Ratings of Tree Species Environmental Suitability

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Version 1.1

May 20, 2025

Executive Summary

Environmental suitability refers to the combination of climate and habitat factors that determine a species' ability to thrive in a particular location. British Columbia has **more than 40 different native tree species,** each with distinct patterns of environmental suitability, that drive their unique distributions across the province. While regional climate (e.g. temperature, precipitation and seasonality) is a strong driver of tree species environmental suitability, other local or site level factors such as soil type, moisture and nutrient regimes, also play an important role.

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, highlighting the need for an environmental suitability rating system for tree species.

This document describes an approach for rating environmental suitability for the tree species of British Columbia and adjacent jurisdictions in western North America to the **climatic and edaphic conditions of a site**. It describes the background and motivation for this process as well as clear definitions for each environmental suitability rating category and a logic-flow for how to apply them. It provides examples of rating decisions for different species and site series, outlines the development and review of the suitability ratings to date, and documents known issues and areas for improvement. Finally, it highlights a case study on Douglas-fir as a quantitative assessment of historical suitability ratings for this species.

The set of environmental suitability ratings are the basis for projecting tree species response to climate change at a site series level, as implemented in the Climate Change Informed Species Selection (CCISS) tool. While the environmental suitability ratings were initially developed as an input to the CCISS analysis, they are a knowledge base with many potential applications and are intended to be used in conjunction with other information (e.g., forest health considerations, management objectives, etc.) to inform reforestation prescriptions and other management decisions. The complete set of environmental suitability ratings are available through the BC Data Catalogue.

Acknowledgements

We would like to thank the members of the Provincial FOR Ecologist team both current and previous for their inputs to and thorough review of multiple components of this report. The following BC Ministry of Forests ecologists provided regional environmental suitability ratings for tree species: Allen Banner (ret.), Ray Coupe (ret.), Del Meidinger (ret.), Richard Kabzems (ret.), Tom Braumandl (ret.), Bob Green (ret.), Bruce Rogers (dec.), Heather Klassen, Sari Saunders, Deb MacKillop, Hardy Griesbauer, Mike Ryan, Erica Lilles and Daniel Sklar. Thank you to Destany Crane, Debora Obrist and Colin Mahony for additional support on this project.

Author contributions

WHM developed the conceptual framework, wrote the original draft of this document and curated the ratings dataset. CGC oversaw formal review and updates to the ratings dataset with support from VC and KD, wrote additional sections, reviewed/edited and incorporated external feedback on this document with support from VC, and conceptualized and completed the quantitative ratings validation.

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Introduction

Overview

This document outlines the creation and evaluation of environmental suitability ratings for tree species in British Columbia and adjacent jurisdictions at a site series level. These ordinal ratings are simplified environmental response curves that are amenable for Biogeoclimatic Ecosystem Classification (BEC) based climate change modelling at a site series level. The ratings reflect the probability for successful establishment and growth of a species across the entire environmental space of a site series in the baseline climate normal period of 1961-90.

The process described in this document aims to create a consistent set of definitions and criteria for assigning suitability ratings based on environmental (i.e. climate and site level (edaphic)) conditions alone. This was motivated by the need to separate environmental constraints from other non-climate related considerations (e.g. sawlog objectives and forest health) for accurate projections of changes in species suitability under climate change. Environmental suitability ratings are expert derived, aided by relevant data and information sources. Expert review of these ratings is ongoing, and quantitative methods are being developed to refine and support these initial expert ratings.

While the environmental suitability ratings were initially developed as an input to the Climate Change Informed Species Selection (CCISS) analysis (Mackenzie and Mahony 2021), they are a knowledge base with many potential applications. To that end, the FFEC is developing suitability ratings as a stand-alone open data product. Environmental suitability ratings are intended to be used in conjunction with other information (e.g., forest health considerations, management objectives, etc.) to inform reforestation prescriptions and other management decisions.

Motivation

As climate-change is dramatically altering forest ecosystems across the province (Morgan and Daust 2013), the need for a solely environment focused rating system for tree species at the Provincial level is clear. The current standard in the Chief Forester's Reference Guide (CFRG) applies a four-class suitability rating system (primary, secondary, tertiary, unrated/unsuitable) to each tree species in every recognized site series that occurs in British Columbia. The CFRG suitability ratings are defined as 'ecological suitability for a timber objective', and based on an assessment of three factors:

- silvicultural feasibility (environmental conditions);
- crop reliability (forest health considerations); and
- maximum sustainable productivity (ability to supply timber for sawlog production).

In the CFRG, each site series always has at least one primary species indicating the best species choice to meet the timber objective. These ratings have been used historically to inform the identification of preferred and acceptable species in the creation of stocking standards.

However, there is no consistent or documented approach to how a CFRG suitability rating is created from an assessment of these different factors. For example, the CFRG suitability ratings are generally higher for preferred timber species (e.g., Douglas-fir) and often lower for less commercially valuable species (e.g., subalpine fir). Broadleaved species, which are often less desirable for sawlog timber, were rated using different criteria and categories. Thus, the distinction of environmental consideration versus productivity objectives embedded into a suitability rating is currently unclear.

Furthermore, the CFRG ratings are adjusted within a site series to always present at least one primary species as the “best available species” for sawlog production regardless of the severity of site conditions (i.e. even if there are no species that establish and grow well in this site). While this is desirable from a sawlog management perspective, it may not be realistic in increasingly variable and potentially inhospitable climate and site conditions driven by climate change. In addition, CFRG ratings are not provided for mapped Biogeoclimatic (BGC) subzones/variants without formal site series i.e. areas outside the timber harvesting land base or currently remote with no active harvesting. This creates a gap in the information needed to adequately manage forest ecosystems in these areas under climate change.

Independent ratings for each of the 3 CFRG decision factors (silvicultural feasibility/ environmental conditions + reliability/forest health factors + management goal/intent) would be both more transparent and facilitate the development of stocking standards with different management goals. Here we aim to address this by creating independent ratings for environmental (i.e. climate and site level (edaphic)) conditions alone. Furthermore, considerations for climate change have been included in the CFRG ratings to different extents across the province (for example in Kootenay-Boundary footnotes 203/204 and Thompson-Okanagan). In all cases where species were uprated or downrated due to climate change, this has been noted with a footnote or other mechanism. However, these considerations have not been incorporated consistently at the Provincial scale. For these reasons, the CFRG species suitability ratings are problematic for alternative (non-sawlog) management prescriptions and for climate change projections of tree species performance into the future.

Species Environmental Suitability Ratings

This document describes an approach for assessing the environmental suitability of western North American tree species to the climatic and edaphic conditions of a site series, and for the creation of a species by site series suitability rating matrix for British Columbia and adjacent jurisdictions. This set of environmental suitability ratings are then the basis for projecting tree species response to climate change at a site series level, as implemented in the Climate Change Informed Species Selection (CCISS) tool. The intention of CCISS is to provide foresters with a climate change lens for their reforestation prescriptions whether developing conventional or non-sawlog management stocking standards or landscape level objectives. However, the CCISS tool only addresses environmental factors in building a reforestation prescription, under the expectation that foresters will integrate CCISS results with information from forest health specialists, management objectives, and other site-specific factors.

Environmental suitability has been defined as the probability of a species occurring in a specific location given the state of the environment (Drake and Richards 2018). In the context of the CCISS analysis, **tree species environmental suitability ratings** refer to the degree to which a tree species can be successfully established and maintained to maturity under specific climatic & edaphic conditions in the absence of independent limiting factors such as biotic (e.g. forest health) or abiotic (e.g. fire) disturbances. The species environmental suitability ratings are focused on the establishment phase of reforestation when trees are most vulnerable to environmental stresses, but these ratings should also reflect success through rotation. **The primary rating criterion is an assessment of the probability of successful establishment and growth of a species across the entire environmental space of a site series, in the baseline climate normal period of 1961-90.**

The baseline environmental suitability does not include regions where a species is absent in natural stands due to non-climatic factors such as unfavourable disturbance regimes or migration lags. However, environmental suitability ratings are being developed for some species in areas outside of their historical range ("outside home range" OHR) to better capture the species fundamental niche and leverage observations of successful reforestation in areas with low natural presence or abundance of a given species (see Appendix B). In some cases, species have been added upon review of available data, including historically less reliable species (e.g. Pw historically down-rated due to blister rust in the CFRG). Additionally, species with demonstrated suitability outside of their historical range (e.g. Lw) are given OHR environmental suitability ratings as described in Appendix B and Mackenzie and Griesbauer (2025). Finally, **deciduous tree species**, which were not consistently rated in the CFRG, have been given environmental suitability ratings following the same criteria used for conifers. Assessment of suitability ratings for deciduous species is ongoing, but still currently incomplete (see *Known Issues and Next Steps*).

