of defoliation events can cause mortality in stressed trees, though unlikely with healthy overstory trees; however, insects will still impact tree growth during years of heavy defoliation (Nealis & Régnière, 2009).

LIFE CYCLE OF WSB

In the month of August, the WSB lays overlapping eggs on the underside of needles, this laying formation resembles the appearance of fish scales (Figure 29). Within two weeks, insects hatch and move to sheltered locations on host trees to establish a hibernaculum. They then moult to a second instar and await the spring in diapause, a period of suspended development, during which metabolic activity is significantly reduced (Nealis & Régnière, 2009). In BC, WSB generally emerge from diapause in May, approximately 2–3 weeks before the budburst of Douglas-fir needles (Figure 31). A delayed synchrony of 18-day days between larvae emergence and budburst is considered optimal for outbreaks. The larvae then proceed to disperse (level of dispersal dependent on several factors including host trees food availability and population density) on the wind via fine silken threads. They create feeding shelters and initially feed on last year's needles. Once the bud scales thin enough, the larvae penetrate and consume the newly emerging foliage. They continue to feed passing through several instars, the developmental stages between moults (Figure 28), to reach the 6th or 7th in early to mid-July when they metamorphose into pupae. Two weeks later, they emerge as moths to disperse (Figure 30). WSB can disperse several kilometers in flight (National Resources Canada, 2024) and potentially much further in strong winds. They then lay their eggs and restart the above-described life cycle (Figure 27) (B.C Ministry of Forests, n.d.)

RISK OF DISPERSAL

WSB suffers significant losses during the early larval stages between the emergence from diapause and the budburst, when, dependent on several factors, varying numbers of budworms disperse on silken threads in the wind to find feeding sites (B.C Ministry of Forests, n.d.; Nealis, 2003). Factors that increase dispersal include high larval populations, reduced resources from previous years feeding, and poorly timed emergence, which results in buds not being ready for mining. These increased levels of dispersal increase the impact from predators or inability to find a feeding site which can result in significant mortality events.

CLIMATE AND WEATHER

WSB emergence from diapause is synchronized with weather conditions and the timing of budburst. A mismatch between these events can significantly impact population density (Nealis, 2012) and 18 days pre bud burst is considered optimal (Srivastava et al., 2024; Thomson & Benton, 2011). Heavy rainfall or frosts during migration, either to a winter shelter to enter diapause, or after diapause to feeding sites, can either dislodge the WSB leading to an inability to feed, or freeze them, both leading to mortality.

HISTORIC RANGE AND CLIMATE CHANGE

Historically defoliation events in B.C. were equally as likely in BC's Coastal versus the Interior since records of WSB started in 1909 (B.C. Ministry of Forests, n.d.). This shifted in the 1970s when the geographic range of outbreak level occurrences transitioned towards the colder drier Interior (Campbell et al., 2005; Maclauchlan et al., 2018). They did not, however, disappear from the Coastal region, as they are endemic, but rather the conditions weren't optimal for an outbreak. Climate is considered a significant factor in the emergence of outbreaks due to the importance of delayed synchrony of the emergence of the larva and the budburst in spring. Thomson and Benton (2011) proposed that the disappearance of outbreaks on Southern Vancouver Island in the early 20th century was caused by rising sea temperatures, which increased average winter air temperatures. This change caused a break in delayed synchrony between WSB emergence from diapause and the budburst of Douglas-fir. Insect populations have also been shown to fluctuate with the cycles of global climate oscillations like the ENSO cycle (Bai et al., 2021).

HISTORICAL OUTBREAKS IN THE WHISTLER AREA

Fluctuations in outbreaks for Coastal BC already described generally characterize the last fifty years of outbreak in the Whistler area. Figure 32 shows the decadal WSB extent from 1967-2020. This shows a serious outbreak in the 1970s. 1981-2000 shows very little in the area. The 2000's sees some spotting of WSB emergence. The 2010's shows little WSB activity.

CURRENT WHISTLER WSB OUTBREAK

2022 saw some WSB appearance north of Pemberton (Figure 33), 2023 WSB spread back into the Whistler area (Figure 34), with a dramatic increase in 2024 (Figure 35). In recent years, WSB outbreaks have primarily been observed in the lower BC Interior. However, in an experiment by V. Nealis (2012), the fitness of the final instars was compared across Coastal regions and Interior locations of different altitudes. The study found that larvae at Coastal locations exhibited the highest fitness levels. Among interior populations, those at higher altitudes fared better than those at lower altitudes.

WHISTLER AREA WSB PREDICTIONS

Figure 37 show the predictions from a decadal model for 2040 (Srivastava et al., 2024). The model from which can be adapted for yearly output with some investment of time and resources.

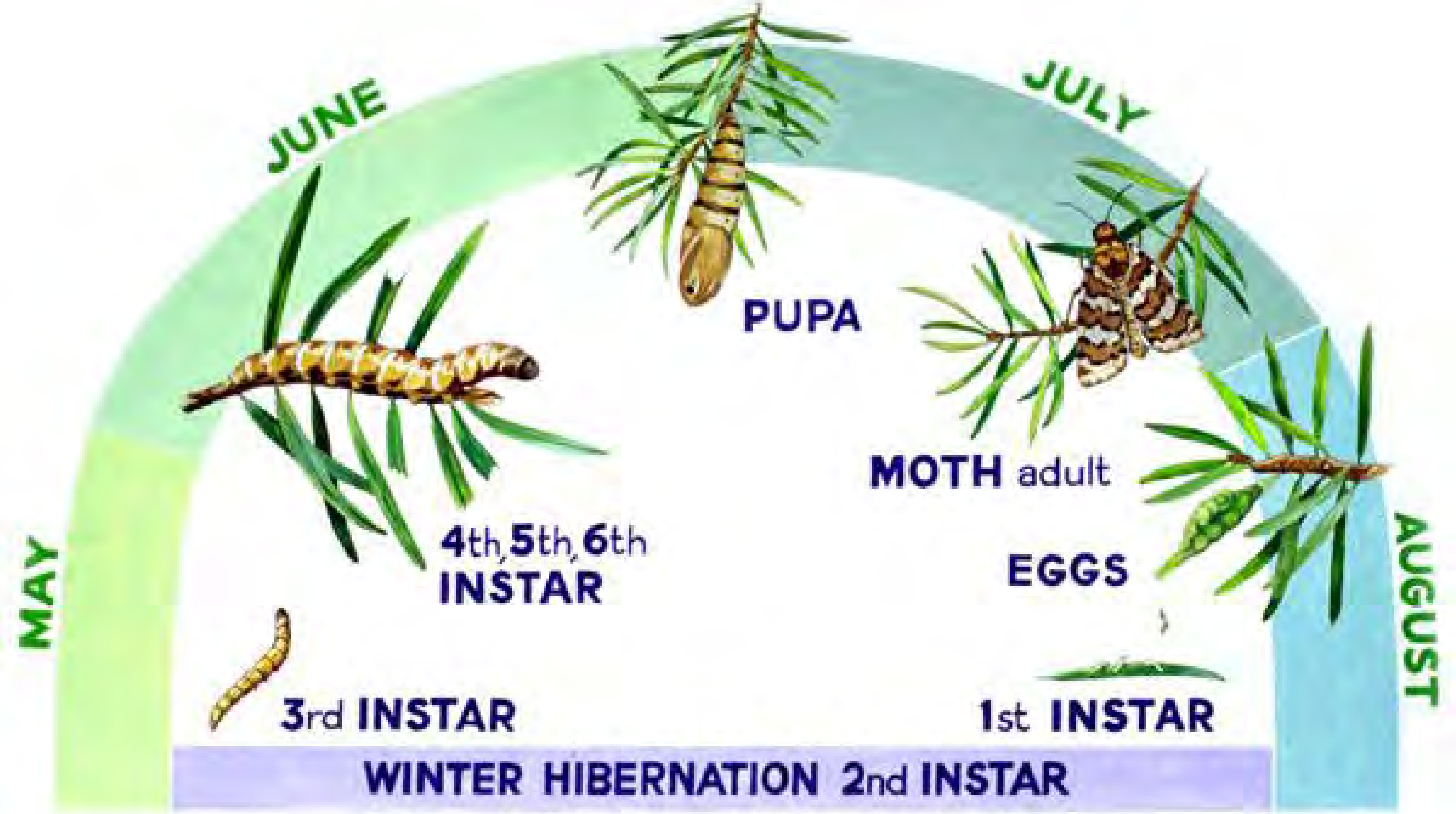


Figure 27: Spruce Budworm life cycle

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Figure 28: Late instar WSB caterpillar.

