

Review of British Columbia's contemporary and projected western larch seed planning zones in light of climate change.

Barry Jaquish

Research and Knowledge Management Branch,

B.C. Ministry of Forests and Range

Kalamalka Forestry Centre, Vernon, B.C.

February 26, 2010

Background

The catastrophic effects of mountain pine beetle on the forests of central British Columbia combined with the projected effects of climate change have stimulated intense debate over forest management throughout the region. One commonly suggested approach to mitigating these effects is to increase the region's ecosystem complexity through the planting of either exotic tree species or native species whose distribution lies outside the central Interior. While the benefits of introducing exotic species remains controversial and speculative, the assisted, or facilitated, migration of native species presents a valuable tool for enhancing ecological complexity and ensuring the species' pace of migration matches the expected rate of climate change.

Western larch (*Larix occidentalis* Nutt), a species native to the upper Columbia River basin in southeastern B.C. (Fig. 1), is often suggested as a desirable candidate for introduction because of its rapid early growth, desirable wood properties, and generalist mode of adaptation. Indeed, western larch is already commonly planted north of its native range in southeastern B.C. (Plate 1) and over the last three decades numerous small operational and research plantings have demonstrated western larch's reforestation potential on many sites throughout the central Interior (Plates 2, 3, 4, and 5). Ecologically, it appears that western larch's fundamental niche exceeds its realized niche. Climate envelope modelling also suggests that the future climate space amenable to western larch lies far north of its contemporary distribution.

While climate envelope predictions suggest that the climate space amenable for western larch will likely shift northwards, these predictions fail to account effectively for the species' intrinsic ability to respond to climate change (Thuiller et al. 2008); life history characteristics, adaptive

strategies, population genetic structure, and patterns of genetic variation are commonly ignored. In order to make informed decisions regarding assisted migration or planting outside a species' natural range, managers should incorporate knowledge of a species' genetic architecture to adjust seed transfer guidelines and seed zone boundaries to assure that planting stock remains physiologically suited to the climate of planting sites.

Since bioclimate models show that with increasing temperatures plant distributions will likely shift upwards and northwards (Jump et al 2009), a review of the B.C. western larch seed zones and seed transfer rules should consider the northern movement of the species and take into account populations presently growing in the U.S. Therefore, in early 2009 we (Barry Jaquish, Research Branch, B.C. Ministry of Forests and Range and Dr. Gerald Rehfeldt, retired, USDA Forest Service, Moscow, Idaho) initiated a study of the ecological impacts and management strategies for western larch in the face of global warming.

The objectives of this range-wide project were to:

- (1) define the climate profile with a bioclimatic model that predicts the presence or absence of western larch from climate variables;
- (2) develop models of genetic variation that predict genetic differences among populations from inhabited climate;
- (3) develop and map seed zones within predicted distributions for present and future climates;
- (4) identify populations that are likely to become threatened and identify appropriate conservation strategies; and,
- (5) develop management strategies for the transfer of the seed sources to future location of their optimal climate, taking into consideration future distributions, adaptation of populations, and variability among General Circulation Models (GCM).

The work has been completed and the paper has been submitted for publication (Rehfeldt and Jaquish 2010). The present note summarizes the analytical approach, presents results and makes recommendations for modifying the B.C. western larch seed planning zones to account for climate change. For brevity, detailed methods and results will not be presented herein. However, if the reader/reviewer requires details, they will be made available from the author.

Methods

The western larch bioclimate model was developed using ca. 185,000 observations from four data sources: (1) permanent sample plots of Forest Inventory and Analysis, U.S. Forest Service, for western United States, (2) plots established for ecological analyses of USA's northern Rocky

Mountain forests, (3) ecological plots of the B.C. Ministry of Forest and Range, and (4) data points from treeless biomes of Brown et al. (1998). Of the 185,000 observations, 2.5 % (4548 observations) contained western larch. The Random Forests classification tree (Breiman 2001) was used to predict presence-absence of western larch from climate variables predicted from the climate surfaces of Rehfeldt (2006). The model thus predicted western larches' realized niche for the contemporary climate (hereafter called the *climate profile*).

Genetic variation in western larch was assessed from the 15-year mean height of populations growing at the range-wide western larch provenance test at Lamb Creek, a site at 1035 m elevation in southeastern B.C., and from a re-analysis of 4-year data from tests conducted in northern Idaho (Rehfeldt 1995). Both tests were established with many of the same populations and represented in their aggregate much of the botanic distribution of western larch (Fig 1). Multiple regression analyses were used to relate genetic variation among populations to the climate of the seed source.