Definitions

The environmental suitability ratings conceptually represent a response curve of the species' tolerances to environmental (climatic and edaphic) gradients (Fig 1). Environmental suitability ratings are intended to reflect the species' response in historical climates, i.e., prior to substantial climate change.

For the purposes of the CCISS analysis, **the reference historical climate is the 1961-1990 climate normals**. For example, if a species has exhibited lower regeneration success in recent years due to the warmer, drier climate of the last decade, this should not influence the environmental suitability rating assigned. The species should be evaluated based on suitability under 1961-90 climate and edaphic conditions.

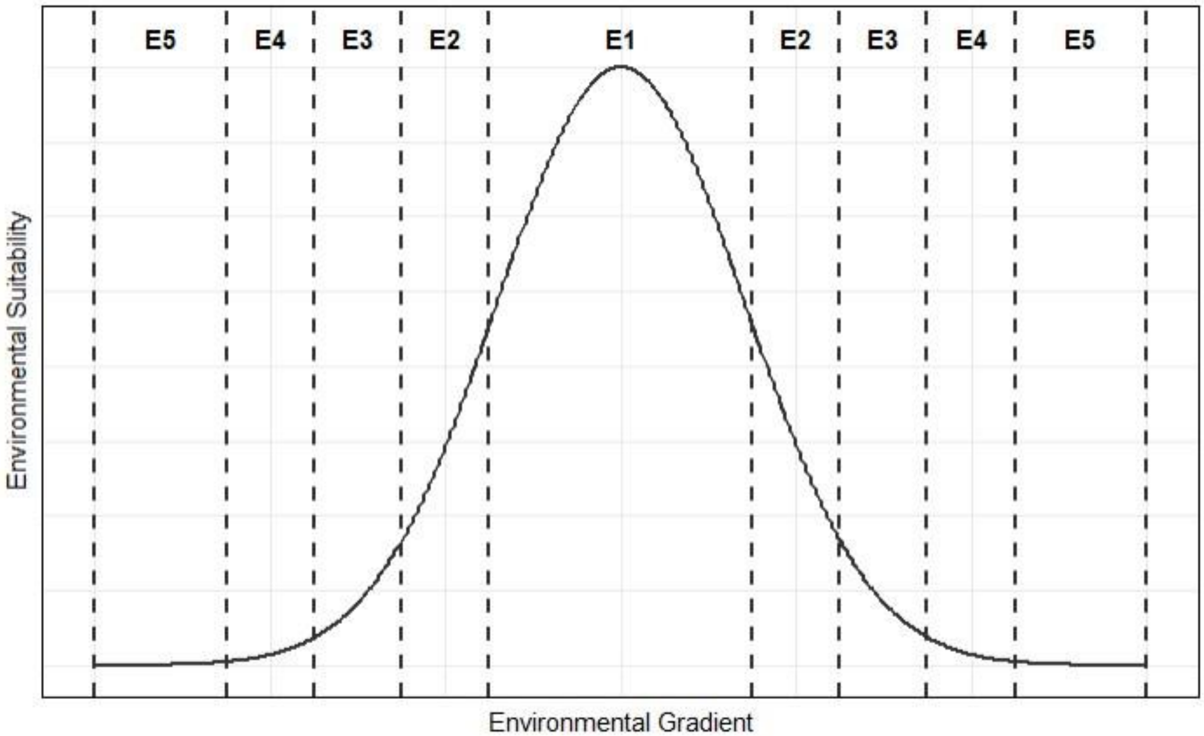

Figure 1: Conceptual model of Environmental Suitability Ratings as a response to environmental gradients.

We define environmental suitability using five categories:

- **E1 – High environmental suitability:** species well within its environmental tolerance range.
    - Widespread establishment/regeneration success on all climate and edaphic conditions representative of the site series. Expect continuous distribution at a landscape or stand level.
    - Good growth rate and form across the full range of site conditions.
    - Typically, no geographic or environmental limitations within the site series
    - The species is generally common and abundant in natural forests but may be of variable abundance where disturbance regime/stand age distribution is unfavorable (e.g., shade intolerant species in low disturbance landscapes).
- **E2 – Moderate environmental suitability:** species occurring outside its core environmental tolerance range.
    - The species has variable abundance in natural forests and/or is often concentrated in select site types of the site series (e.g., warm aspects, higher elevations, elevated micro sites). Patchy or zoned distribution at a landscape and/or stand level are common.
    - Not all site conditions of the site series may be suitable for successful establishment/regeneration.

  - Species success is reduced when established in the open and species is fully exposed to climate conditions (e.g., Cw establishment in open conditions in drier ICH climate is limited by heat and sun exposure).
  - Species may be more susceptible to occasional but expected climatic extremes leading to reduced growth, possible damaged form, or mortality (e.g. drought periods, snowpress, extreme temperatures, flooding).
  - The species may have good growth and survival where successfully established on suitable landscape positions or microsites. However, E2 rating may be used to reflect site series with broadly unsuitable site conditions across species (e.g. frost prone locations, or overly wet Spruce-horsetail site series).
  - May express slow growth rates or poor form across all site series conditions (e.g. site series within woodland subzones or xeric sites).
  - Geographic, topographic, or other environmental limitations are common.
- **E3 – Low environmental suitability:** species occurring near the limits of its climatic or site tolerance.
  - Species is likely to be adjacent to climates or site conditions that do not support its growth and survival.
  - The species is generally infrequent in natural forests and/or has significant environmental limitations in the site series. Only specific landscape positions or microsites in a site series are likely to have establishment/regeneration success, but subsequent good growth is possible when these conditions are met.
  - The species requires canopy cover for establishment and growth. Sites that are fully exposed and open to ambient climate are unsuitable.
  - E3 can be applied in BGCs with very limited growth potential (e.g. site series in parkland subzones) or that have harsh site conditions for trees (e.g. very xeric sites with shallow discontinuous soils).
  - Climatic extremes have a higher probability of causing reduced growth, damage or mortality (e.g. drought periods, snow damage, extreme temperatures).
  - Species express very low growth rates across all conditions (e.g. site series in parkland subzones or treed rock outcrops).
  - Multiple limiting environmental factors are common. Limited viability of the site series for forestry may support an E3 rating for all species in that site series.
- **E4 – Minimal environmental suitability:** species at the very limit of its climatic or site tolerance. Species may occur sporadically but typically not forming any component of the forest canopy.
  - Scattered occurrence of individuals in natural stands but not reaching main canopy (e.g., Hw in the western SBSmc2).
  - Species may have persistent cover but low survival and poor growth.
  - Species assigned an E4 rating are not commercially viable due to poor survival and growth.
- **E5 – Not suitable**:** species is outside of its environmental tolerance range.
  - Environmental constraints preclude successful establishment, and species is not present in natural forests.

**E5 has been manually assigned only if the species was previously ranked as suitable for a site series in the CFRG and is reassessed as unsuitable. E5 rating is assumed where a species has no rating (i.e. is absent) for a given site series in the suitability dataset.

Decision logic flow

The following logic flow was developed to guide the process of assigning/reviewing species environmental suitability ratings in conjunction with the above definitions. This logic flow may continue to be refined as the process is applied to more site series and species as well as with the continued development of quantitative methods to predict environmental suitability.

Step 1. Assess Species Occurrence in BGC and Site Unit

- Species occurs (within environmental tolerance/fundamental niche)
    - E1-4
- Species absent (site is outside of environmental tolerance/fundamental niche)
    - E5

Evidence:

- Presence in Provincial BEC Database: Site series summary data; or,
  Occurrence in CFRG

Step 2. If Species Occurs, Assign Initial Environmental Suitability Rating from BEC Data

Evidence:

- Abundance and constancy of species in natural stands (Realized Niche)
    - High –E1, Med-E2, Low-E3, Trace- E4

Step 3. Modify Initial Suitability *

*Multiple conditions of up/downweighing could alter rating by >1

Evidence:

- CFRG rating + footnotes / Operational plantation success
- SIBEC
- Professional experience and observation.