Figure 29: WSB egg mass on underside of needle.

Figure 30: Adult WSB moth.

Figure 31: "1 bud slightly swollen, 2 buds swollen, green to grey–green in colour, bud scales still closed, 3 burst of bud scales, tips of needles emerging, 4 needles elongated to about double the bud length." (Malmqvist et al., 2017)

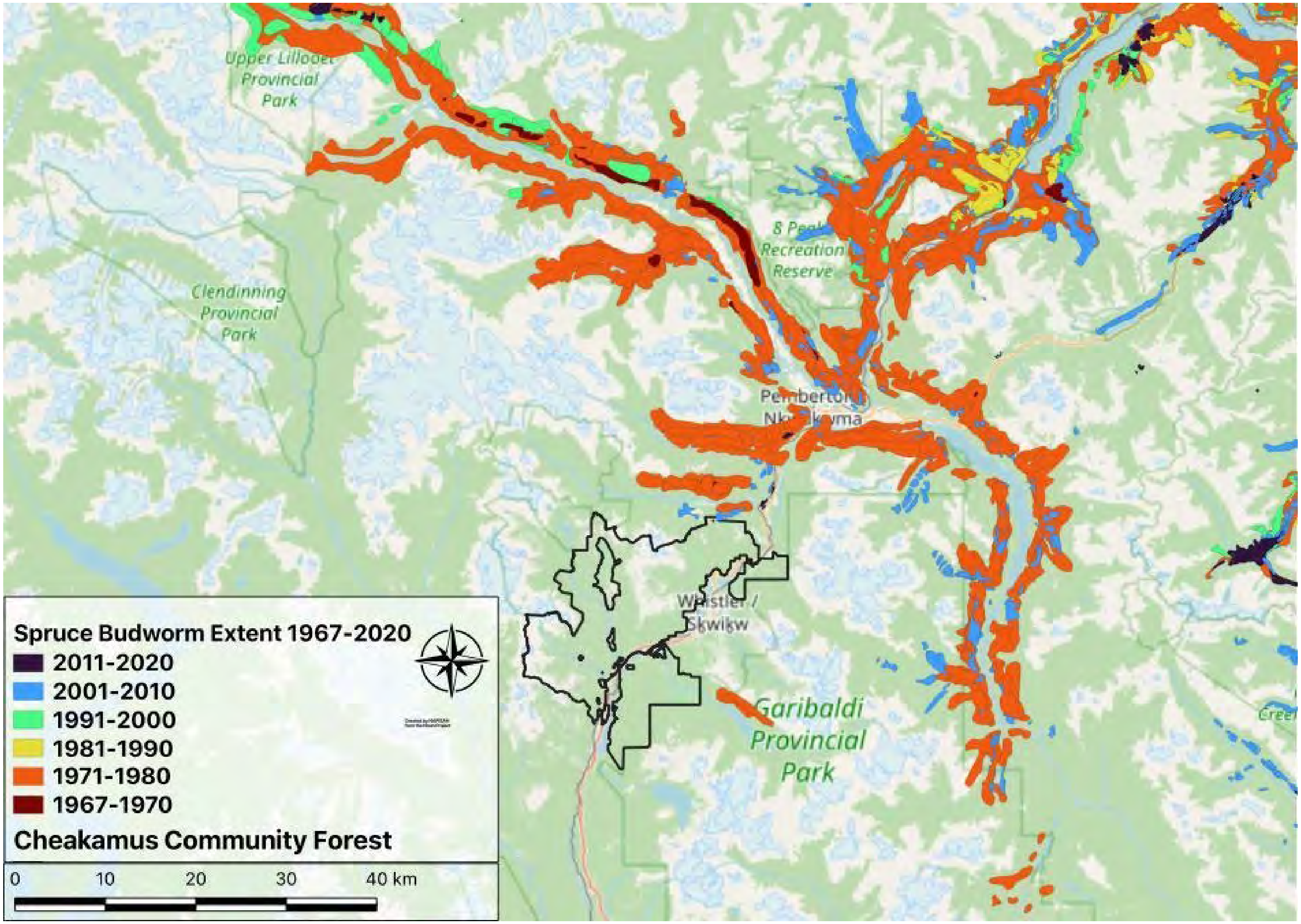

Figure 32: WSB Decadal extent from 1967-2020.

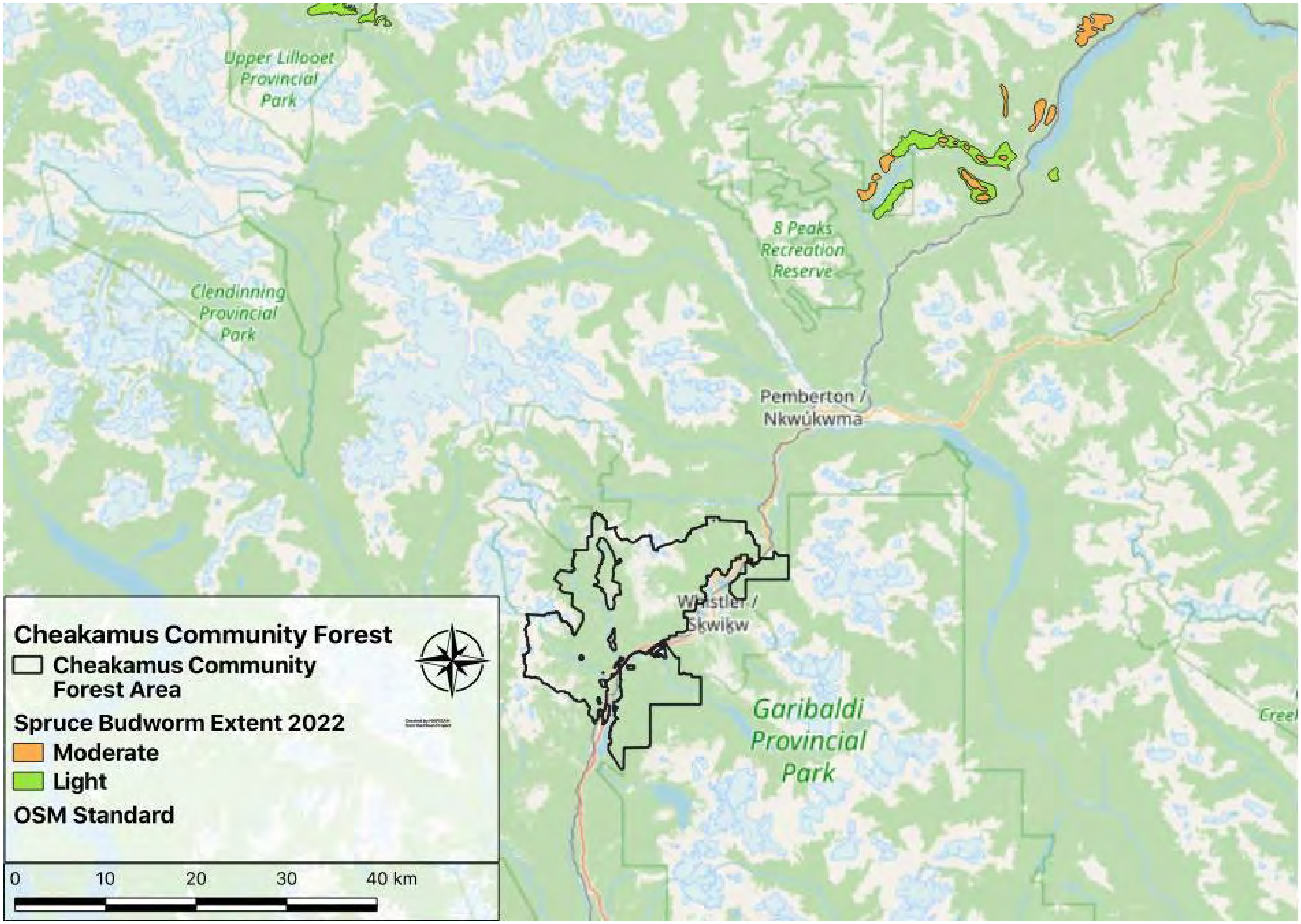

Figure 33: WSB extent and severity in 2022.