Projections of the climate profile and the genetic attributes into future climate space were made for three General Circulation Models (GCM) and two emissions scenarios developed by the International Panel on Climate Change (IPCC): (1) Canadian Centre for Climate Modelling and Analysis (CCCNA) using the CGCM3 model, SRES A2 and B1 scenarios; (2) Met Office, Hadley Centre (UKMO), using the HadCM3 model, SRES A2 and B2 scenarios; and (3) Geophysical Fluid Dynamics Laboratory (GFDL), using the CM2.1 model, SRES A2 and B1 scenarios.

Results

Bioclimatic model

The 8-variable model for describing the climate profile had an out of bag error of 2.9% for which the errors of commission (*i.e.* species absent but predicted present) and errors of omission (*i.e.* species present but predicted absent) average 4.9 % and 0.05%, respectively. The most important climate variables that described the climate profile were: (1) an interaction of the summer dryness index and winter temperatures, (2) the ratio of summer to total precipitation, and (3) an interaction of degree-days $>5^{\circ}\text{C}$ and the mean temperature in the coldest month. Visual agreement between the mapped climate profile and the current western larch range map from Little (1971) suggested a strong model fit (Fig 1).

Climate profile projections

Projections of the contemporary climate into the climates of the future portray very different impacts on western larch (Fig. 2). By the end of the century, the contemporary climate profile would all but disappear according to UKMO, would be reduced by about 70% according to GFDL, and would remain relatively constant in total area according to CCCMA. All projections, however, agree that much of the future distribution would be on lands currently not inhabited by the species today. Agreement among the mapped projections can be examined by superimposing them and viewing the result as a probability that the future climate would be suitable (Fig 3). Projections for 2030 indicate that suitable climates should be concentrated in four geographic regions (coloured dark blue). However, by 2060 the concurrence would be greatly reduced, with the only areas of unanimity restricted to some valley locations in the Coastal Mountains in B.C.

Models of genetic variation for growth and adaptive traits

Regression equations for predicting genetic effects (ht15 at Cranbrook; and PC1 and PC2 for 4-year growth and adaptation data in North Idaho) were all statistically significant ($p < 0.0001$). Mapped patterns of genetic variation for the three attributes are shown in Fig 4 for pixels lying within the climate profile (Fig. 1). This figure shows generally that 15-year height of populations at Lamb Ck. was greatest for populations from the valleys in south-central B.C. and lowest for populations in the Blue Mountains and Cascade Mountains of Oregon and Washington. Trees of highest growth potential and highest tolerance to *Meria* needle cast originated from the valleys of northern Idaho and adjacent B.C. Populations from highest elevations had the highest mortality, mostly from *Meria*.

Seed zones: contemporary climate

Histograms produced by ARCMAP software were used to delineate five discrete seed zones that are genetically unique and tend to be stratified by geography and elevation (Fig. 5 top left). Three of the five seed zones extended from southeastern B.C. well into the U.S. suggesting that improved western larch seed from B.C. seed orchards should be adaptively suited to many sites in the Inland Empire¹. The other two zones were restricted to the east slopes of Cascade Mountains in Oregon and Washington. The breadth of these seed zones are consistent with previous work which suggested limits of transfer of about $\pm 200\text{m}$ (Rehfeldt 1982). These contemporary seed zones were consistent with existing B.C. western larch seed zones; however, ARCMAP did delineate a very small low elevation East Kootenay zone (coded brown on Fig. 5). The low elevation Nelson zone (coded blue on Fig. 5) zone occurred below 1200 m and a large

¹ The Inland Empire is the geographic region centred in Spokane, WA and encompassing eastern Washington, north-central Idaho and western Montana.

second zone (coded yellow on Fig. 5) encompassed the current Nelson zone above 1200 m., eastern parts of the Thompson Okanagan zone, and the mid-elevation EK zone. In contemporary climates, seed from the current East Kootenay and Nelson high elevation seed orchards would be adaptively suited to this region.

Seed zones: projected to year 2030

Projecting the five seed zones to the 2030 climates generated for the A2 scenarios (*i.e.* a world with high carbon emissions similar to or slightly higher than today) of the three GCMs produced the widely disparate results of Figure 5. All three models predicted a shift in distribution to the northwest and the UKMO Hadley model predicted the most severe range reduction. Figure 6 synthesizes the disparate results in a map showing the five seed zones in the same base colors used in Fig 5, with colour intensity denoting concurrence among the projections. In all five zones, the intensity follows a four colour gradient with the lightest to darkest gradients indicating concurrence of 3 to 6 scenarios, respectively. In general, the East Kootenay high elevation (yellow) population migrates northwest; the East Kootenay low elevation (brown) population migrates up in elevation; the Nelson low elevation population (blue) migrates north; and the Coast/Cascade mountain populations (red and green) remain relatively constant. Since all three projections predict extirpation of the Coast/Cascade populations, these populations merit consideration for conservation.