Maintain initial rating where:

- Low(er) CFRG rating but no environmental constraint footnotes (i.e. the species was downrated in the past based on timber values)

Upweight initial rating where:

- High CFRG rating and no environmental constraint footnotes (+1)
- Widespread historical plantation success (pre 1990)

- High SIBEC values

Downweight initial rating where:

- Low CFRG ratings and presence of environmental constraint footnotes (-1)
- Poor performance in operational plantings (pre 1990)
- Subpar SIBEC values

Step 4. Further adjustments:

- **Reduce to E3 or E4**: Evidence of 'decline' in natural or planted stands where reduced vigour and growth occurs in stands after successful establishment. For example, Pl planted in ICHmw1 does well initially but both growth and form decline as the species matures. This decline is not directly attributable to single forest health event or climate change but may be due to a combination of climatic or site conditions stress and forest health factors.

Rating and Review Process to Date

Initial suitability ratings were assigned in 2017 by A. Banner (Coast and North Area), T. Braumandl (Kootenay-Boundary, Thompson-Okanagan), W. MacKenzie (Alberta), D. Meidinger (USA) for all regions using the following information resources.

1. Chief Forester's "reference_guide_incorporating_lmh_70_edits_Oct_2017.xlsm". Rankings modified from primary, secondary, tertiary ratings used in this file using above definitions.
2. Geographic and Site limitation footnotes from CFRG.
3. Relevant BGC Field Guides.
4. Site Index Estimates by BEC Site Series (SIBEC) where available; https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/ecosystems/sibec
5. Krajina, Klinka, and Worrall 1982. Distribution and Ecological Characteristics of Trees and Shrubs of British Columbia.
6. Klinka, Worrall, Skoda, Varga. 2000. The distribution and synopsis of ecological and silvical characteristics of tree species of British Columbia's forests.
7. Chapter 6 (Ecological Principles: Applications; Silvical characteristics and regeneration implications of major tree species) from Regenerating British Columbia's Forests (1990).
8. Data summarized from Provincial BEC database provided by Will MacKenzie and Kiri Daust - Edatopic grids with tree species abundance for each BEC variant.
9. Ecologists' field experience.

Subsequent review of this output in 2018-2019 led to some clarification of definitions and modifications to initial ratings attributes. The initial ratings were then reviewed in 2021 by regional experts. Complete reviews occurred in the Coast Area (H. Klassen, S. Saunders), Thompson-Okanagan (M. Ryan), Kootenay-Boundary (T. Braumandl), Northeast and Alberta (R. Kabzems). Spot checks were undertaken in Omineca (B. Rogers, H. Griesbauer), Skeena (E. Lilles), and

Cariboo Region (R. Coupe). D. Meidinger did a second assessment of USA ratings in 2023 following field visits and re-modeling of the USA BGC maps (MacKenzie and Meidinger 2024).

In November 2024-April 2025, there was another thorough round of review by regional experts, and updates were made to the environmental suitability ratings definitions and dataset. The definitions as written in this document reflect this most current round of review, and the 2025 open data (BC data catalogue) version of the environmental suitability ratings reflect the updated definitions for the regions that were reviewed (Coast, Omenica, Cariboo, Thompson-Okanagan, Kootenay Boundary, Skeena). For additional details see Appendix D: Regional updates -change summary.

In some cases, this assessment has resulted in commercially valued species receiving lower environmental suitability ratings relative to the suitability rating in the CFRG. Species indicative of a BGC unit may also receive a lower rating in some cases (e.g., Fd as an E2 in the IDFdk4 where cold temperature limitations are widespread). Site series near the limits of tree species environmental suitability (e.g., parkland climates, sites with very thin soil veneers) will often have no tree species with an E1 rating (high environmental suitability), due to general constraints to trees in these environmental conditions.

Additional quantitative approaches are being developed to assess and predict species environmental suitability. In 2024, an ordinal random forest model was trained from these ratings with climate and site-level environmental variables. This model was then used to predict environmental suitability ratings for all site series not previously rated in the CFRG. This process was also used to identify inconsistent expert species ratings which should be reassessed. Site series with extra-edatopic factors (cold-air site series, floodplains, etc.) have been flagged in the data set but are not yet explicitly used in the modelling. Furthermore, a Bayesian hierarchical model is in development; this approach incorporates expert environmental suitability ratings as prior knowledge to inform climate and edatopic based predictions of tree species abundances across the province (using the Provincial BEC database) (see Appendix F: Quantitative ratings validation). These and other quantitative approaches will assist in the continued review of environmental suitability ratings and will inform areas for potential future refinement.

Known issues and Next Steps

While the definitions of environmental suitability and the species ratings have been thoroughly reviewed to this point, given the scale of this project, known issues and areas for improvement still remain. Documenting these areas will be key for future improvements in development and implementation of these concepts and associated datasets.

Gaps in review

Review of the environmental suitability ratings by forest experts has been ongoing since 2018 (see *Rating and Review Process to Date*). However, as review has progressed over time, updates and clarifications to the ratings definitions have been made, and the E4 category has been added. Not all regions of the province have been reviewed to the same extent using this most recent set of definitions and categories (as of May 2025). Furthermore, some regional reviews are still in progress including Kootenay Boundary, Haida Gwaii, Northeast, and Skeena regions (Appendix D). Outside of the province, the Northwestern US and Alberta have also not been reviewed in this most recent round. This does not necessarily indicate an issue with the quality of these data in these regions, however, the interpretation of suitability ratings from these areas may be inconsistent when comparing with other more recently updated regions (see Appendix D). Region wide review is ongoing, with the objective of having any gaps in review brought up to date by the next formal release of the suitability ratings dataset. Non-forested ecosystems (i.e. realm/class) that contain trees were inconsistently reviewed across the province (e.g. Midbench Floodplains (Fm), Grasslands (Gg), Wetland swamps (Ws) etc.), with more thorough review in areas of higher prevalence of these ecosystems such as the Coast.

Validation for adjacent jurisdictions

Quantitative validation of the Environmental Suitability ratings dataset currently is underway for the tree species of British Columbia, using the BEC plot dataset (see Appendix F). However, similar validation has not yet been carried out in adjacent jurisdictions (i.e., Northwestern US and Alberta), although some non-quantitative validation has occurred (e.g., site visits and expert review). Quantitative validation presents a number of inherent challenges, including access and alignment of datasets and methodologies from different jurisdictions, and adequately accounting for potential sources of modeling error for species whose ranges cross jurisdictions and thus incorporate data from multiple sources. Fortunately, Bayesian modeling provides a powerful framework in which to explicitly incorporate and account for these potential sources of error. Therefore, the methodology which has been used for validating the BC BEC plot data may also be effective for regional validation in adjacent jurisdictions. Nonetheless, this will require additional engagement and collaboration with other ministry personnel, across provincial and international boundaries, which is both time and resource intensive. This is an important next step in the refinement of the Environmental Suitability ratings dataset, particularly as more species with historic ranges outside of BC are predicted to move into the province with climate change.

Broadleaf species

**NOTE: The terms 'broadleaf and 'hardwood' are used interchangeably to denote non-conifer tree species. Mixed-wood refers to a forest management and/or forest ecosystem type with both conifer and non-conifer (i.e. broadleaf) species with stands having 25-75% broadleaf cover.*

Historically, broadleaf* species were not comprehensively rated in the CFRG, as they were not typically considered a desired species for planting due to potential competition with conifer species establishment and growth (Harper and Roach 2014). Thus, these species were rated using a different system than for conifer species, and there were limits to their planting densities (B.C. Ministry of Forests 2000). However, over time, this mindset has shifted to acknowledge the importance of broadleaf species and mixed-wood systems in sustainable forest management with multiple objectives including wildlife habitat, forest health, wildfire resiliency, and cultural values (Harper and Roach 2014). Yet, despite these openly agreed upon benefits to forest ecosystems and extensive research in this area, broadleaf and deciduous species have not been consistently incorporated into forest policy and management.

For these reasons, we lack comprehensive information regarding the environmental suitability of deciduous species at the site series level across the province, and information is unevenly spread among different broadleaf species and biogeoclimatic zones. This information gap is reflected in the Environmental Suitability ratings dataset (see Appendix E). However, some amount of this variation can be attributed to differences in the natural geographic distributions of these species.