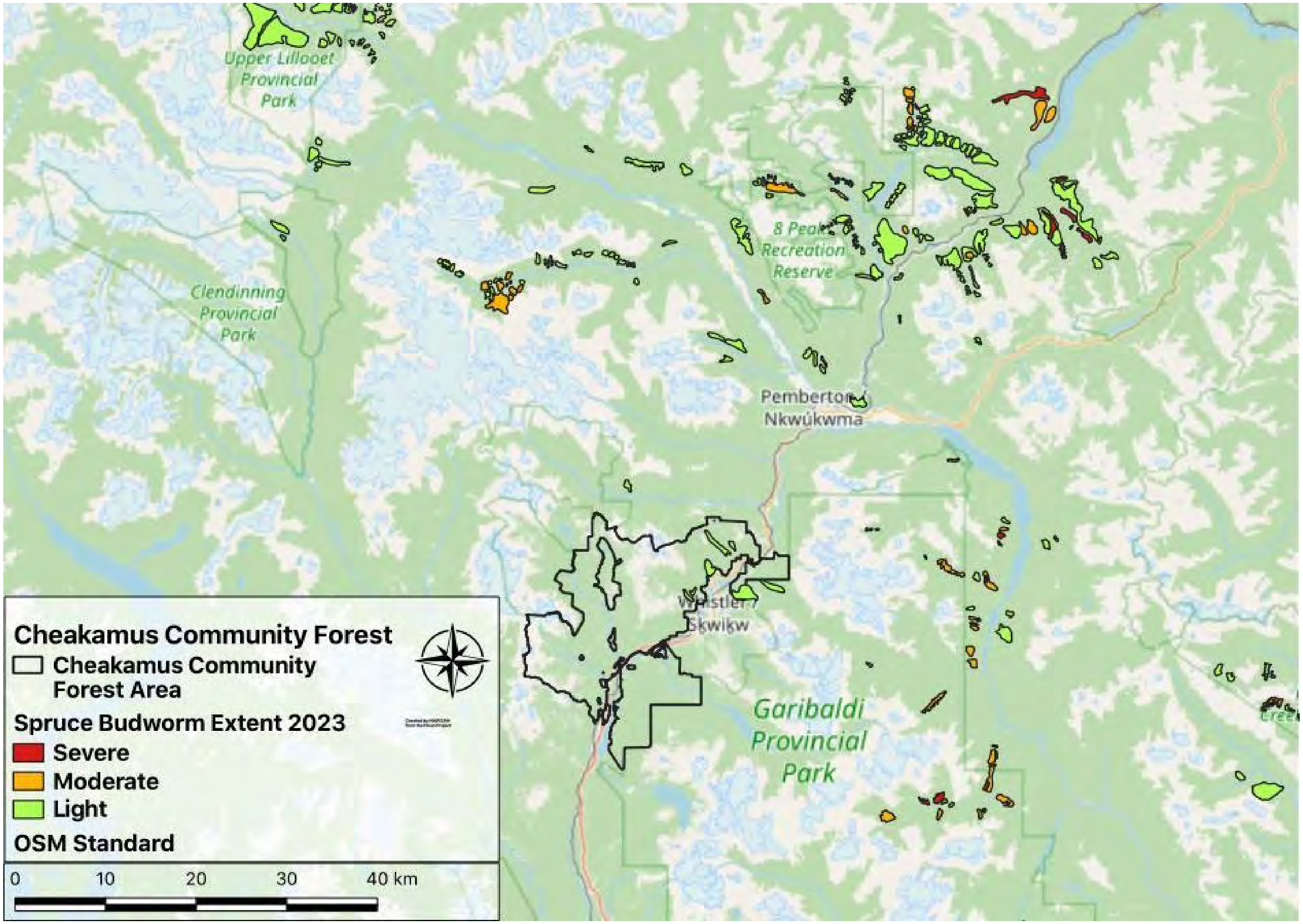

Figure 34: WSB extent and severity in 2023.

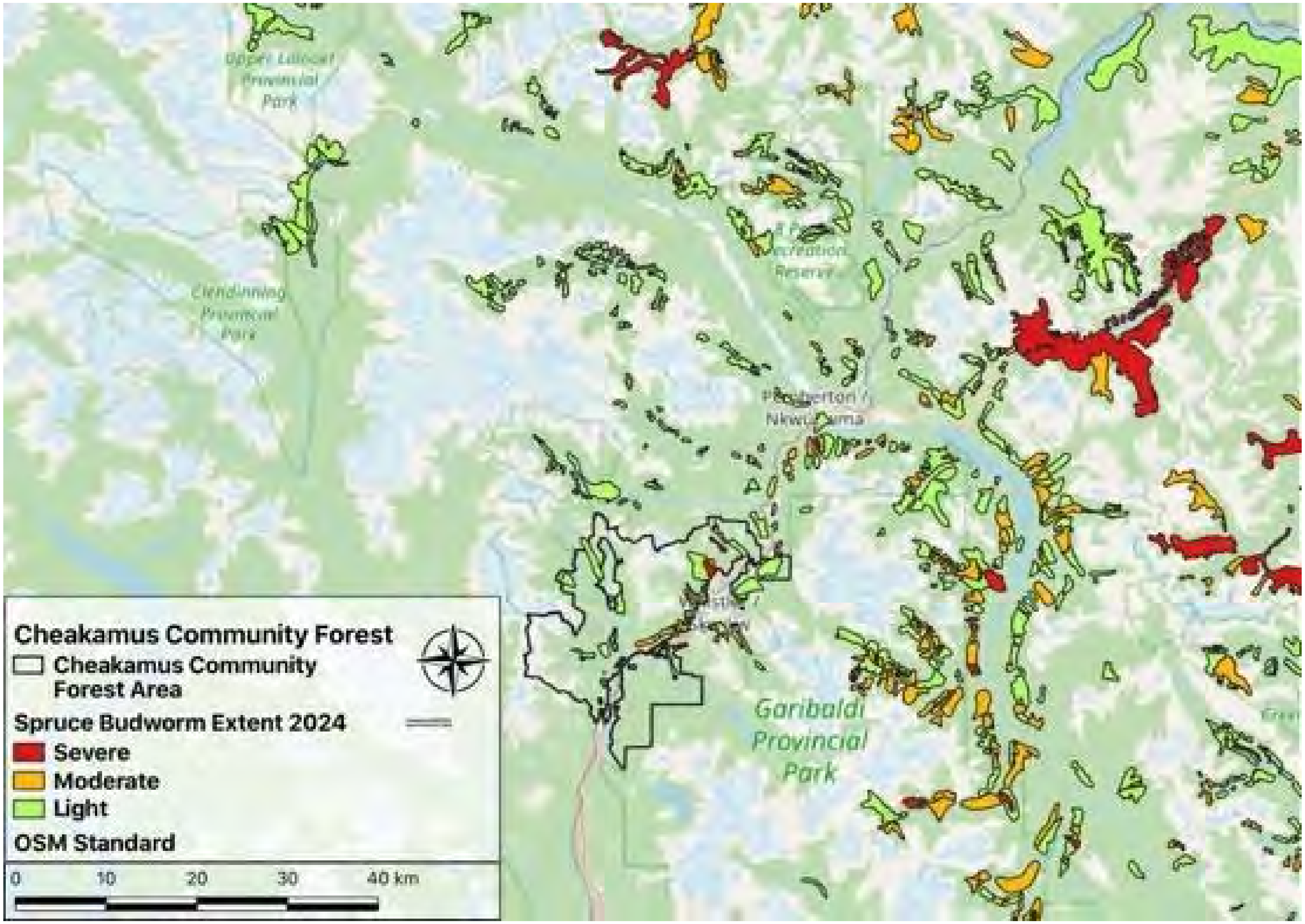

Figure 35: WSB extent and severity in 2024.