Maps like Figure 6 show range-wide concurrence among three GCMs and two scenarios for the 2030 location of the five seed zones. It provides fundamental information required for making informed decisions for western larch seed transfer, seed zone delineation and conservation. For example, geographic areas can be identified that have the highest probability of being suitable for western larch based on 2030 climate. For these suitable areas, one can then select contemporary sources of seeds with the highest probability of being genetically compatible with the future climate.

Recommendations for British Columbia

The year 2030 projected climate space that appears suitable for western larch in B.C. is presented in Figure 7 and shows locations where at least one of the six scenarios projects climate space appropriate for western larch. The climate space is subdivided according to the five contemporary seed zones that were initially delineated on the basis of equivalent growth potential, survival and resistance to *Meria* needle cast, and subsequently projected to the climate of 2030. Each colour coded seed zone is further subdivided by six shades to denote the agreement among three GCMs and their two scenarios. The lightest colour represents the projection for a single scenario, while the darkest colour represents agreement among all six scenarios. In essence, these colour gradients represent the probability of successful introduction of western larch. Uncoloured regions indicate little chance of success and should be avoided; dark shades indicate regions with high likelihood of success.

In B.C., seed orchards presently exist for the Nelson low, Nelson high and East Kootenay seed planning zones. Seed zone delineation in this project suggests the Nelson low orchard is appropriate for the blue zone, while the Nelson high and East Kootenay orchards are appropriate for the yellow zone. No orchard is available for the brown, red or green zones. However, year 2030 projections for the red and green zones are restricted and long-term projections suggest extirpation of these populations. Therefore, these red and green populations merit consideration for conservation. Consideration should also be given to the establishment of an East Kootenay low elevation (*i.e.* brown zone) seed orchard.

Unfortunately but not surprisingly, these new projected western larch seed zones fail to align consistently with contemporary biogeoclimatic (BEC) zones, variants or sub-variants. Therefore, contemporary BEC units cannot be used to guide future western larch seed deployment. Instead, to account for the broad regional differences in geography, the 2030 projected western larch distribution was subdivided into six quadrants: nw = northwest, ne = northeast, cw = centralwest, ce = central east, sw = southwest, and se = southeast. Within each quadrant, GIS was used to overlay elevation layers on each seed source to establish elevation limits for the respective seed source. Overlays for each quadrant are presented in the attached pdf maps² and results are summarized in Table 1.

The process presented herein for western larch seed deployment to anticipate and respond to climate change can be summarized as: 1) determining if the geographic location of the prospective site is within the suitable projected climate space for western larch, 2) identifying the appropriate seed source for the site and noting the level of risk associated with planting from the respective zone colour shade, and, 3) confirming elevation suitability from Table 1. Given the risk levels associated with the six scenarios, the concurrence of 2 or more scenarios is recommended for initial consideration.

² Pdf elevation maps created by Matt Leroy, Tree Improvement Branch

Table 1. Elevation bands for western larch seed sources for geographic region quadrants presented in Figure 7 and 8.

Quadrant	Seed Zone (zone colour in maps)				
	EK high (yellow)	Nelson low (blue)	EK low ^a (brown)	SSM high ^a (red)	SSM low ^a (green)
Northwest	500 - 1000	200 - 700m	-	-	-
Northeast	500 - 1200	-	500 - 800	-	-
Centralwest Interior Coast	600 – 1500 700 - 1600	700 – 1200 700 - 1200	600 – 1000		
Centraleast	700 - 1500	700 - 1300	700 – 1200	-	-
Southwest	1000 - 1800	600 - 1300	900 - 1400	1100 - 1800	900 – 1500
Southeast	1200 - 1800	600 - 1500	1000 - 1600		

a. No seed orchard available for these seed zones.

References

- Breiman L (2001) Random forests. *Machine Learning* 45:5-32
- Brown DE, Erichenbacher F, Franson SE. (1998) A classification of North American biotic communities. University of Utah Press, Salt Lake City
- Jump AS, Mátyás C, Peñuelas J (2009) The altitude-for-latitude disparity in the range retractions of woody species. *Tree* 1147 (in press)
- Little EL Jr. (1971) Atlas of United States trees, volume 1, conifers and important hardwoods. U.S. Department of Agriculture, Miscellaneous Publication 1146. Washington, DC
- Rehfeldt GE (1982) Differentiation of *Larix occidentalis* populations from the Northern Rocky Mountains. *Silvae Genetica* 31:13-19
- Rehfeldt GE (1995) Genetic variation, climate models and the ecological genetics of *Larix occidentalis*. *Forest Ecology and Management* 78:21-37
- Rehfeldt GE (2006) A spline climate model for western United States. General Technical Report 165. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO
- Rehfeldt GE, Jaquish BC (2010) Ecological impacts and management strategies for western larch in the face of global warming. *Mitigation and Adaptation Strategies for Global Change*. (accepted)
- Thuiller W, Albert CH, Arujo MB, et al (2008) Predicting global change impacts on plant species distributions: future challenges. *Perspectives in Plant Ecology, Evolution and Systematics* 9:137-152