A further concern is that the Environmental Suitability ratings definitions for broadleaf species have evolved over time. Earlier iterations, development, and review processes placed distinct emphasis on post disturbance successional dynamics. For example, in the 2018-2019 review (see *Rating and Review Process to Date*), an E1 rating was only given where a species was considered the dominant deciduous tree species in the mature stage (e.g., middle bench floodplains). A rating of E2 was given where the deciduous species would thrive in disturbed sites and an E3 was given where the deciduous species has limited establishment success following disturbance. We have now revised these guiding principles, **with the recommendation to apply the same set of environmental suitability ratings to broadleaves as to conifers** (E1-E5 definitions pages 4-5).

While Environmental Suitability ratings definitions in this report are intended to be applied consistently to all species, we acknowledge that the seral and early successional dynamics inherent to the biology of many deciduous species can make a ‘one size fits all’ rating system challenging. We encourage the practitioner to determine and apply the environmental suitability ratings based on life history of each species independently, rather than in comparison to conifer species. For example, if a deciduous species can establish and grow well in the environmental conditions given site, it could receive a high rating, even if it does not make it to an older, more mature stand age. Furthermore, variable abundance of deciduous species under unfavorable disturbance regimes does not necessarily preclude a high rating, given that the climate and edaphic conditions of the site series are well within the species’ environmental tolerance range.

Moving forward, we aim to fill in the ratings of deciduous species where they are missing, with consistent definitions and terminology. This comprehensive knowledge base will be necessary to inform sustainable forest management and mixed-wood approaches for achieving multiple priorities under future climates and disturbance regimes across BC.

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Appendix A: Examples of Environmental Suitability Ratings Decisions

Some decision/discussion examples for environmental suitability ratings:

1. Bl and Sx/Se in ESSF forests. Both generally receive an E1 rating even where Bl dominates the mature forest. Regeneration of either species is likely to be highly successful. However, where growth potential is lower reflecting generally limiting environmental conditions, such as in woodland and parkland environments, lower suitability ratings are applied to all site series, see point 2 below.

2. Increasingly cold and snowy conditions with elevation are generally stressful for tree species in the woodland and parkland environments leading to increased tree spacing and reduced vigour and form (esp. parkland). Species in these BGCs have generally been given max suitability values of E2 and E3 respectively.

3. Cw establishment in open conditions (e.g., clearcut) is not generally an issue in coastal or wetter interior environments and is given a rating of E1. However, in some ICH climates, heat and sun exposure may limit the species in the establishment phase – these likely also represent climates/sites where the species is less suitable and an E2 or lower rating may be assigned. Similar factors affect Fd where planting under partial canopy is recommended/required (footnote 27).

4. Where a species' previous reference guide rating was lower due mainly to perceived silvicultural/wood quality concerns (e.g., Bl, Cw, Hw), a higher rating was often assigned based on environmental suitability. (e.g., Bl previously assigned a E2 in some ESSF subzone/variants but now assigned an E1 for some site series (e.g., SBSmc2, Kamloops ESSF)).

5. Where a species' previous reference guide rating was high due mainly to high timber desirability (e.g., Fd), but portions of the site series range are not considered highly suitable a lower rating is often applied even though on the suitable portions of the site series the species may perform well (e.g. Fd on N facing slopes in the BGxh1).

Appendix B: Outside home range (OHR) suitability ratings

The term "outside home range" (OHR) refers to tree species environmental suitability ratings that have been assigned in a geographical area (i.e. biogeoclimatic subzone-variant) where the species does not occur naturally. In some cases, OHR species were restricted by something other than climate, such as migration limitations (for example, western larch) or forest health factors (for example, Western white pine limited by blister rust). Because OHR species have differences in the climatic baselines of field trials and are often limited in available data and supporting documentation, their incorporation into the CCISS tool and species environmental suitability ratings must be treated with caution.

Inclusion in the CCISS tool

Currently, OHR environmental suitability ratings are only included in the CCISS tool when there is strong evidence to suggest that a species was well suited to the climatic regime of the historical reference period (1961-1990). Strong evidence includes species that have been capable of successful establishment, productivity, and resilience in an area for at least several decades as evidenced in long-term plantings of the species. In other words, the area lies within the species' historic fundamental, but not realized, niche. These trees may not occur naturally in the area of interest (AOI) due to low migration rates, geographic isolation, or other non-climatic factors, but will likely be successful in this area immediately.

OHR species may receive E1-E4 environmental suitability ratings upon careful review of available information. All CCISS projections based on OHR species suitability ratings are indicated as 'Outside Home Range (OHR)' in the CCISS tool with the option to toggle OHR suitability ratings on-off (see "Methods – OHR" tab in the CCISS tool). For a detailed description of the inclusion criteria for off-site/OHR species into the Environmental suitability and CCISS modeling framework, see Mackenzie and Griesbauer (2025) with attention to Table 1.

Currently, CCISS includes OHR occurrences of western larch (Lw), Douglas-fir (Fd), and Western white pine (Pw), supported by the following evidence: **Western larch -** Range modelling using historic climates strongly suggests the suitability of western larch beyond its historical range (Rehfeldt & Jaquish 2010). **Douglas-fir** - Successful operational and research off-site trials >30 years of Douglas-fir in the AOI. E.g plantations in the ICHmc2 of the Skeena region. Extrapolated suitability into intermediate site or climatically similar areas. E.g. Douglas-fir added to SBSdk and ICHmc2 based on plantation evidence – extend into the ICHmc1 which is both a climatic and geographic intermediate between the two. **Western white pine** - Successful operational and research off-site trials >30 years of Western white pine in the AOI. E.g plantations in the ICHmc2 of the Skeena region.

Caveats and considerations for application

We have included OHR species where reasonable evidence exists to harness the best available knowledge and more accurately capture the species' fundamental climate niche. Species like western larch are being actively managed and planted outside of their historical range. Excluding OHR species would limit the effectiveness of the CCISS tool to inform current forest management practices.

However, often suitability to the historical baseline climate (1961-1990) is not proven. Successful operational and research trials that extend well into the 1961-1990 period are less common. There are limitations to range models and there is uncertainty in suitability extrapolated into intermediate or climatically similar areas. We have included the option to remove OHR suitability ratings from CCISS projections as there is less certainty in the accuracy of these ratings. There is some hesitation around projecting off-site species into future climate given the already high levels of uncertainty in assisted migration. Users should interpret the results with caution and use other lines of evidence and local knowledge when making decisions.

As with all species planted in an assisted migration framework, risks associated with planting off-site tree species will also depend on climatic factors, including the (i) climatic distance between current and future climates in a region, (ii) uncertainty in projected future climates, and (iii) current climatic variability and extreme events beyond the tolerance of species. Additionally, there can be unintended consequences to assisted migration, such as the concerns raised by many First Nations over the planting of western larch implications to wildlife habitat.

Appendix C: Chief Forester Reference Guide (CFRG) Footnotes

C1. Environment Limiting Footnotes

Footnote	Footnote text	Footnote Type code
13	most suitable at upper elevations	H
10	most suitable on cool aspects	H
12	most suitable on cold air drainage sites	H
15	most suitable in the northern portion of the BGC unit	H
27	partial canopy cover required for establishment	H
69	recommended at upper elevations only when planted in the southern portion of the BGC unit	H
46	most suitable to area north of the Dean Channel	H
207	obstacle planting recommended	H
24	most suitable in wetter portion of the BGC unit	A
28	limited by moisture deficit	A
14	most suitable at lower elevations	C
9	most suitable on warm aspects	C
16	most suitable in the southern portion of the BGC unit	C
205	limited by cold temperatures	C
22	most suitable in the southern Gardner Canal-Kitlope area	C
32	limited by growing-season frosts	F
34	risk of snow damage	S
66	Recommended as preferred where risk of snow damage is low or risk of frost damage on spruce is high	S
41	limited by poorly-drained soils	W
55	acceptable on subxeric and submesic sites	W
1	most suitable on elevated microsites	W
17	most suitable in the western portion of the BGC unit	Tc
18	most suitable in the eastern portion of the BGC unit	Tm
20	not suitable on the outer coast	Tc
44	suitable in areas with strong maritime influence	Tc
45	suitable in areas with strong continental influence	Tm

H = Heat related limitation (may include aridity); **A** = Aridity limitation; **C** = Cold limitation; **S** = Snow limitations; **F** = Frost limitations; **Tm/c** = Maritime/Continentality Limits; **W** = Overly wet site conditions.