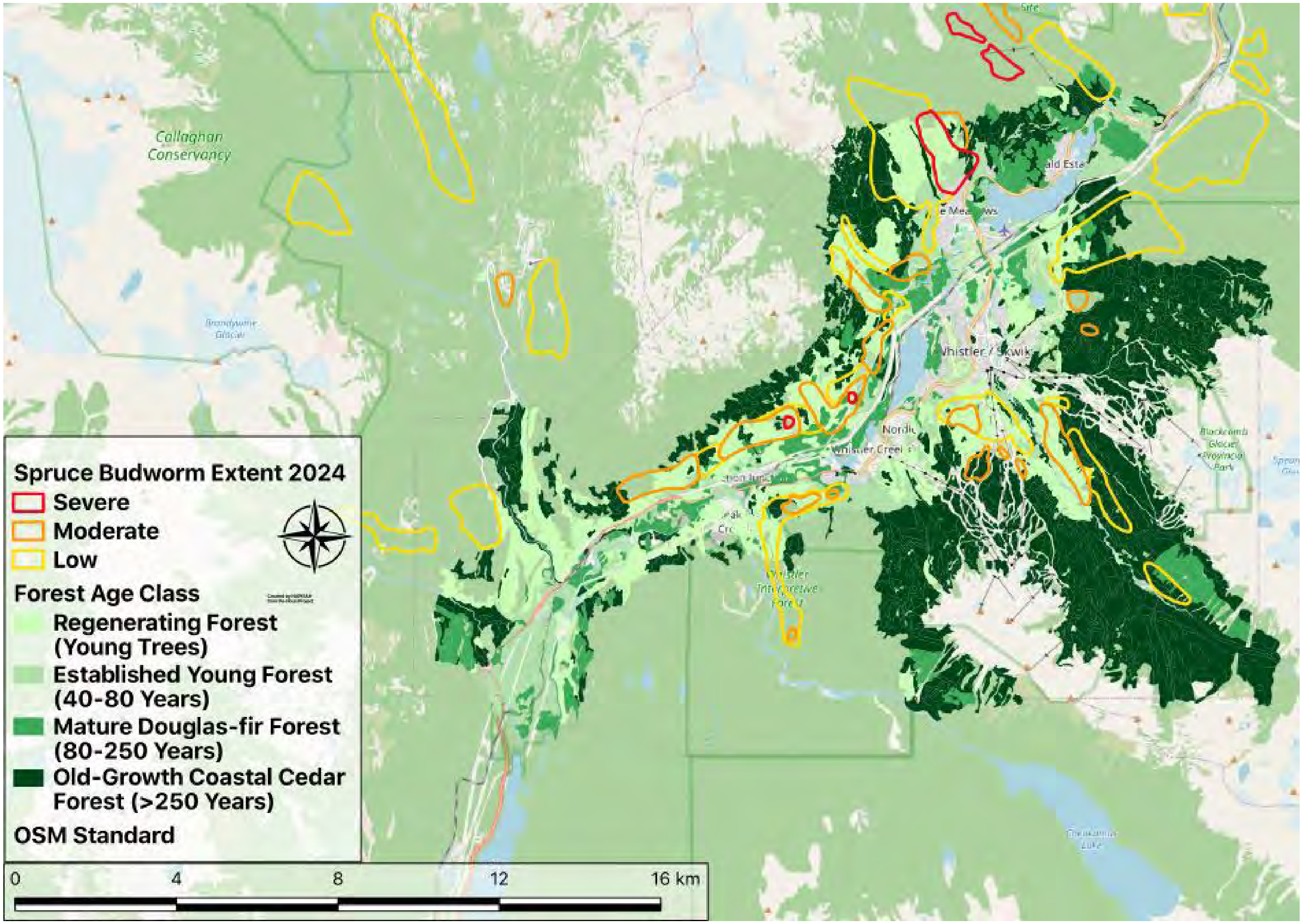

Figure 36: WSB extent in 2024 overlayed on top of forest age classes.

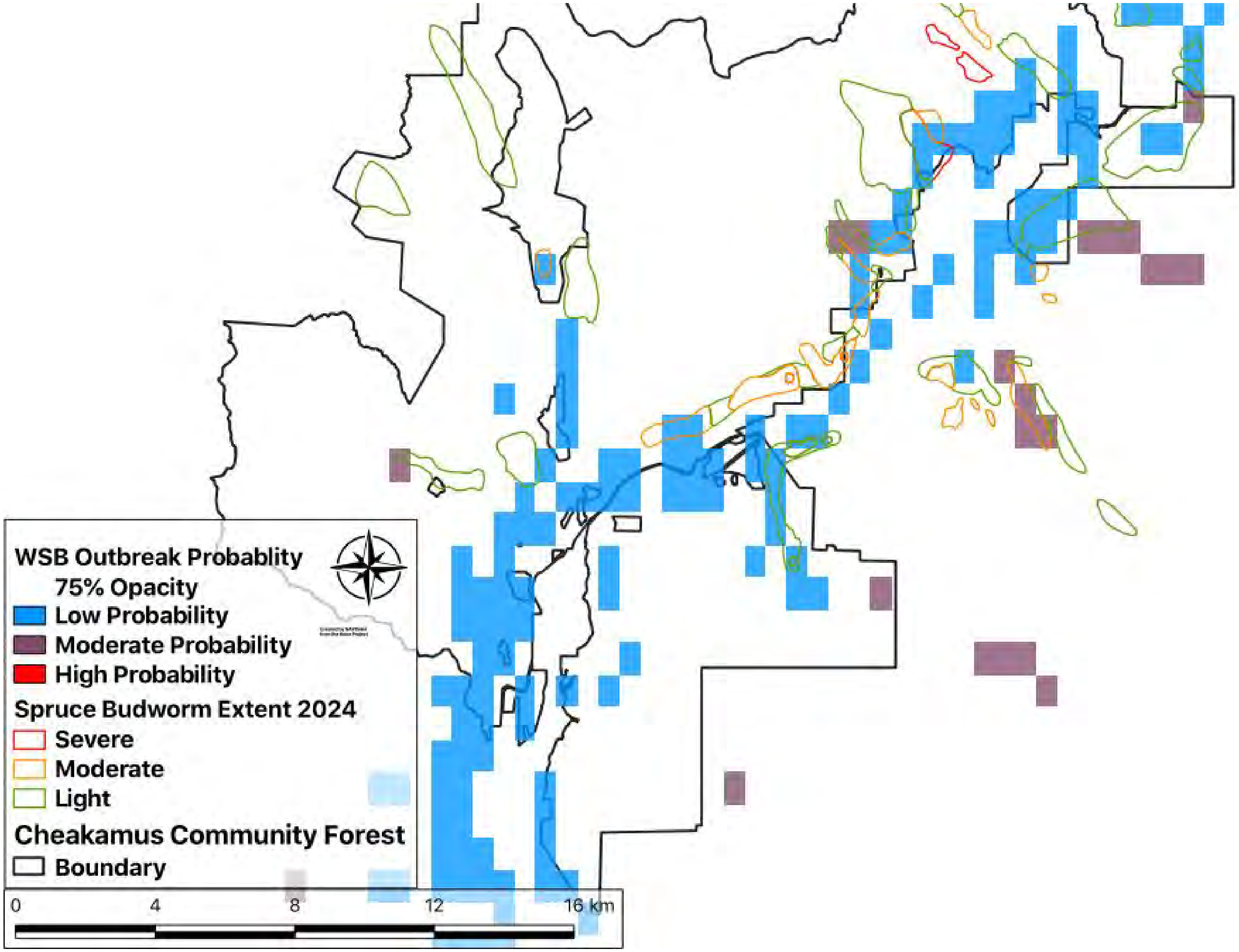

Figure 37: WSB extent in 2024 overlayed on top of predictive model for the years 2011-2040.

MANAGEMENT OF WSB

WSB life cycling, spread predictions, and subsequent management options are not fully understood. Much more research and monitoring are required to better respond to WSB outbreaks. Furthermore, WSB outbreaks are highly dependent on local and temporal factors related to weather, climate changes, and forest ecology - all of which are in a constant cycling of change. Therefore, management of WSB should be approached using a local lens, such that management planning and adaptive management are applied from the beginning.