Plate 1. Western larch planting northwest of Golden near Rogers Pass



Plate 2. Western larch planted south of Burns Lake – 20-years: (Fig 9b site E100)
(Seedlot 5101 – Lower Lussier River - 1100 m. East Kootenay seed zone)



Plate 3. Western larch planted southeast of Houston, B.C. – 28-years (Fig 9b site L046)



Plate 4. Date Ck Demonstration Forest: north of Kispiox (Flathead Valley seedlot)
18-years



Plate 5. Western larch planted at Prairie Ck south of Horsefly Lake – 21-years.
Seedlot 3395 - Kettle Valley 1280 m. Thompson Okanagan seed zone)



Figure 1. Mapped climate profile (yellow and red pixels) of *Larix occidentalis* in relation to Little's (1971) digitized range map (lines). Yellow, 50 – 75 % of the votes; red, 75 – 100 % of the votes. Dots within the inserts are approximate locations of data points, black containing *L. occidentalis*, light blue without *L. occidentalis*.

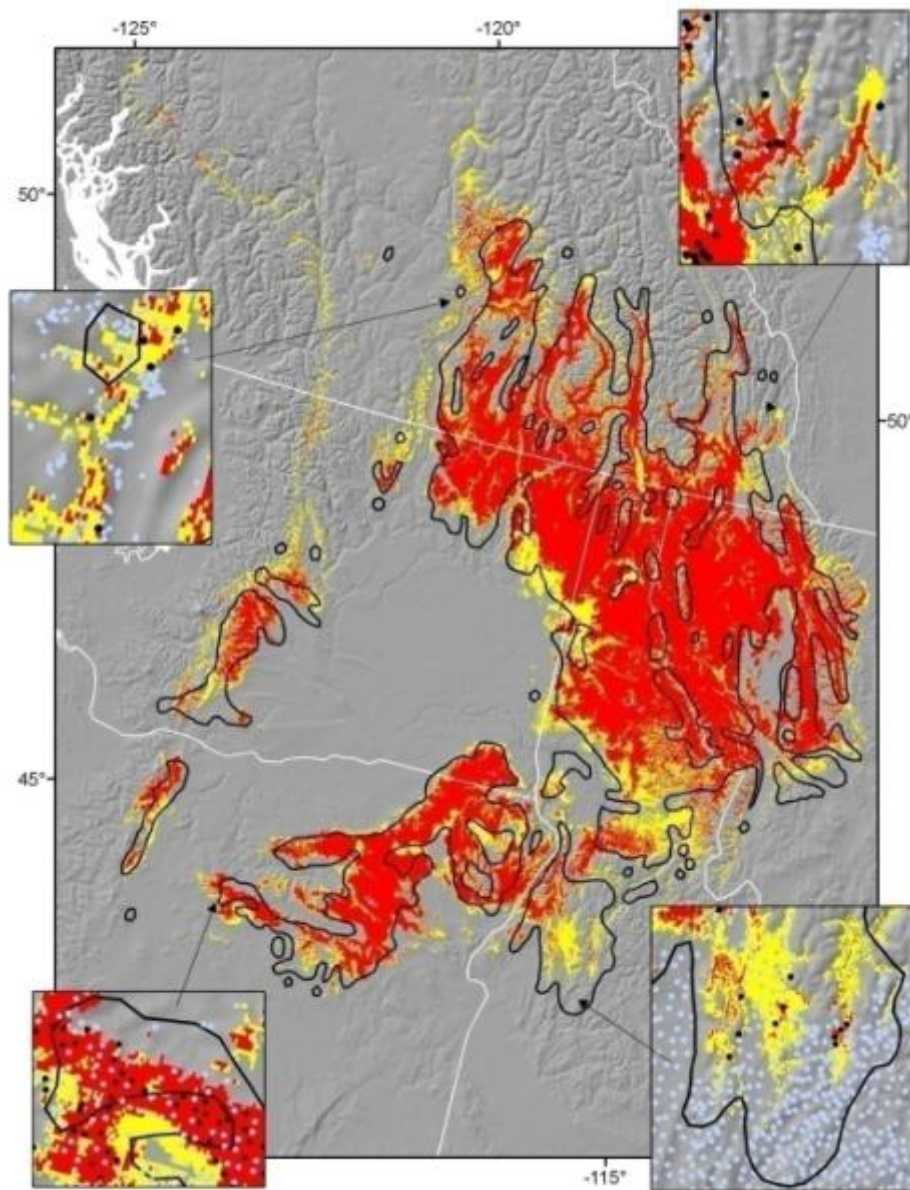


Figure 2. Mapped climate profile of *Larix occidentalis* for the contemporary climate (upper left) and for future climates as depicted for the SRES A2 scenarios and three GCMs in decades centered on 2030, 2060, and 2090. CCCMA, Canadian Centre for Climate Modelling; GFDL, Geophysical Fluid Dynamics Laboratory; UKMO, Met Office, Hadley Centre.