C2. Biogeographic Range Limitations

Footnote	Footnote text
60	Acceptable only in the Squamish District
61	Acceptable only in the Squamish District on cold air drainage sites
19	not suitable on Haida Gwaii
21	suitable only on the mainland

C3. Site or Soils Limiting Footnotes

Footnote	Footnote text
2	most suitable on thick forest floors
3	most suitable on coarse-textured soils
4	most suitable on medium-textured soils
6	most suitable on very nutrient-poor sites
7	most suitable on nutrient-medium sites
8	most suitable on steep slopes
11	most suitable on crest slope positions
39	avoid exposed and windy sites
42	most suitable on sites with a fresh soil moisture regime
52	most suitable on sheltered microsites with deep soils

Appendix D: Regional updates- detailed change summary

Based on the review of suitability ratings from November 2024- May 2025 by regional experts (FOR ecologists) the following updates were made from the previous version of the environmental suitability ratings for BC (2021). These updates are based on a combination of: improvements to the environmental suitability ratings definitions, updates to BEC mapping and site series designations (BEC v13), and additional thorough review by experts supported by a combination of knowledge and experience, BEC guides, literature review, BEC plot data, and other sources.

Completed:

Region: Coast

Reviewed by: Dr. Sari Saunders, Heather Klassen

6.3% of reviewed ratings were updated (192/3027)

3% of total ratings were added where previously missing (91/3027)

Region: Omineca

Reviewed by: Daniel Sklar

13.6% of reviewed ratings were updated (46/339)

Region: Cariboo

Reviewed by: Kristi Iversen

15.2% of reviewed ratings were updated (170/1114)

9% of total ratings were added where previously missing (100/1114)

Region: Thompson-Okanagan

Reviewed by: Mike Ryan

42% of reviewed ratings were updated (566/1339)

5% of total ratings were added where previously missing (66/1339)

Region: Kootenay Boundary

Reviewed by: Deb Mackillop

16.3 % of reviewed ratings were updated (118/724)

Region Skeena and Northeast

Reviewed by: Daniel Sklar, Erica Lilles

11% of reviewed ratings were updated (135/1227)

15.2% of total ratings were added where previously missing (187/1227)

Appendix E: Environmental Suitability ratings for Deciduous tree species

Table E1. Native deciduous species of British Columbia and their respective number of environmental suitability ratings in the current dataset. N ratings (spp) is the number of total site series where a species has been rated and N ratings (zone) are the total number of ratings for each species, broken down by Biogeoclimatic Zone.

Species code	Common name	Scientific name	BGC zone	N ratings (spp)	N ratings (zone)
At	Trembling aspen	*Populus tremuloides*	BG	701	11
			BWBS	701	93
			CDF	701	2
			CWH	701	10
			ESSF	701	17
			ICH	701	207
			IDF	701	105
			MS	701	39
			PP	701	6
			SBPS	701	34
			SBS	701	174
			SWB	701	3
Ep	Paper birch	*Betula papyrifera*	BG	627	6
			BWBS	627	77
			CDF	627	1
			CWH	627	126
			ESSF	627	1
			ICH	627	207
			IDF	627	71
			MS	627	23
			PP	627	6
			SBS	627	109
Act	Black cottonwood	*Populus trichocarpa*	BG	485	9
			CWH	485	83
			ESSF	485	21
			ICH	485	161
			IDF	485	55
			MS	485	24
			PP	485	6
			SBPS	485	7
			SBS	485	119
Dr	Red alder	*Alnus rubra*	CDF	293	12
			CWH	293	281
Mb	Bigleaf maple	*Acer macrophyllum*	CDF	186	12
			CWH	186	165
			IDF	186	9

Ac	Poplar	Populus bals., tric, or hybrid spp	CDF	125	11
			CWH	125	98
			ICH	125	2
			IDF	125	12
			SBPS	125	1
			SBS	125	1
Acb	Balsam poplar	*Poplar balsamifera*	BWBS	64	63
			SWB	64	1
Kc	Cascara	*Frangula purshiana*	CDF	33	6
			CWH	33	27
Ra	Pacific arbutus	*Arbutus menziesii*	CDF	29	15
			CWH	29	14
Gp	Pacific dogwood	*Cornus nuttallii*	CDF	27	5
			CWH	27	22
Qg	Garry Oak	*Quercus garryana*	CDF	20	15
			CWH	20	5
Up	Pacific crab apple	*Malus fusca*	CDF	19	1
			CWH	19	18
Wt	Stika Willow	*Salix sitchensis*	CWH	13	13
Mv	Vine maple	*Acer circinatum*	CWH	7	7
Vb	Bitter cherry	*Prunus emarginata*	CWH	3	3
Wp	Pacific willow	*Salix lucida*	CWH	2	2
Ws	Scouler's willow	*Salix scouleriana*	CWH	2	2

Appendix F: Quantitative Ratings Validation

F1. Bayesian modeling

A Bayesian hierarchical modeling approach was used to quantitatively assess and validate the species Environmental Suitability ratings using the provincial BEC plot database. This approach incorporates expert ratings from environmental suitability tables as prior knowledge to inform climate and edatopic based predictions of tree species relative abundances (BEC plot-level) across the province.

Bayesian inference combines prior knowledge with sample data to inform the posterior probability distribution of a given outcome (van de Schoot et al. 2014). In this application, the expert suitability ratings provide an excellent baseline of prior knowledge (i.e., expert beliefs) regarding species' tolerances to environmental (climatic and edaphic) gradients across the province. The provincial BEC plot database then provides a wealth of sample data (i.e., evidence) of actual species environmental tolerance to inform and update these subjective prior distributions.

While relative abundance of a given tree species at the plot level is not a perfect proxy for environmental suitability, it is a consistently measured metric of species performance and can provide valuable insights into habitat preferences and climatic or site level factors that may limit a species distribution and/or growth (Lunghi et al 2018). Increases or decreases in environmental suitability ratings do not necessarily scale linearly with relative abundance, but are generally positively correlated (VanDerWal et al. 2009, Weber et al. 2017), and thus we use this approach to mathematically combine these expert generated and field sampled datasets (Fig F1).

F2. Modeling approach: Douglas-fir Case Study

We developed three corresponding linear hierarchical regression models using the 'brms' package in R (v 2.2.1, Bürkner 2017) in this analysis: 1) the prior model, 2) weakly informed data model, and 3) an expert informed data model. The output from the prior model is used both to inform and compare to the outputs of the posterior data model following a similar approach by Murray et al. (2009). Here we show an example of this approach for Douglas-fir (*Pseudotsuga menziesii;* abbreviated Fd) a widespread, ecologically and economically important conifer species in BC and Western North America. To begin, we combined the environmental suitability ratings (v 13_4) with all BEC plot data for this species (Fd) by site series (n = 2603, Fig F1). There was an average of 7.7 plots (min=1, max =76) corresponding with each site series level suitability rating for Fd, with a disproportionate number in zonal sites (i.e. 01/101 site series).