The literature outlines three main types of approach to WSB management:

- **#1) Improve Local Understanding:** Gather local knowledge and inventory information related to WSB and WSB movement, spread,
    - Monitor and better understand trends in WSB spread and populations;
- **#2) Site-level Response:** b.t.k. spraying, silvicultural interventions and timber salvage
- **#3) Landscape Planning:** Long term management activities.

#1) GREATER LOCAL UNDERSTANDING

Speaking to both Ministry of Forest employees and local entomologists provided the authors with an understanding of the importance of ongoing WSB monitoring in planning management response. These professionals explained how monitoring is currently conducted and how it can be improved. Currently the BC Ministry of Forests utilises a method of observation for the budworm extent year over year which is called Aerial Overview Survey (AOS) (B.C. Ministry of Forests, n.d.). AOS is a manual ocular assessment of WSB extent, used to create the polygons in Figure 36. In future years a shift to Sentinel satellite observation and programmed detection would enhance the monitoring of WSB, a method currently employed in Eastern Canada. This is a good way of seeing the extent of the damage so far in the year, both to understand the possible extent the following year, as well as to inform the forest managers of any areas that it would be necessary to spray with b.t.k.

Another monitoring method for the anticipation of the coming year's severity is egg mass sampling. This can be done with little training, but as of yet has not been a method applied South of Pemberton. This consists of cutting down branches as assessing the density of the egg masses on the underside of the needles and is measured in number of egg masses per 10 square meters of foliage.

BIOSim is a tool that can be used to simulate and visualize biological processes and insect development in response to climatic variables. It has models for both Douglas-fir budburst and WSB emergence. (Régnière & Saint-Amant, 2022)

Ministry of Forests Regional Forest Pathologist for the West Coast region, David Rusch, suggested that collaboration between the Ministry of Forests and RMOW to set up monitoring plots would be advantageous to both parties moving forward.

#2) SITE-LEVEL RESPONSE

Site-level responses are characterized as responses that are generally at the site-level or across multiple sites level - so generally less than 250 ha. Site-level responses are in direct response to WSB activity and are therefore executed in the shorter term (generally <1 year).

B.T.K.

Short term damage mitigation is exclusively the application of b.t.k., a biological pesticide of high efficacy against WSB. B.t.k. is a bacterium that when ingested by a moth forms crystals in their gut preventing feeding and causing starvation. For it to be effective, b.t.k. needs to be sprayed during the active feeding stage of WSB, roughly between the 4th and 5th instars, post budburst. WSB feeds more in warm dry conditions, and b.t.k. is easily washed away in the rain. Applications therefore need to be implemented strategically to ensure the resources are not wasted. A Coastal Region pest management plan (PMP) for WSB is currently underdeveloped by the Ministry of Forests, with an upcoming decision as to whether it is implemented. This plan would facilitate the aerial spraying of b.t.k., which would otherwise be a more costly and resource heavy endeavour (BC Government, 2008).

SILVICULTURAL INTERVENTIONS

PROMOTION OF SPECIES MIX

Diversifying species composition further strengthens stand resilience. Mixed-species stands reduce the availability of suitable feeding sites for Western Spruce Budworm (WSB) and force larvae to disperse more widely, increasing their vulnerability. Strategies such as patch cuts with planting, selective thinning, underplanting with non-host species, and controlled under-burning create healthier stands that are less prone to severe WSB impacts (BC Government, 2024). Together, these interventions foster robust, adaptive stands better equipped to withstand pest outbreaks.

STAND STRUCTURE MANIPULATION

Silvicultural interventions focusing on stand structure manipulation are a key strategy for mitigating the impacts of WSB. Dense stands are particularly vulnerable, as they provide abundant foliage for larvae to feed on, while poorly managed canopy structures facilitate budworm dispersal (Maclauchlan et al., 2018; Nealis & Régnière, 2009). By reducing stand density and enhancing species diversity, forest managers can improve tree resilience and decrease the likelihood of severe outbreaks (Nealis, 2012; Oregon Dept. of Forestry, 2017).

WSB lay their egg masses in the tops of overstory trees, where larvae hatch and either feed or disperse to understory branches via silken threads (B.C Ministry of Forests, n.d.). In stands lacking suitable understory foliage, larvae often fall to the ground and starve, highlighting the importance of managing vertical stand structure. Increasing crown separation of large, full-canopy overstory trees increases the distance larvae must travel to find feeding sites, raising mortality rates through starvation, exposure, or predation (Nealis & Régnière, 2009).

STAND IMPROVEMENT

Density control treatments, including thinning, spacing, and under-burning, promote wider inter-tree spacing, encouraging full crown development and vigorous tree growth (Nealis, 2003). These conditions enhance tolerance to defoliation and limit the continuity of foliage, which disrupts WSB dispersal and feeding (Maclauchlan et al., 2018). Selective thinning of Douglas-fir and other preferred host species, in both the understory and overstory, is an effective way to reduce palatable foliage and decrease stand susceptibility (Senf et al., 2017).

TIMBER SALVAGE

Effective salvage logging of timber affected by spruce budworm infestations requires prompt action to mitigate wood degradation and economic losses. Initiating salvage operations within two to three years following tree mortality is crucial, as delays can lead to significant reductions in wood quality due to decay and infestations by secondary pests. Early planning and preparedness are essential to facilitate timely interventions, ensuring that salvage efforts are both efficient and economically viable (Sewell & Maranda, 1978).

#3) LANDSCAPE PLANNING

Landscape-level responses are characterized as responses that are generally at broad scales such as the entire CCF or parts of the CCF. Landscape-level responses are generally preventative and have a long-term scope (generally 5+ years).

Landscape-level considerations require forest managers to revise and incorporate adaptive management planning into existing plans such as the CCF's FSP and/or the CCF's Climate Resilience Plan. Within these documents the CCF should consider, where appropriate, to look at forest management practice modifications that include:

- Conversion to alternative species,
- Promotion of species mixes,
- Stand structure manipulation, and
- Overall landscape health and stand improvement.

CONVERSION TO ALTERNATIVE SPECIES

Alternative species are less susceptible to budworm feeding. Even-age silviculture systems (clearcut, seed tree, shelterwood) can work in appropriate ecosystems in conjunction with the promotion or planting of alternative species. Species less susceptible to WSB include: western larch, lodgepole and ponderosa pine and spruce. All other species commonly grown in B.C. (excluding Douglas-fir and true firs) can be considered non-hosts.

PROMOTION OF SPECIES MIXES

Mixed species, in single or multi layered stands, are likely to sustain shorter and milder outbreaks. In ecosystems where uneven-age or multi-layered stand management is the desired silvicultural system, or is the only option, species mosaics should be promoted where possible.

For example, partial cutting regimes could retain a lodgepole and/or ponderosa pine component within an existing stand, thus encouraging future establishment of these species.

STAND STRUCTURE MANIPULATION

Manipulation of stand structure is an important tactic. High stand-densities increase stand hazard by providing an abundance of new foliage for larvae. Stocking and density control facilitate rapid growth of individual trees and permit selection of genetically superior trees more tolerant of defoliating insects.

Density control can be achieved through harvesting and silviculture treatments such as thinning, spacing and under-burning. Greater inter-tree distances achieved through density control promote full crowns and more vigorous growth so that tolerance to budworm feeding is enhanced. Attempts should be made to minimize large, full-canopy trees overtopping smaller, less foliated trees. Overstorey trees provide a means of budworm dispersal down onto trees growing under the canopy radius. Where multi-layered stand structure is desired, alternating layers by host and non host species also reduces stand risk.

STAND IMPROVEMENT

Generally promoting healthy forests that can more readily adapt and withstand effects from climate change is critical. Many of the recommendations and strategies within this report outline ways in which to do this. The CCF is developing a Climate Resilience Plan in 2024 and 2025 and this Plan will directly promote landscape-level recommendations to promote healthy forests that are more resilient and resistant to pest and disease outbreaks.

