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Assisted Migration to Address Climate Change in British Columbia Recommendations for Interim Seed Transfer Standards

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Ministry of Forests and Range
Forest Science Program

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Gregory A. O'Neill, Nicholas Ukrainetz, Michael Carlson, Charles Cartwright, Barry Jaquish, John King, Jodie Krakowski, John H. Russell, Michael Stoehr, Chang-Yi Xie, and Alvin Yanchuk

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Prepared by
B.C. Ministry of Forests and Range
Kalamalka Research Station
3401 Reservoir Rd.
Vernon, BC V1B 2C7

Gregory A. O'Neill
Nicholas Ukrainetz
Michael Carlson
Barry Jaquish

B.C. Ministry of Forests and Range
Research Branch
PO Box 9519, Stn Prov Govt
Victoria, BC V8W 9C2

Charles Cartwright
John King
Michael Stoehr
Chang-Yi Xie
Alvin Yanchuk

B.C. Ministry of Forests and Range
Cowichan Lake Research Station
Box 335, 7060 Forestry Rd.
Mesachie Lake, BC V0R 2N0

Jodie Krakowski
John H. Russell

Prepared for
B.C. Ministry of Forests and Range
Research Branch
Victoria, BC V8W 9C2

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1 SUMMARY

Climate change is expected to result in trees in most regions of British Columbia becoming increasingly maladapted to the climates in which they are planted. Consequently, planting seedlings adapted to future climates (assisted migration) is recognized as a key strategy to address climate change, as it will help maintain healthy, productive forests, and ensure capture of gains obtained from decades of selective breeding.

To examine opportunities to incorporate assisted migration into British Columbia's seed transfer system, the feasibility of increasing the upper elevational transfer limit of British Columbia's Class A and Class B seed was assessed by calculating the climatic transfer distance associated with elevational transfers. A rationale was developed for quantifying an appropriate climatic distance and range to migrate seed, and was used to evaluate elevational transfer increases of 100 and 200 m.

Results indicate that of the 30 Class A Seed Planning Units (SPUs) examined, eight should retain their current upper elevation limits, one should have its upper elevation limit increased by 100 m, and the remainder should have their upper elevation limits increased by 200 m. Upper elevation transfer limits of Class B seed should be increased by 200 m for eight species, by 100 m for two species, and should remain unchanged for three species. Specific recommendations are provided in Tables 2 and 3.

Deployment of orchard seed in the lowest 200 m of the western white pine—Maritime and interior spruce—East Kootenay SPUs is discouraged, as is transfer of Class B seed of amabilis fir and western hemlock more than 200 m downward and western redcedar more than 300 m downward.

2 BACKGROUND

As the climate changes, natural selection and seed migration will result in tree populations adapting to new climates. However, it appears that the rate of climate change will outpace that of evolution (Aitken et al. 2008), resulting in significant shifts in forest productivity (Wang et al. 2006b; O'Neill et al. 2008); consequently, proactive intervention through assisted migration of seed during plantation establishment is required to maintain optimum forest health and productivity and to ensure capture of gains obtained from selective breeding (Rehfeldt et al. 1999; Wang et al. 2006b).

Geographic variables (latitude, longitude, and elevation) act as surrogate measures of climate in British Columbia's seed transfer system. By constraining seed deployment to sites that are geographically proximal to a seedlot's origin, one is reasonably assured that planted seed originates from sites that are climatically similar to the plantation. A comprehensive Climate-Based Seed Transfer (CBST) model that accommodates assisted migration will exploit geographic information systems, fine-scale climate models, and recent advances in the field of genecology. A CBST system is being developed by the Research Branch of the B.C. Ministry of Forests and Range (MFR) (O'Neill and Ukrainetz 2008) and will improve the seedlot–site match in current and future climates to maintain plantation productivity throughout the forest rotation, ensure that gains from tree improvement efforts are fully realized, and minimize the risk of pests, diseases, and abiotic damage. However, implementation of a CBST system is still several years away. Consequently, the current project examines interim opportunities to implement a conservative degree of assisted migration into the current geography-based seed transfer system.