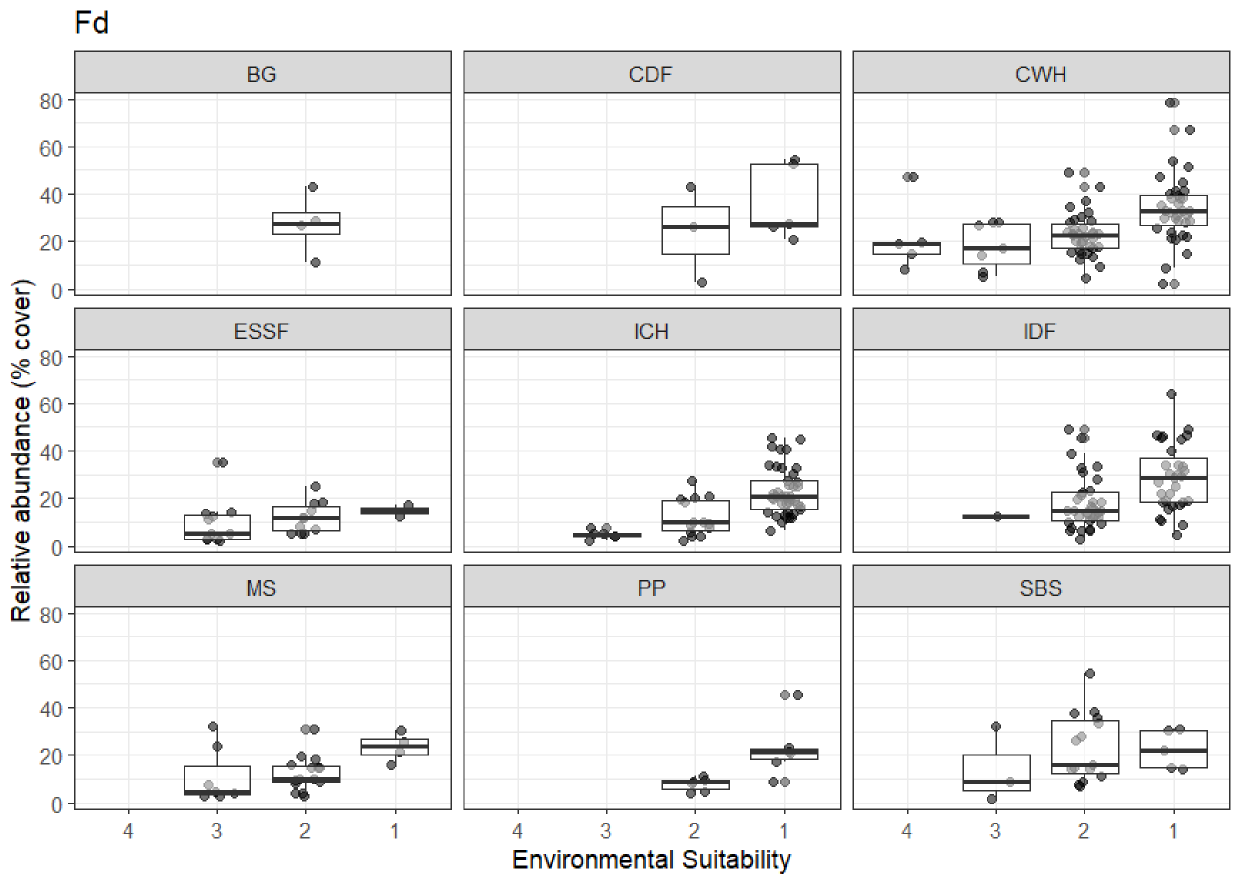

Fig F1. Combined dataset of BEC plot relative abundances (% cover) for Douglas-fir (Fd) by Environmental suitability ratings (E 1-4) for all rated site series in BC (n= 2306). Box and whisker plots indicate the median, upper (75th) and lower (25th) quartile values (boxes) and the minimum, maximum values of 1.5 x the inter quartile range in the whiskers (whiskers) for each suitability class. Points show the plot relative abundances in each suitability class averaged by site series. Data are plotted by Biogeoclimatic zone (BGC). BG= Bunchgrass, CDF=Coastal Douglas-fir, CWH= Coastal Western Hemlock, ESSF=Engleman Spruce Subalpine Fir, ICH= Interior Coastal Hemlock, IDF= Interior Douglas-fir, MS= Montane Spruce, PP= Ponderosa Pine, SBS= Sub-boreal Spruce.

Prior model

The purpose of the prior model is to incorporate information from the expert suitability ratings into a model to generate parameter estimates (i.e. posterior distributions) which can then be used as prior distributions in a subsequent data model. To do this, we simulated plot level relative abundance/ percent cover values (for tree species) based on pre-set bounds for each suitability rating category, informed by the literature (modified cutoffs proposed by Mariotte 2014) and expert knowledge (Fig F2a). For each species, we first determined the number of BEC plots within each given suitability rating category (i.e. number of data points for each box and whisker plot -Fig F1) Then for each rating category (E1, E2, E3, E4), we simulated the same number of relative abundance values within the following bounds:

- E1 (High environmental suitability): 12.01% to 100% plot cover

- E2 (Moderate environmental suitability): 2.01 to 12% plot cover
- E3 (Low environmental suitability): 0.51 to 2% plot cover
- E4 (Minimal environmental suitability): 0 to 0.5 % plot cover

We then used a decreasing power law function (λ =1.5) to smooth the distribution of the simulated data to reflect a negative exponential curve commonly observed in species abundance datasets (few observations with high relative abundance, many observations with low relative abundance) (Fig F2b).

a) b)

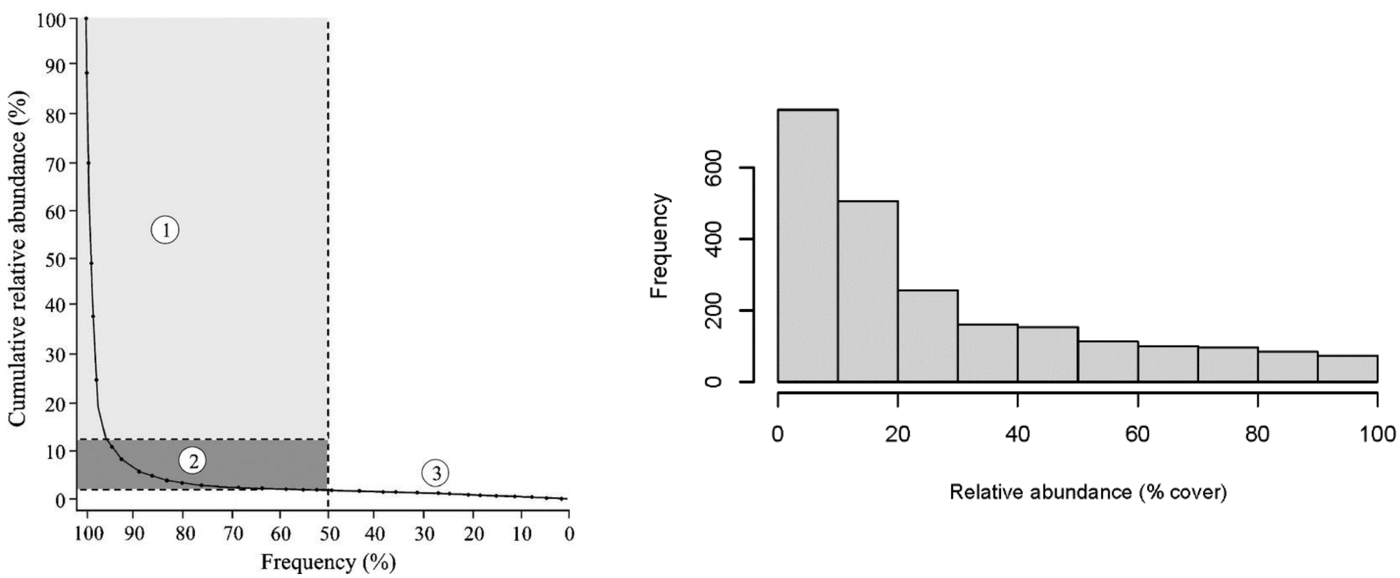

Fig F2. a) In the conceptual framework by Mariotte 2014, Dominants (1) are considered to be 12% or greater of the cumulative relative abundance of the plant community at a site, subordinate species (2) occupy 10% of the plant community from 12-2% relative abundance, and transient species (3) would have a cumulative relative abundance below 2%. For the purposes of this modeling exercise, we have assigned E1 rating as dominant species (12% and greater), E2 rating as subordinate (2-12%), and we split the transient category between E3 (0.5-2%) and E4 (<0.5%) b) Histogram showing the distribution of the simulated dataset of plot relative abundances based on suitability ratings for Douglas-fir (Fd) using the modified cutoffs described (n=2306).

We then modeled these simulated relative abundances in response to plot level and regional level climate parameters as well as edaphic (site level) information (Eq1). Response values were square root transformed and modeled with a skew-normal distribution. Plot level climate parameters included 25 expert derived climate variables downscaled to the 20 x 20m plot scale resolution through the climR package in R (v1.09, Daust et al. 2024). These variables were then collapsed into three Principal Components axes (PC1, PC2, PC3) capturing 91% of the total variation in climate space across all sites. Regional level climate was informed by a categorical predictor of biogeoclimatic zone of each plot location. Site level edaphic parameters were informed by a random (i.e. group level) categorical predictor of the edatopic space (i.e. soil moisture regime x soil nutrient regime combination) of each plot location based on site series (e.g. 3-4C, 1-2 A-B). In the following, the term 'edatope' is used interchangeably with edatopic space.