Fertilization for stand improvement can promote full crowns and increased tree growth. The relationship of forest fertilization to budworm defoliation is not fully understood at this time.

APPENDIX B: WILDFIRE MODELLING

Step 1: BurnP3+ Modelling and Mapping

BurnP3 Overview

Burn Probability (BP), **Head Fire Intensity** (HFI), and **Rate of Spread** (ROS) are important variables to consider when evaluating the potential wildfire threat and risk of a given area. These variables determine where the greatest potential fire behaviour might occur and how effective suppression or mitigation resources might be in addressing it. Burn-P3 wildfire modelling software generates BP, HFI, and ROS outputs by simulating wildfire events over spatial and temporal surfaces to generate a probability distribution of wildfire simulations. Through the use of Monte-Carlo simulations BurnP3 and its successor, BurnP3+, leverages the Prometheus fire growth engine along with the Canadian Forestry Fire Danger Rating system to simulate wildfires on a landscape. The model can be run over any number of iterations (or fire seasons) and ignitions to examine multiple aspects of fire hazard and risk. The method below will outline one approach to characterize wildfire threat and risk using BurnP3+.

BurnP3 Conceptual Model

In order to best understand wildfire threat and risk to communities burn probability mapping has been a key improvement to landscape scale risk assessment work focused on community safety and wildfire mitigation. A major assumption of this approach is that by characterizing the fire environment and fuels for a given landscape and using stand level fire growth models to simulate thousands to hundreds of thousands of fires, a manager can best assess the relative probability of wildfire at any given point on area of interest[31]. This conceptual idea does not intuitively transfer over to a true probability of wildfire, but can be used in combination with other techniques to garner the mean or average probability of wildfire for a given season and region. Iterations denote the number of times that a year is simulated. Likewise, the number and location of fires occurring each year is determined either by a historical fire data frequency distribution or kernel density analysis. Simulations are designed to reflect realistic fires which likely move through contiguous, heterogenous landscapes. This differs from other wildfire threat methodologies, such as the PSTA, by simulating the wildfires may actually spread through a landscape, as well as the potential intensities of the wildfire. Mitigation specialists, fire ecologists, or foresters working with simulation models must be aware of the constraints of this type of analysis and how to best employ and interpret the results of these models to transfer to operations[32].

Burn-P3 Major Inputs

Major inputs to BurnP3 and BurnP3+ include digital elevation models, historical spatial ignition patterns, fire weather data and fuel type (Fire Behaviour Prediction System, FBP) datasets. In addition, the program's estimates are improved using interpolated wind grids, Biogeoclimatic zones and Natural Disturbance Type regime data – all of which help better describe the landscape conditions conducive to fire behaviour and best contextualize the regional impact of fire on nearby communities. The size of the area undergoing a fire simulation is particularly important for estimating ignition patterns, since area directly affects the sampling size of historical ignition locations that can be used in modelling. So, it is important to use broad enough regions and time frames to capture the fire climate and fire fuels relationships at the appropriate scale. Results from Burn-P3 thus allows for WUI

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[31] *Marc-André Parisien et al., "Applications of Simulation-Based Burn Probability Modelling: A Review," International Journal of Wildland Fire 28, no. 12 (2019): 913, https://doi.org/10.1071/WF19069.*
[32] *Parisien et al., "MAPPING WILDFIRE SUSCEPTIBILITY WITH THE BURN-P3 SIMULATION MODEL."*

areas to be assessed relative to the larger landscape, and understand potential interactions and landscape patterns of fire threat.

Burn-P3 Major Outputs

Burn-P3 outputs are in the form of raster cell grids, where each cell grid represents a given area (e.g., 50 m grid resolution means that each square on the map represents 2500 square meters). Chosen cell resolution is determined by a variety of factors including, but not limited to; the scale of historical fire behaviour patterns, potential computational load, data quality, landscape size, and forest/fuel/landscape structural patterns. Users can choose any multitude of outputs options but the BurnP3+ model outputs Rate of Spread rasters, Head Fire Intensity, and perimeter data for each fire run in a given simulation. Further outputs include most of the major outputs from the Fire Behaviour Prediction System of the CFFDRS. Interpretation of the results is open ended but to summarise usually users will generate surfaces of the mean or median rate of spread and head fire intensity for every cell on the landscape. As well, the system itself automatically computes the average burn probability per cell as the number of times that cell burned divide by the number of iterations. This can be interpreted as the total number of fires (ignitions) burned across the total number of years (iterations), thus the average burn probability for a given cell.

Frontera employs these methods to produce 3 key outputs for threat and risk assessments:

- Mean/Median/90th weighted Head Fire Intensity (**HFI**) (kw/m),
- Mean/Median/90th weighted Rate of Spread (**ROS**) (m/min), and
- Burn Probability (**BP)** (%).

The median HFI and ROS determines the severity of a wildfire and how difficult it can be to suppress it based on behaviour. Relative burn probability of a wildfire occurring in each area is based on the number of times a grid cell was burned in simulations. BurnP3 burn probability outputs are then reproduced as a relative value for any given cell on the landscape. Since some areas and forest types are more prone to fire ignitions and spread, relative probability gives a better assessment of the potential risk for a given landscape as opposed to an absolute value. This approach contextualizes any given location in an area of interest to the broader landscape and helps better inform decision: land managers can prioritize threatened areas with higher relative burn potential rather than highest absolute burn potential. For both HFI and ROS, the median is generated by Burn-P3 out of the total iterations for each cell grid. Median is used instead of the mean in order to limit the influence of outliers, as in common in fire data, but 90th percentile values may also be used for threat mapping.

Burn-P3 Inputs

In addition to spatial inputs, there are multiple non-spatial parameters that the user must set. (Table 5).

Table 5. Major Burn-P3 model inputs and methods for derivation.

Input	Description	Further Information
Ignition Probability Surfaces	Mapped surface of ignition probability based on biophysical and anthropomorphic input variables fitted to a random forest classification model for both Human and Lightning.	Surfaces are generated by season and ignition variables. If all seasons for summer fires (Spring, Summer, Fall) are used then 3 grids are created per ignition cause (Human or Lightning)

Input	Description	Further Information
Seasons (Optional)	Used to control and alter different Burn-P3 model parameters. Seasons can be unrelated to environmental conditions, can be related to fire distributions or follow typical summer weather patterns. (Ie early summer (spring), mid-summer (summer) or late summer (fall))	Can affect timing of ignitions, hours per day of burning, ignition surfaces and green-up parameters
Natural Disturbance Type (NDT) and Weather Zones (WXZ	Spatial maps of NDT and WXZ which correspond to landscape patterns of climate and vegetations. Used to differentiate by areas of common weather patterns or fire types	Do not have to correspond to BC's NDT or WXZ (BEC) system. Can be based on any ecologically sound method to distribute the landscape area by climate and fire trends.
Weather Station Data	Spreadsheet that includes metrics used in Fire Weather Index (FWI) System and as inputs into the FBP system which drives Prometheus.	Can use different stations for different mapped weather zones based on location. Analyst makes an assessment about data quality and length of station data. Usually at least one station per weather zone. Yet stations apply to fires burning by natural disturbance type zone.
Distribution sets	Spreadsheets detailing the frequency distribution, location, and percentage of different non-spatial parameters Can also be random or based on previously set coordinates	1. Number of ignitions per year (percent of frequency) 2. Proportion of ignitions occurring in spring, summer, fall, and as human or lightning-caused 3. Number of spread event days – the days when fires are noticeably increasing in size 4. Number of hours per day of burning
Minimum fire size	How large a fire must grow after ignition to be recorded and considered escaped	NA

Input	Description	Further Information
Green-Up/Curing/Wind Grids	Optional inputs which modify the date of green up of deciduous fuel stands (switching fuel types), the curing percentage of grass fuel types, and the domain or average wind speed and direction grids for the particular region respectively.	NA

Field Reconnaissance

The FBP fuel types used in Burn-P3 as a spatial data set require field verification as the spatial data may not capture all recent landscape changes and/or may be inaccurate within particular areas of interest. Reconnaissance was conducted and any inconsistencies between field observations and the spatial data set were corrected using field-derived shapefiles of true fuel types. The fuel type layer was vectorized to merge polygonal changes and then reverted to a raster layer to be implemented in Burn-P3.