This analysis seeks to assess the impact of an upward shift of the upper elevation boundary of 30 of British Columbia's Seed Planning Units (SPUs),[1] and an upward shift of the Class B elevational transfer limits of 12 of British Columbia's commercial tree species. Shifts of Class B latitudinal or longitudinal transfer limits and Seed Planning Zone (SPZ) boundaries were not considered because correlations of climate with latitude and longitude are not as strong as with elevation. Therefore, allowing more northward and eastward transfer or transfer into another region would be less effective than upward transfer in procuring seedlots that are adapted to climates warmer than the planting site.

3 METHODS

Climate transfer distance – Class A seed

To assess the impact of modifications to British Columbia's Class A (orchard) seed transfer standards (Snetsinger 2006), the distance that orchard seed would be moved in terms of temperature and precipitation was calculated for 100-m elevation bands of each of 30 SPUs, effectively translating elevational transfer to climatic transfer. Class A seedlots were treated as having a single climatic origin.

The most recent orchard seedlot of the most advanced orchard was selected for each of the 30 SPUs. The geographic co-ordinates and elevation, as well as gametic contribution, were obtained for each orchard parent in each selected seedlot registered in the Seed Planning And Registry (SPAR) system. ClimateBC (Wang et al. 2006a) was used to determine current (1961–1990) mean annual temperature (MAT) and mean annual precipitation (MAP) for each parent. Seedlot mean MAT and MAP, weighted by gametic contribution of parents, were then calculated. Using the distribution of parental MAT and MAP, 90th percentile values of parental origins were determined and overlaid onto SPU climate distribution scatterplots to provide graphical insight into the relative climatic location of orchard seedlots and their deployment zones (Appendix 1).

Current MAT and MAP at 370 205 points in British Columbia located on a 1600 × 1600 m grid were estimated using ClimateBC. SPU coverages were overlaid onto the climate grids using ArcView, and, for each SPU, the climate (MAT and MAP) distance from the orchard seedlot to each gridpoint in the SPU was determined and averages calculated for each 100-m band.

Climate transfer distance – Class B seed

To assess the impact of modifications to British Columbia's Class B seed transfer standards, maps of Class B Seed Planning Zones (SPZs), Biogeoclimatic Ecosystem Classification (BEC) zones, and Vegetation Resource Inventory (VRI) polygons were overlaid onto the 1.6 × 1.6 km grid to identify,

1 For a list of British Columbia's Seed Planning Units go to http://www.for.gov.bc.ca/hti/speciesplan/index.htm.

respectively, the SPZ, BEC zone, and species presence for 12 commercial species at each gridpoint.

Each orchard seedlot has a single climatic origin. Consequently, the analysis of orchard seed transfer involved calculating the climate transfer distance associated with the transfer of a *single* orchard seedlot to all grid locations within each SPZ. Wildstand seed, however, can originate from an infinite number of sources (i.e., climates). Therefore, wildstand (Class B) seed transfer was simulated by creating hypothetical random transfers throughout the province. This was accomplished by randomly pairing all 300 000 gridpoints, after removing those gridpoints associated with non-forested locations (alpine tundra and bunchgrass ecosystems, waterbodies, and urban areas). One point of each pair was randomly assigned as the seed source and the other as the plantation site. For each species, transfers were grouped into 100-m elevation transfer bands (e.g., upward transfers of between 200 and 300 m). Only those transfers that adhered to all aspects of Class B seed transfer standards except elevational transfer, and whose seed source gridpoint location was within the distribution of the species (determined from the Vegetation Resource Inventory) were retained. Average MAT and MAP transfer distances of the retained transfers were calculated for 100-m elevation transfer bands for each species. The feasibility of increasing the upper elevation limit of Class A SPUs and the Class B seed transfer limit was considered by examining the MAT and MAP transfer distances for 100-m elevation transfer bands in light of assisted migration target distances.

Target climate transfer distances

Both recent past and future climate change must be considered when determining the optimum distance to migrate populations (G.E. Rehfeldt, T. Wang, and A. Hamann, pers. comm.). We therefore assume that 100 years ago—prior to significant recent climate change—trees were optimally adapted locally. While there is evidence to suggest that local optimality may not exist in all locations (Namkoong 1969), an assumption of this nature is required as a departure point for considering recent warming in discussions of assisted migration. Consequently, for this exercise we assume that the best population to plant 100 years ago was the local population, and population migration and adaptation were negligible over the past 100 years. Therefore, if the climate has warmed by *X* °C over the last 100 years, the best population for a given planting location in today's climate would be one that originates from a location with a contemporary climate that is *X* °C warmer than the planting location. The same strategy applies to changes in precipitation.