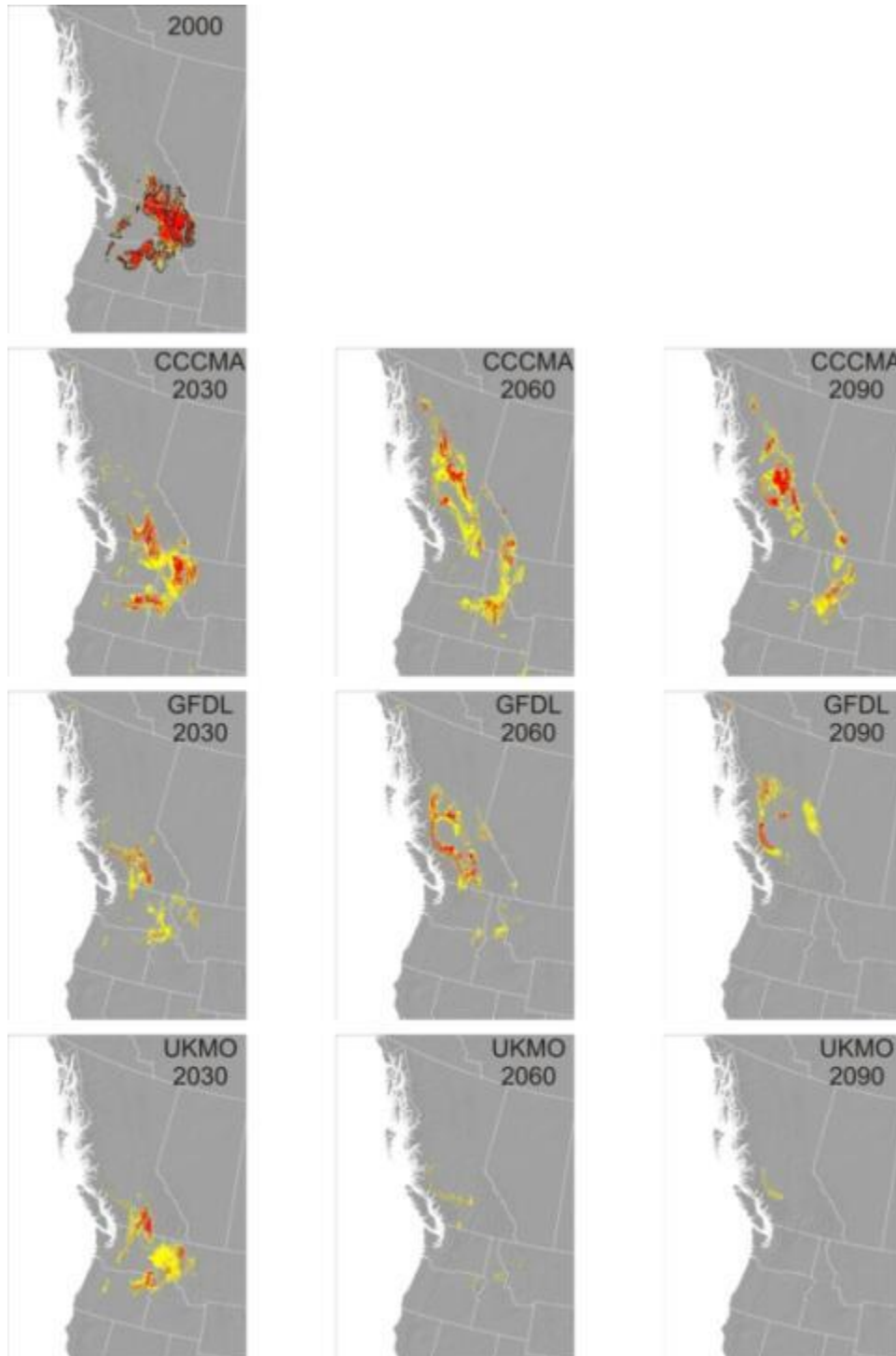


Figure 3. Mapped climate profiles of *Larix occidentalis* for the decade surrounding 2030 (left) and 2060 (right) superimposed for three GCMs and two scenarios. Colouring codes the number of projections that concur (degree of concurrence coded to key in bottom right corner of 2030 figure).