Model Tuning

An advantage to large scale Monte-Carlo based simulation modelling is that it allows for a relatively easy to interpret output and logical conceptual method to predict burn probability for a given region. Yet to this end it can act as a “Black-Box” model which must be tuned, interpreted, and tested by qualified and experienced practitioners with solid understandings of the underlying systems. Deployment of such a model without proper testing or input examining can result in outputs with major levels of error and overconfidence in poor results. As such Frontera employs model tuning for all model runs using BurnP3 and BurnP3+. Initial models are run with small iteration sizes 200-500 in order to test assumptions, examine outputs, and establish model confidence. Key parameters which can be tested are the distribution of ignitions by Season, Natural Disturbance Type, and Cause, the mean and median fire size, the total burned area truncation by the historical number of ignitions, and perhaps best of all the distributions of fire sizes. These historical observations are key to improving model fit and ensuring the final model run is as accurate as possible. Final models are then run on large numbers of iterations and fires to ensure model stability and the best model assessment of regional burn probability.

Step 2: Wildfire Threat Mapping

The Burn-P3 outputs are raster cell grid maps, and each cell in the grid can be overlayed with HFI, BP, and ROS to determine multiple aspects of fire threat within a single grid cell area. Each grid cell identifies:

1. The median or 90th ROS in metres per minutes
2. The median or 90th HFI in kilowatts per metre (kW/m)
3. The likelihood of fire occurring in each cell (**BP**)

Overall wildfire threat can be quantified by putting these maps together for each grid cell by giving a range of values a score. The scores for each component are obtained by binning a range of values as shown below in Table 6.

Note: The range applied for head fire intensity is based on the PSTA scoring system[33], and rate of spread intervals were derived from the National categorization from Natural Resources Canada[34]. Relative probability scoring is tailored to each area of interest using R-generated data analyses, which identifies outliers to remove possibly erroneous maximum values and is usually standardized to a maximum value. The analyses then define equal interval breaks based on every tenth percentile using the newly calculated maximum probability.

Table 6. Scoring system for Burn-P3 components.

Score	Median HFI (kw/m)	Score	Relative Probability (%)	Score	Median Rate of Spread (m/min)
0 (nonfuel)	0	0 (nonfuel)	0	0 (nonfuel)	0
1	0.01 – 1,000	1	> 0 to 10th percentile	1	> 0 – 1
2	1,000.01 – 2,000	2	> 10th to 20th percentile	2	> 1 – 3
3	2,000.01 – 4.000	3	> 20th to 30th percentile	3	> 3 – 6
4	4,000.01 – 6,000	4	> 30th to 40th percentile	4	> 6 – 10
5	6,000.01 – 10,000	5	> 40th to 50th percentile	5	> 10 – 14
6	10,000.01 – 18,000	6	> 50th to 60th percentile	6	> 14 – 18
7	18,000.01 – 30,000	7	> 60th to 70th percentile	7	> 18 – 20
8	30,000.01 – 60,000	8	> 70th to 80th percentile	8	> 20 – 22
9	60,000.01 – 100,000	9	> 80th to 90th percentile	9	> 22 – 25
10	> 100,000	10	> 90th percentile and all outliers	10	> 25

The final output of spatially mapped wildfire threat is the result of taking the three scores of each important component of wildfire threat (BP, ROS, and HFI) and utilizing the weighted sum equation:

Wildfire Threat = (Head Fire Intensity Score*0.3) + (Rate of Spread Score*0.3) + (Probability of Burn Score*0.4)

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33 https://catalogue.data.gov.bc.ca/dataset/bc-wildfire-psta-head-fire-intensity
34 https://cwfis.cfs.nrcan.gc.ca/ha/fbnormals?type=ros&month=7

The assigned weights for each score represent the importance of that component influencing the overall wildfire threat. All scores range between 0 and 10, with 0 representing non-fuel areas (i.e., no chance of a fire occurring), 1 representing the lowest threat level, and 10 representing the highest threat level. Final wildfire threat is reclassified into four possible rankings using the PSTA ranking system[35]:

Table 7. BurnP3 scores and threat rating.

Scores given equal interval	Overall, Threat Rating
> 8 – 10	4 (Extreme)
> 6 – 8	3 (High)
> 3 – 6	2 (Moderate)
> 0 – 3	1 (Low)
0	0 (No Threat)

[35] https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/wildfire-status/prevention/fire-fuel-management/fuels-management/2020_determining_wildfire_threat_and_risk_at_a_local_level.pdf

APPENDIX C: PNW OLD GROWTH FORESTS & CLIMATE CHANGE

INTRODUCTION

Old growth forests have seen a decline worldwide. In the Pacific Northwestern United States, the historic extent of Old Growth conifer forests comprised 64% of total land cover which was reduced to approximately 19% as of 2000 (Jiang et al., 2004; Strittholt et al., 2006). In British Columbia, a quarter of all forests are considered old growth, however this includes low productivity subalpine and bog forests. Only about 1% of these forests are considered highly productive old growth forests growing large trees (Price et al., 2021).

Old growth forests are of significant value in the Pacific Northwest for several reasons. They provide important habitat for flora and fauna, many of which cannot survive except in conditions unique to old growth forests (Government of British Columbia., 2024). Significant carbon storage is also attributed to old growth forests, and after conversion to young forest it can take up to 200 years to approach the storage capacity of the replaced old growth stand (Harmon et al., 1990). Old growth forests also have significant cultural value both to the indigenous and settler communities.

Climate change is impacting temperatures globally and while similar changes in temperature have happened in the past and forests have adapted, the rate of change in temperature predicted for the twenty first century is likely too fast for trees to either adapt of migrate to their new climactic range and could induce high mortality in mature conifer forests (McDowell et al., 2015; McDowell & Allen, 2015; Urban et al., 1993). When future climate predictions are averaged, temperatures are set to increase and annual precipitation remains relatively constant, however with more extreme weather events. This is defined by drier hotter summers, with longer periods of drought and shorter more intense precipitation events (P. W. Mote & Salathé, 2010).

Climate change impacts aren’t necessarily all negative for Pacific Northwest forests, with some models predicting increased productivity for parts of the region where it is not water deficiency but energy deficiency that is limiting factor in forest health and productivity. These areas can benefit from increased temperatures, potentially expanding the range of some forests into new areas.

Climate refugia is considered an area that can buffer the pace of change of climate so that resources that have value either ecological, physical, or sociological can be retained (Morelli et al., 2020). This report aims to assess how Pacific Northwest old growth forests are impacted by climate change, whether they can act as refugia and how they compare to younger forests in that regard.

CLIMATE PREDICTIONS IN THE PACIFIC NORTHWEST

Climate change affects forests through many interconnecting factors including direct effects like increases in temperature and changes in precipitation levels and patterns. It also creates secondary effects including increased occurrences of extreme disturbance events like wildfire and insect outbreaks, but these won't be a focus in this paper. In this section we will examine only the direct changes in temperature and precipitation, and how these affect the vapour pressure deficit (VPD).

VAPOUR DEFICIT

Vapour deficit (VPD) is defined as the maximum amount of water the air can hold at a given temperature, minus the actual amount of moisture in the air. As the air can hold more moisture at higher temperatures, if the temperature increases, but the amount of water in the air remains constant, then the VPD increases. If the amount of water in the air drops while there is an increase in temperature, the VPD will rise exponentially (Ficklin & Novick, 2017).

Vapor Pressure Deficit is the difference between the Saturated Vapor Pressure (SVP) and Relative Humidity[36]. Saturated Vapor Pressure is the maximum amount of moisture the atmosphere can hold according to its temperature. And Relative Humidity is the amount of moisture currently suspended in the air.

TEMPERATURE & PRECIPITATION

For the Pacific Northwest, as can be seen in Table 8, the annual mean temperature will increase anywhere between 1.6°C and 5.4°C over the next 75 years (in comparison to 1970-1999 average). This however may not be as important as the seasonal change in average temperature which shows more drastic increases in temperature for the summer in comparison to the winter.