The geographic or climatic distance that seed should be migrated to best address *future* climate change and to ensure maximum adaptation throughout the rotation (i.e., the *target climate transfer distance*) has not been examined in the scientific literature. It has been suggested (G.E. Rehfeldt and T. Wang, pers. comm.) that planting populations best adapted to the climate expected at a site at 1/3 of the rotation (i.e., at approximately 25 years from present) will achieve the best balance of tree volume growth and survival—tree volume growth being greatest among populations adapted to end-of-rotation climates when mean annual volume increment is greatest, and survival being greatest in populations adapted to start-of-rotation climates when trees are most sensitive to stress.

To quantify the amount that MAT and MAP have changed in the last 100 years and the amount that they are projected to change over the next 25 years, ClimateBC was used to determine MAT and MAP at two locations within each of three regions (coastal, southern interior, and northern interior) for 30-year periods centred on 1915, 2025, and 2055 using pessimistic and optimistic scenarios of the Canadian Global Circulation Model (i.e., CGCM2-A2 and -B2). Estimates of future MAT and MAP were averaged across scenarios and locations within each region. MAT and MAP in each of the three regions were extrapolated to 1909 and interpolated to 2008 and 2033. Differences between these values describe the amount of change over the last 100 years and the amount anticipated in the next 25 years.

Climate transfer ranges

To provide a degree of operability about the target climate transfer distance, we identify a *climate transfer range*—a climatic distance on either side of the target transfer distance—that seed can be moved and still maintain acceptable adaptation and productivity. Based on transfer functions for a number of species,[2] we assign an MAT transfer range of +/- 1.5 °C from the target MAT transfer distance for all species. We assign an MAP transfer range of +/- 600 and +/- 1200 mm from the target MAP transfer distance for interior and coastal British Columbia regions, respectively. As an example—if an SPU has a target MAT transfer distance of -1.9 °C, and a 1.5 °C MAT transfer range about this target, the *transfer limits* would be between -0.4 and -3.4 °C.

The appropriateness of increasing the upper elevation boundary of the SPU (Class A seed) or the elevation transfer limits (Class B) by 100 and 200 m was assessed by determining for each SPU (Class A) and species (Class B) if the increase in the elevational boundary or transfer limit would transgress MAT and MAP transfer limits identified in the preceding paragraph.

4 RESULTS AND RECOMMENDATIONS

Target climate transfer distance

MAT in coastal, southern interior, and northern interior British Columbia has increased 1.1, 1.5, and 1.6 °C MAT, respectively, over the last 100 years, values consistent with those calculated directly from weather station data (Rodenhuis et al. 2007). According to Global Circulation Models (GCMs), MAT is expected to increase an additional 0.4, 0.5, and 0.6 °C MAT over the next 25 years (Table 1). MAP in coastal, southern interior, and northern interior British Columbia has increased 34, 34, and 98 mm MAP, respectively, over the last 100 years, consistent also with direct weather station data, and is expected to increase an additional 17, 8, and 18 mm MAP over the next 25 years. Therefore, to offset past and future climate change, seed transfer should target transfer distances of -1.6, -2.1, and -2.2 °C MAT, and -51, -42, and -116 mm MAP in these regions. Bracketing these climate transfer targets with climate transfer ranges proposed in the preceding section provides acceptable limits for seed transfer (Table 1).

Seed transfer – Class A seed

The asymmetric design of British Columbia's current elevational and latitudinal seed transfer standards (Snetsinger 2006), and the origin of orchard parents toward the lower elevations of most SPUs, result in seed generally being moved upward and northward, and is reflected in the prevalence of negative MAT transfers in Appendices 2 and 4. Consequently, assisted migra-

2 MAT and MAP transfer range were inferred from transfer functions for *Pinus contorta* (Rehfeldt et al. 1999; Wang et al. 2006b; O'Neill et al. 2008), *Abies balsamea* and *Fraxinus americana* (Carter 1996), *Larix* sp. (Rehfeldt et al. 1999), *Pinus taeda* and *Picea abies* (Schmidtling 1994), and *Larix occidentalis* and *Picea engelmanii* x *glauca* (O'Neill, unpublished).