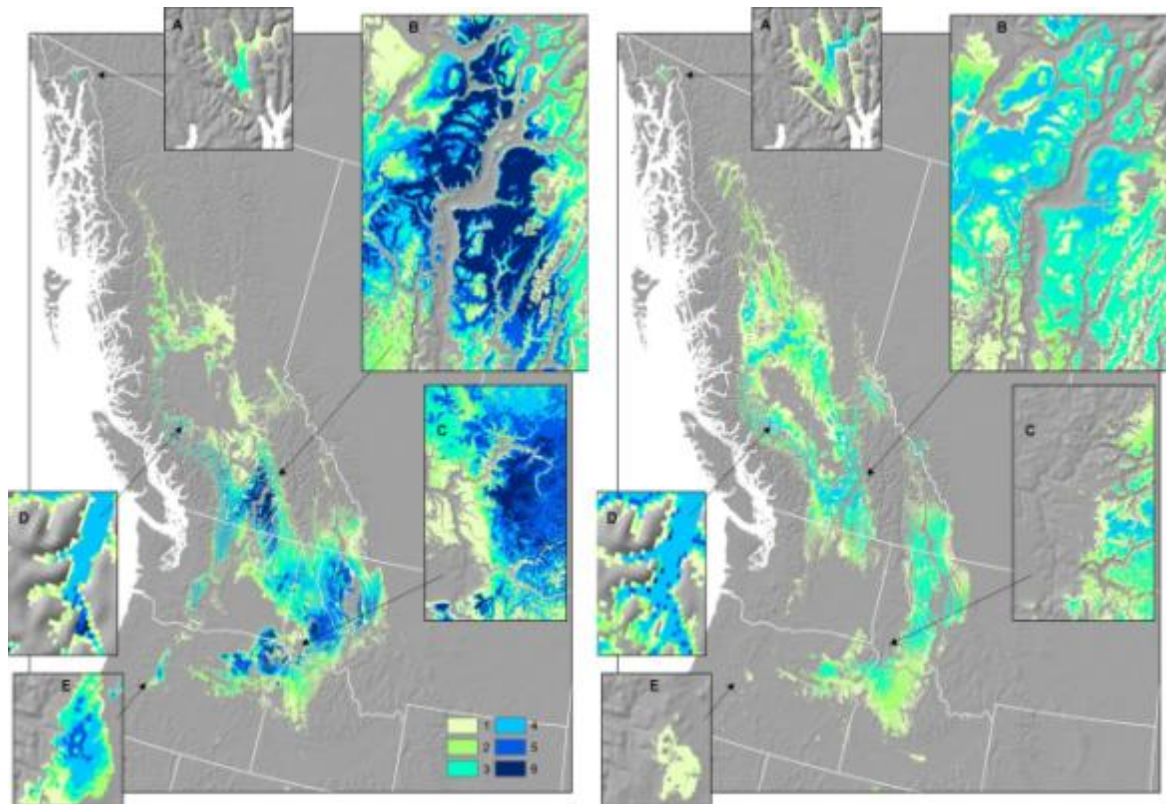


Figure 4. Mapped genetic variation in three characters predicted from regression models: A, 15-year height of trees growing at Lamb Creek, B.C. (asterisk); B, first principal component (height and resistance to *Meria*) of 8 traits measured on 4-year seedlings at Priest River, Idaho (asterisk), and C, second principal component (mortality from *Meria*) of traits measured in Idaho. White dots in A and B locate seed sources included in the tests. Shading indicates predicted performance of populations within the contemporary climate profile (Fig. 1), dark for high values and light for low values.