Precipitation on the other hand is predicted to be difficult to distinguish from natural variability until the later part of the century, with best estimates of +1%, +2% and +4% in 2010-2039, 2040-2079, and 2080-2100 periods respectively (Table 8). Again, with precipitation however, the problems arise with the seasonal differences, with some models predicting a reduction of summer precipitation as much as 20-40% (P. Mote et al., 2008; P. W. Mote & Salathé, 2010).

[36] *https://www.dimluxlighting.com/knowledge/blog/vapor-pressure-deficit-the-ultimate-guide-to-vpd/#:~:text=Vapor%20Pressure%20Deficit%20is%20the,currently%20suspended%20in%20the%20air*.

Table 8. Temperature and precipitation change when compared to 1970-1999 average. Low represents the lowest model, high, the highest, and average is the weighted mean of the models. 2020s represents 2010-2039, 2040s represents 2040-2079 and 2080s represents 2080-2100. (P. Mote et al., 2008)

2020s*	temperature	precipitation
low	0.6°C (1.1°F)	-9%
average*	1.2°C (2.2°F)	+1%
high	1.9°C (3.4°F)	+12%
2040s*	**temperature**	**precipitation**
low	0.9°C (1.6°F)	-11%
average*	2.0°C (3.5°F)	+2%
high	2.9°C (5.2°F)	+12%
2080s*	**temperature**	**precipitation**
low	1.6°C (2.8°F)	-10%
average*	3.3°C (5.9°F)	+4%
high	5.4°C (9.7°F)	+20%

EFFECTS OF CLIMATE CHANGE PREDICTIONS ON PACIFIC NORTHWEST FORESTS

Given these predicted temperature and precipitation trends, the projected increase in VPD is particularly concerning for forest ecosystems. The following section will explore how these changes influence forest physiology, focusing on the effects of elevated VPD on tree hydraulic function, gas exchange processes, and the potential mitigating role of CO_2 fertilization.

HYDRAULIC LIMITATIONS AND INCREASED VPD

One of the most critical consequences of rising VPD is its impact on tree water balance. As atmospheric demand for moisture increases, trees experience intensified water loss, meaning that during extended drought events, reducing soil moisture levels may not have the capacity to meet the demands of tree transpiration and atmospheric water loss. This imposes considerable hydraulic stress, particularly on large conifers in old-growth forests, where extended hydraulic pathways result in greater resistance to water flow due to increased gravitational potential and friction losses within the xylem. This makes them more susceptible to hydraulic failure during extreme drought events. (McDowell & Allen, 2015). This was seen when in a post 2002 drought event in the Southwestern United States, mortality in three coniferous species nearly doubled (Williams et al., 2012).

Younger trees require less water and have lower water transport requirements, but they are more dependent on surface soil moisture, due to a much larger proportion of their fine root mass being concentrated within the top 20cm of soil which can dry out quickly during droughts. In contrast, large trees have greater access to groundwater given their deeper root systems. In times of drought water extraction is focussed in deeper root layers potentially mitigating some of these effects (Warren et al., 2005). This does not, however, eliminate their vulnerability to hydraulic stress, particularly during extreme or extended dry periods.

STOMATAL CONDUCTANCE

Stomatal conductance (G_s) refers to the rate at which CO_2 enters and water vapor exits the leaf through small pores called stomata. It is a key indicator of a tree's capacity for gas exchange and plays a critical role in both photosynthesis and water regulation. Under high VPD conditions, trees often close their stomata to conserve water reducing G_s, which limits CO_2 intake and impairs photosynthesis. As trees grow taller, their extended hydraulic pathways increase resistance to water flow, which naturally reduces G_s. This physiological trade-off, while protecting the tree from excessive water loss, can negatively impact overall tree health, especially in the upper canopy of old-growth forests (McDowell & Allen, 2015; Pangle et al., 2015).

CO_2 FERTILIZATION

There is some evidence that the VPD increases can be offset by an increase in CO_2 fertilization leading to increased water use efficiency. This is achieved as higher CO_2 mean the stomata can remain partially closed while gaining their needed CO_2 reducing water loss (Allen et al., 2015; Littell et al., 2010; Sleen et al., 2015). However, there is little research so far into how this affects water efficiency in drought conditions, and one study found that two coniferous species did not have improved chances of survival with CO_2 fertilization during drought events (Duan et al., 2015).s

CLIMATE RANGE SHIFTS AND TOPOGRAPHIC BUFFERS

Although climate change poses a significant threat to Pacific Northwest forests and some areas will suffer, others may benefit from the changes. This section explores how climate-related range shifts and local topography may buffer forests against some of the stresses induced by rising temperatures and VPD.

CLIMACTIC LIMITATIONS AND POTENTIAL RANGE SHIFTS

In North America, forests' climactic limitations can be split into 2 broad groups, energy deficient and water deficient. Energy deficient forests are either limited by light availability or by temperature. These forests seem to have benefitted from the changing climate over the past century (Littell et al., 2010). However, water limited ecosystems are likely to go into decline as the atmospheric and plant water demands increase in response to temperature and VPD increases. Both these influences together may cause a shift in geographical range of ecosystems. Some range may be lost in areas that were water deficient that can no longer support the plant and atmospheric demands for water. Some range may still be gained where the only limitation was energy which has now become more readily available (Urban et al., 1993).

TOPOGRAPHY

Beyond these large-scale shifts in forest distribution, local environmental factors such as topography also play a crucial role in shaping climate responses. This can be the case in North facing aspects or cool depressions in the landscape reducing the temperature and therefore VPD and atmospheric water demands. Watersheds can also create a buffer for intense drought events due to higher groundwater availability (Cartwright et al., 2018). This ensures a larger buffer in terms of temperature and/or water availability, prolonging the time before the climate changes make the area unsuitable for the forests in these areas, allowing more time for adaptation.

OLD GROWTH AND YOUNG FOREST MICROCLIMATE COMPARISON

TEMPERATURE DIFFERENCES

Old-growth forests play a critical role in mitigating climate stress due to their higher water use efficiency compared to younger forests (Farinacci et al., 2024). In addition, their structural complexity provides a natural cooling effect, which can help offset some of the temperature increases expected with climate change. Studies have shown that old-growth forests can be up to 2.5°C cooler than mature plantation forests (>50 years old) (Frey et al., 2016).

Further comparisons highlight even greater temperature differences between old-growth and recently disturbed forests. In Douglas fir forests, clearcuts aged 10–15 years exhibited peak daily temperatures exceeding 30°C, while adjacent old-growth forests remained around 20°C, a striking 10°C difference. On average, old-growth areas maintained temperatures 1.4°C cooler, with soil temperatures differing even more significantly (14°C in old growth vs. 18°C in clearcuts) (Chen et al., 1993, 1999).

HUMIDITY AND VPD DIFFERENCES

Beyond temperature, humidity and VPD also varied considerably. Old-growth forests maintained a relative humidity of 79% and a VPD of 0.42 kPa, compared to 71% and 0.70 kPa in clearcuts. As discussed earlier, both temperature and humidity strongly influence VPD, which is a key factor in determining the future resilience of Pacific Northwest forests. These findings underscore the importance of preserving old-growth forests as climate buffers, as they provide more stable microclimatic conditions that may help mitigate the effects of rising temperatures and increasing atmospheric moisture demand (Chen et al., 1993, 1999).

CONCLUSIONS

Old growth forests have been found to have cooling effects both in comparison to mature plantations forests, and younger regenerating forests. They have also been shown to have lower VPD and higher humidity. However, the differences between old growth and mature plantation and younger forests, does not negate the levels of change expected due to climactic predictions. While old-growth forests can serve as refugia, their effectiveness depends on local climatic conditions.

In water-limited ecosystems already at the edge of survivability, old-growth forests may not provide enough buffering to prevent increased tree mortality. In such cases, large trees may be replaced by smaller, more drought-adapted species.

The Pacific Northwest has a large variability in both micro and macroclimate in due in part to large areas of coastal proximity, as well as many mountainous regions. This means that many areas, whether it be due to north facing aspects, cool depressions, watershed areas, or high altitude, are in fact energy limiting rather than water limiting. As climate change progresses, these energy-limited areas may not only serve as refugia but could also facilitate the expansion of old-growth forests into newly suitable climatic zones.