Eq 1 $y_{ij} = \beta 0 + \beta 1 \cdot PC1_{ij} + \beta 2 \cdot PC2_{ij} + \beta 3 \cdot PC3_{ij} + \beta 4 \cdot Zone_i +$

$[u_{j0} + u_{j1} \cdot PC1_{ij} + u_{j2} \cdot PC2_{ij} + u_{j3} \cdot PC3_{ij}] + \sigma_{ij} + \alpha_{ij}$

Where:

y_{ij} is the simulated relative for the i-th observation (i.e. plot) in the j-ith edatope. $B0$ is the global intercept, $\beta 1, \beta 2, \beta 3$ are the fixed effect coefficients (i.e. slopes) for PC1, PC2, and PC3, respectively and $\beta 4$ is the coefficient (i.e. slope) for biogeoclimatic zone. Hierarchical components of the model [indicated in brackets] include μ_{j0} the random (i.e. group-level) intercept for the j-th edatope, and $\mu_{j1,}\ \mu_{j2,}\ \mu_{j3}$ the random (i.e. group-level) slopes for PC1, PC2, and PC3 within the j-th edatope. σ_{ij} is the residual model error for the i-th observation in the j-ith edatope and α_{ij} is the skewness parameter for the response.

For the prior model, we used the 'brms' package's default priors including a normal distribution with a mean of 0 with a standard deviation of 4 for the global intercept and the skew (α) term, flat (non-informative) uniform distribution $[-\infty, \infty]$ for all β parameters, and a Student's t-distribution for all u hyperparameters (random i.e. (group level) intercepts and slopes) and residual error (σ), with 3 degrees of freedom, a mean of 3.9, and a standard deviation of 2.5.

Hierarchical models were run in the 'brms' package in R (v 2.2.1, Bürkner 2017) with 2 chains, each with 5000 iterations, including a 2000 iteration warm-up phase. Convergence was assessed using the Gelman-Rubin diagnostic ($\hat{R}$=1) and trace plots to visually inspect mixing of the chains. Adequate sampling was assessed with Effective Sample Size (Bulk & Tail ESS) estimates >1000. We used posterior predictive checks to assess the model's fit to the observed data (Fig F3).

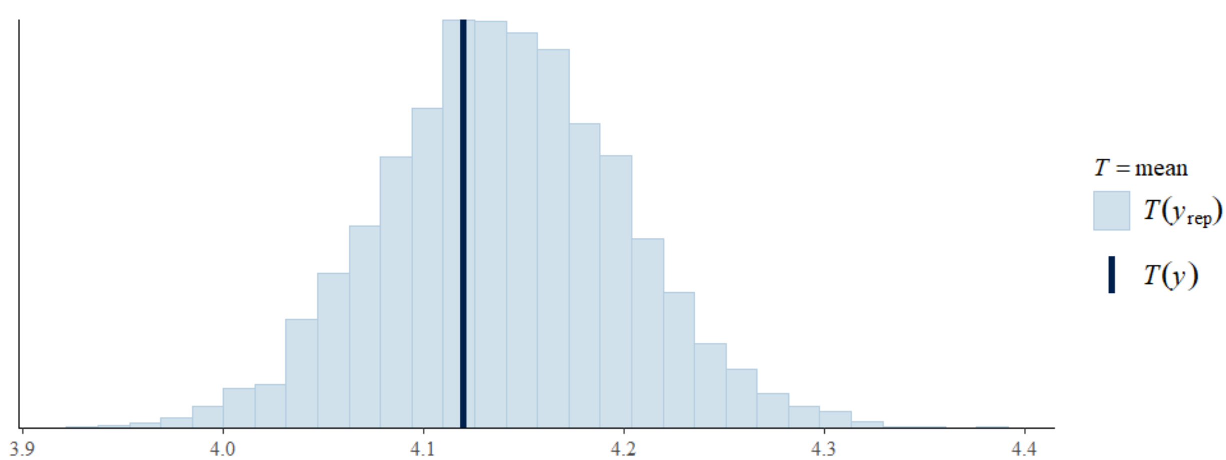

Fig F3. Posterior predictive checks of the prior model trained on simulated data (square root transformed) of plot relative abundances for Douglas-fir. The dark blue line indicates the mean of the distribution of the simulated response data (y) and the light blue histogram shows the model predicted data. As the dark blue line is in the center of the histogram, it indicates the model is able capture the true mean of the response data.

After assessing model fit, we generated parameter estimates (mean and standard deviations) for each model parameter using the summary function in 'brms' (Table F1). These values are then used as Bayesian priors in the expert informed data model (see next section, *Data models*). We then resampled from the prior model using the argument sample_prior = "only" to generate full posterior distributions from our parameter estimates for later comparison to the data model poteriors.

Table F1. Prior model estimates (mean) and standard deviations (sd) for regression coefficents (β terms), group level hyperparameters (u terms) and error terms (α, σ). All estimates are normally distributed. PC1, 2, 3 refer to the first 3 Principal components axes of 25 climate parameters. Zone estimates ($\beta 4$) are relative to (i.e. offsets from) the categorical baseline which was the Bunchgrass zone (BG) (i.e. reference level). Zone acronyms in Fig F1 caption.

Parameter	Estimate (mean)	Error (std.dev)	95% Credible interval
Intercept	1.77	0.51	[0.74, 2.72]
PC1 (β1)	-0.08	0.03	[-0.15, -0.02]
PC2 (β2)	-0.1	0.06	[-0.22, 0.02]
PC3 (β3)	0.22	0.12	[-0.02, 0.46]
Zone CDF (β4)	2.07	0.53	[1.07, 3.17]
Zone CWH (β4)	1.63	0.5	[0.70, 2.67]
Zone ESSF (β4)	0.86	0.5	[-0.05, 1.88]
Zone ICH (β4)	2.75	0.47	[1.88, 3.73]
Zone IDF (β4)	1.73	0.46	[0.91, 2.72]
Zone MS (β4)	1.13	0.48	[0.27, 2.13]
Zone PP (β4)	1.19	0.49	[0.29, 2.24]
Zone SBS (β4)	1.12	0.47	[0.24, 2.11]
Intercept (μj0)	0.41	0.16	[0.18, 0.80]
PC1 (μj1)	0.08	0. 03	[0.04, 0.15]
PC2 (μj2)	0.12	0.06	[0.04, 0.27]
PC3 (μj3)	0.28	0.12	[0.09, 0.58]

Data models

Next, we modeled the sample data (i.e., BEC plot data) with the same predictor variables and model structure (Eq 1) as described above. We leveraged the power of Bayesian inference to create two data models, one using weakly or non-informative priors and one using the expert derived priors from the suitability ratings, as estimated through the prior model (Table 1). For the weakly informed data model, we used the default brms priors as described above (see prior model). Again, all models were run with 2 sampling chains, each with 5000 iterations, including a 2000 iteration warm-up phase. Convergence was assessed using the Gelman-Rubin diagnostic ($\hat{R}$=1) and trace plots to visually inspect mixing of the chains. Adequate sampling was assessed with Effective Sample Size (Bulk & Tail ESS) estimates >1000. We used posterior predictive checks to assess the model fits to the observed data and to compare the weakly informed model to the expert informed model (Fig F4 a, b).