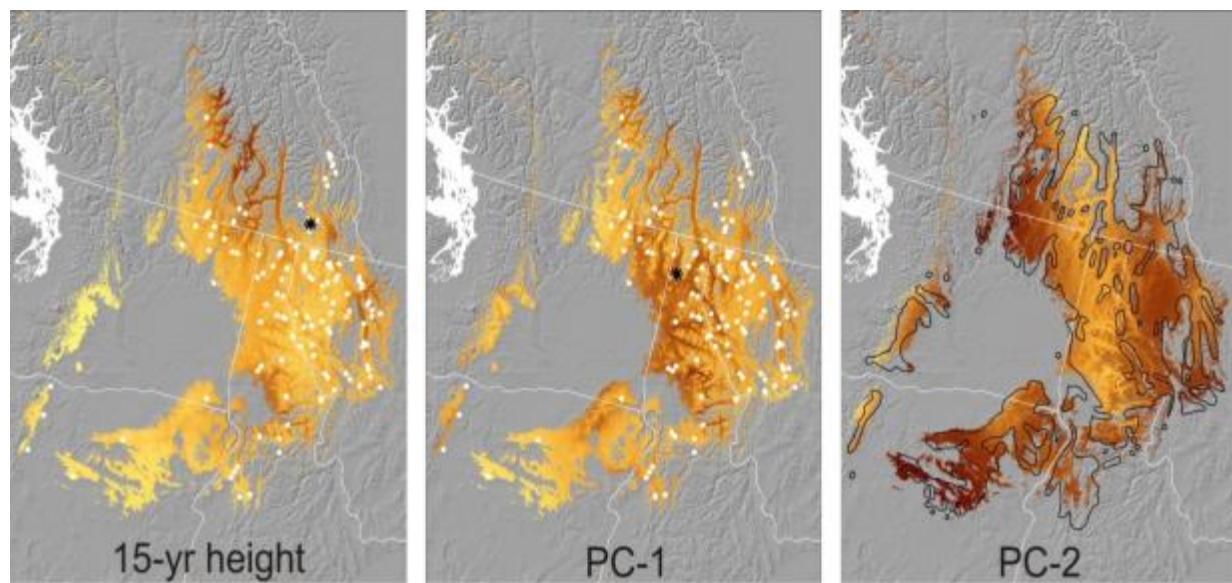


Figure 5. Map of five seed zones (upper left) and their 2030 projections according to the A2 scenarios of CCCMA (upper right), GFDL (lower left), and UKMO (lower right). Inserts A-E (upper left) are repeated in all panels.

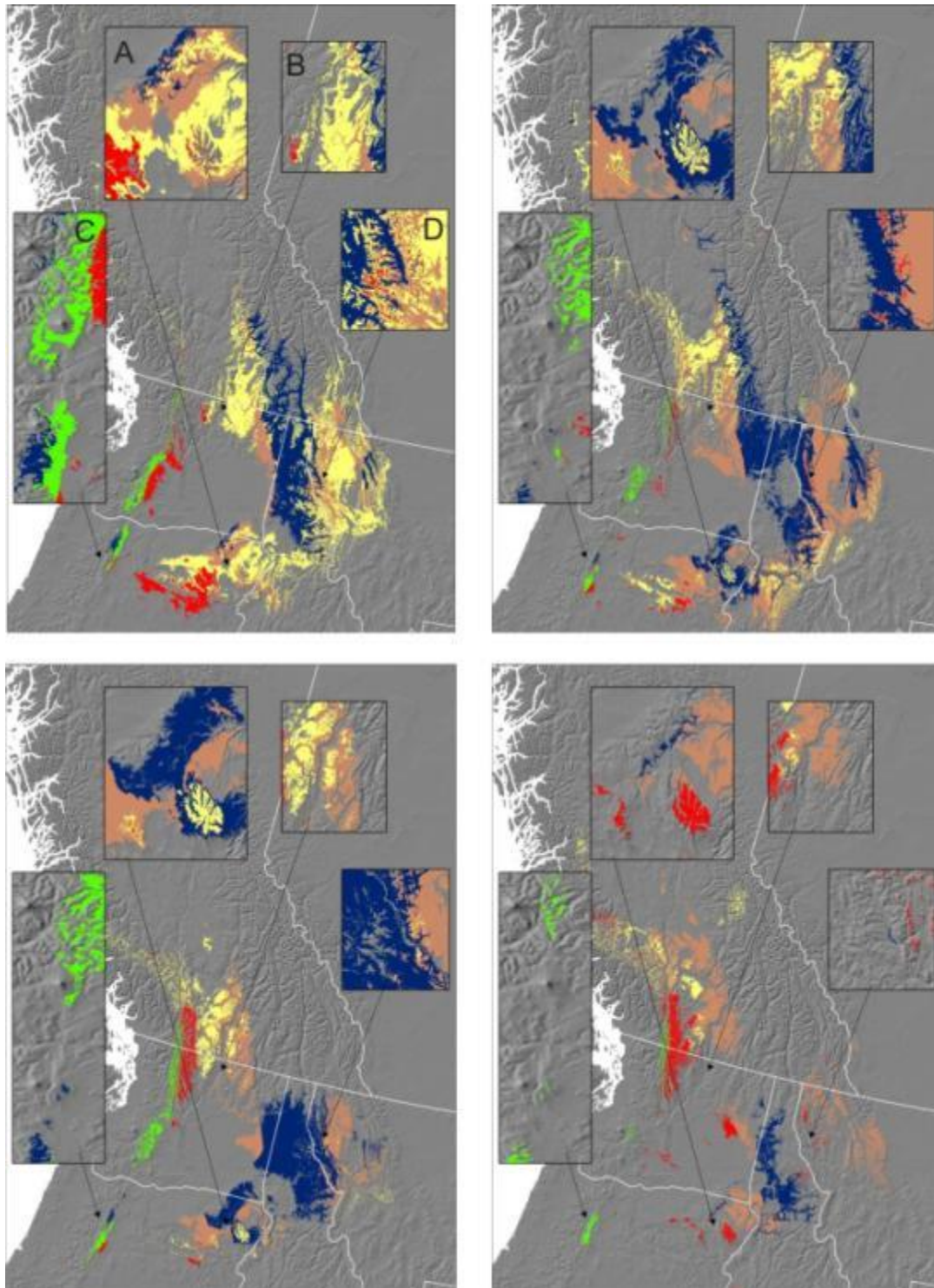


Figure 6. Range-wide concurrence among three GCMs and two scenarios for the 2030 location of the five seed zones. Zones are coded by the colour paths in Fig. 5, blue, yellow, brown, green and red, with the darkest shades of each denoting agreement of six projections. Four shades of each colour code the agreement among GCMs and their scenarios (lightest, agreement among 3 projections; darkest agreement among 6 projections).

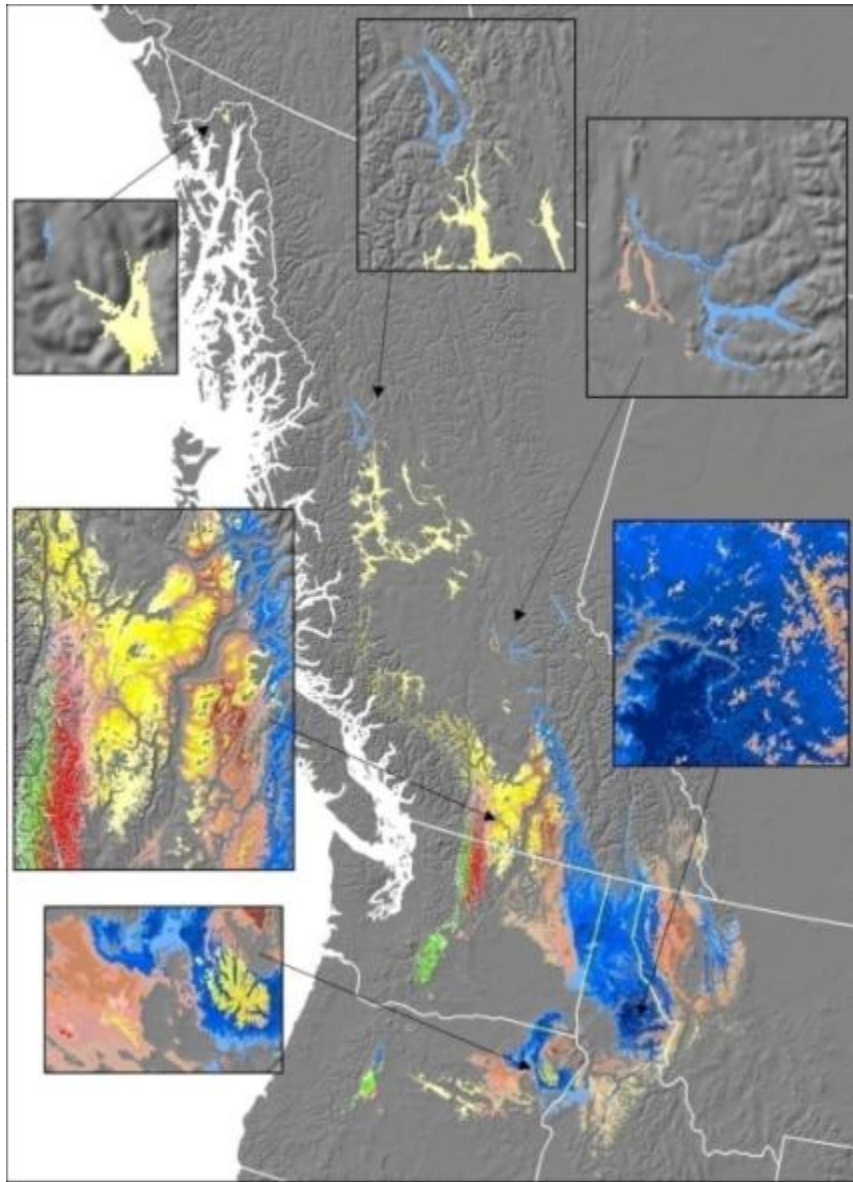


Figure 7. Concurrence among three GCMs and two scenarios for the 2030 location of the five seed zones in B.C. Zones are coded by the colour paths in Fig. 5 (blue, yellow, brown, green and red). Six shades of each colour indicate the agreement among GCMs and their scenarios (lightest = 1 scenario; darkest = 6 scenarios). Rectangles indicate quadrants used to define seed zone elevation limits: nw and ne = northwest and northwest; cw and ce = centralwest and centraleast; sw and se = southwest and southeast.