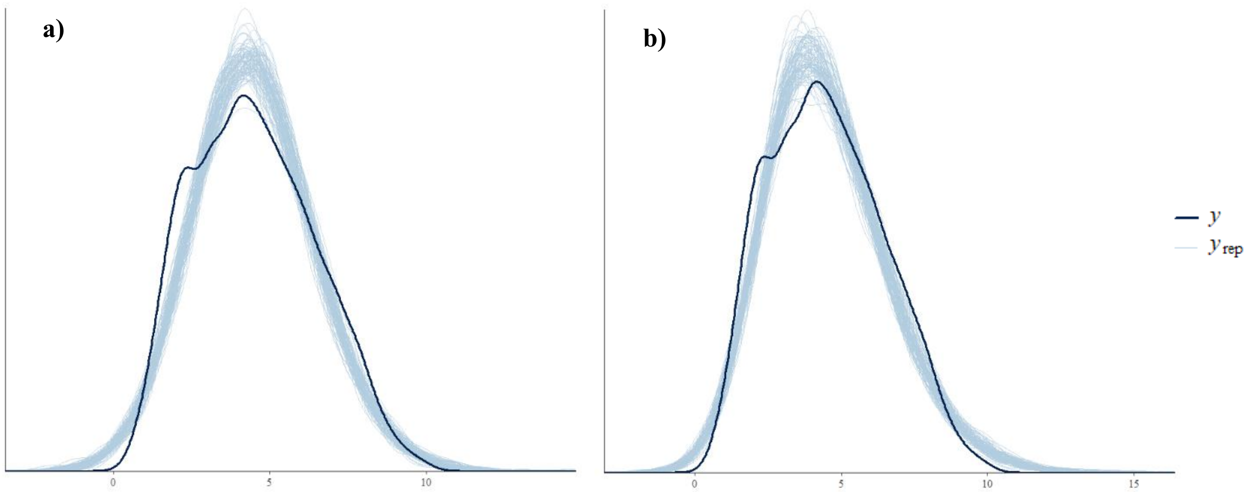

Fig F4. Posterior predictive checks of the data models with a) weakly informative (i.e. brms default) priors and b) expert informed priors from Table F1. Models were trained on BEC plot relative abundance data (square root transformed) for Douglas-fir. The dark blue line indicates the distribution of the observed plot data (y) and the light blue lines (y_{rep}) indicate model predicted responses from 10 replicate model runs. Relative agreement between light and dark blue lines indicates that the prior model captures and can accurately predict the structure of the true data, with the expert informed model b) having an improved fit.

Finally, we resampled from the expert informed data model model using the argument sample_prior = "only" to create posterior distributions from our expert priors. We then compared the posteriors of the priors only and the full model (expert priors + plot data) by biogeoclimatic zone (Fig F5). This allows us to examine in which regional climates the expert priors agree or disagree with modeled plot level relative abundances for Fd. We can use these comparisons to determine areas where expert priors may benefit from additional review. Alternatively, this lack of agreement may indicate that environmental suitability is not well estimated by relative abundance alone. It can also help to highlight regional differences in interpretation and application of suitability ratings definitions. See example for Fd below.

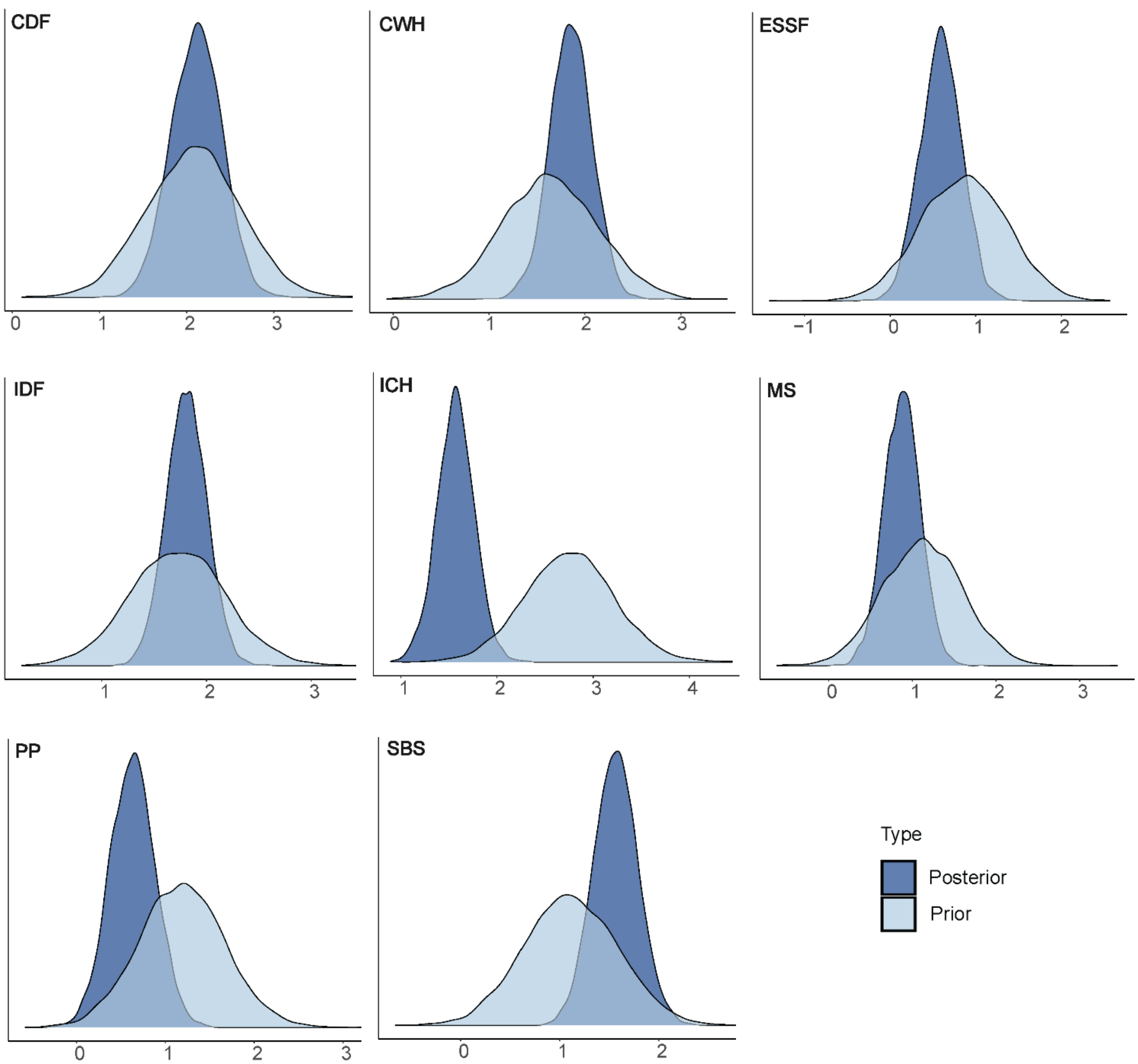

Fig F5. Prior-posterior comparisons of the expert priors as estimated from the prior model (light blue-Prior) and the expert informed data model posteriors (dark blue- Posterior) by biogeoclimatic zone for Douglas-fir (Fd). Density plots show the distribution of the modeled estimates of plot level relative abundances relative to the baseline zone (BG) with zero indicating no difference. Overlap between light and dark blue curves indicates that the expert priors based on environmental suitability ratings are closely aligned with the observed abundances from BEC plot data for that region (e.g., CDF and IDF). Zone acronyms in Fig F1 caption.

E3. Discussion

Keeping all other model predictors constant, the relative plot abundance of Fd is predicted to be greater than in the baseline zone (BG) for all other forested zones (Fig F5), as all posterior curves from the expert informed data model (dark blue) are to the right of zero. Agreement between the expert priors (light blue) and the expert informed data model (expert priors + data- dark blue) differed by biogeoclimatic zone (Fig F5). The data model posteriors (dark blue) were narrower, showing less variation around the mean due to strong influence of informative priors and a larger dataset, which allowed for a more precise estimate of the mean and a more complete capture of the spread of the (data) model posterior.

Generally, prior-posterior agreement for our data model was relatively high, and for most zones the expert priors capture the range of values of the posterior, while slightly under (e.g. CWH) or over (e.g. MS, ESSF) estimating the mean (Fig F5). We found high agreement in zones where Fd is a dominant species at the regional scale, including the Interior Douglas-fir (IDF) and the Coastal Douglas-fir (CDF) zones. In these areas, expert priors accurately capture the predicted mean and spread of the posteriors from the data model, indicating quantitative accuracy of the suitability ratings when compared to BEC plot data.

A few zones had relatively poor overlap, including the Interior Coastal Hemlock (ICH) and the Sub Boreal Spruce (SBS) zones, where expert priors were generally higher or lower than estimates of relative abundance based on plot data (Fig F5). There may be several reasons for this discrepancy. One possibility is that in zones such as the ICH, where tree diversity is quite high, the percent cover of any given species in a community (i.e. plot) may be relatively low compared to other zones with lower tree diversity. However, this lower cover does not necessarily indicate a lower environmental abundance in our prior model (Fig F2). For other zones, such as the SBS, discrepancies may be driven by factors like growth form or climatic limitation overall, since priors based on environmental suitability ratings tended to predict lower cover than what was observed in the plot data. This suggests that while the relative cover of Fd in a plot may be high, it may still exhibit the slow growth rate or poor form—traits indicative of harsher climates as found in a sub-boreal environment—resulting in lower suitability ratings.

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