TABLE 1 *Change in mean annual temperature (MAT) and mean annual precipitation (MAP) observed over the last 100 years and expected over the next 25 years in three regions of British Columbia, and the target and limit of seed transfer distances expected to offset those climate changes*

	MAT (°C)					MAP (mm)				
	Change			Recommended transfer [a]		Change			Recommended transfer	
Region	1908–2008	2008–2033	Total	Target	Limit [b]	1908–2008	2008–2033	Total	Target	Limit [c]
Northern interior	1.64	0.55	2.19	-2.2	-0.7 to -3.7	98	18	116	-116	-716 to 484
Southern interior	1.55	0.52	2.07	-2.1	-0.6 to -3.6	34	8	42	-42	-642 to 558
Coast	1.14	0.42	1.56	-1.6	-0.1 to -3.1	34	17	51	-51	-1251 to 1149

a Target transfer distances are intended to offset past and future increases in MAT and MAP in order to ensure that plantations remain adapted to climate. A negative transfer distance implies seed movement toward colder and drier climates.

b MAT transfer ranges are +/- 1.5 °C of the target.

c Transfer ranges are +/- 1200 mm MAP of the target in the coast region and 600 mm MAP in interior regions.

tion has been practised in British Columbia for several years (Ying and Yanchuk 2006). Nonetheless, these analyses provide insight into the feasibility of increasing the current degree of assisted migration.

Increasing the SPU upper elevation boundary by 200 m resulted in transfers that are acceptable from the perspective of MAT and MAP (i.e., within the MAT and MAP transfer limits) for all but five of the 30 SPUs (coastal Douglas-fir—Submaritime, western white pine—Maritime, western white pine—Kootenay Quesnel, Sitka spruce—Maritime low, and interior spruce—Prince George high) (Appendices 2 and 3). However, increasing the upper elevation limit may result in maladaptive transfers due to aspects of climate other than MAT and MAP. For example, snowfall generally increases with elevation, and may damage species not adapted to heavy snowfall if trees are transferred excessively upward. Consequently, for four of the 25 SPUs for which increases of the upper elevational limit would result in climatically acceptable MAT and MAP transfers, uncertainty remains regarding possible negative impacts of heavy snowload if trees in these SPUs were transferred an additional 200 m upward. Therefore, it is recommended that upper elevation limits remain unchanged for western hemlock—Maritime low, western hemlock—Maritime high, and yellow-cedar SPUs, and be increased by only 100 m for western redcedar—Maritime low. The recommendations are summarized in Table 2. No changes are recommended for SPUs that were not examined.

We also recommend applying genetic worth values of orchard seedlots into the expanded SPUs. That is, where an SPU is extended upward, existing genetic worth values applied to the original elevations should also be applied to the new (higher) elevations. Applying full genetic worth values to Class A seedlings planted in the extended portion of the SPU is appropriate because in most cases the climates encompassed by the test sites are comparable to that of the test sites, especially when considering that the climate of the SPU will shift substantially over the rotation. (Appendix 1 shows the climatic location of the progeny test sites used to calculate breeding values of parents in each orchard.)

Appendix 2 indicates that deployment of orchard seed in the lowest 100 or 200 m of the SPU transgresses the lower MAT transfer limit of many SPUs. However, given the modest degree of the transgressions, the conservative magnitude of the climate transfer ranges used, and the disruption in the seed supply that would be caused by an immediate increase in the lower elevational boundary of many SPUs (i.e., no eligible seed sources would be available for the lowest portions of many SPUs), we do not recommend changes to the lower elevational boundaries. However, use of orchard seed in the lowest 200 m of the western white pine—Maritime and interior spruce—East Kootenay SPUs would result in significant transgressions of the MAT transfer limits; use of orchard seed in the lowest 200 m of these SPUs should be discouraged. Significant transgressions of the MAT transfer limit are also observed with the yellow-cedar—Maritime SPU; however, extensive field testing indicates that the species is anomalous in its tolerance of downward movement. Appropriate deployment of seed at lower elevations will be fully addressed for all species in the climate-based seed transfer system.

Seed transfer – Class B seed

Our analyses indicate that an increase in the upper elevational transfer limit of 200 m would result in climatically acceptable transfers for all species except coastal Douglas-fir and Sitka spruce (Appendix 4). The upper elevational transfer limit for Sitka spruce could be increased 100 m without transgressing the MAT and MAP transfer limits; however, any increase to the upper transfer

TABLE 2 *Results of Class A (orchard seed) climate transfer distance analyses. "X" indicates that an increase in the upper elevation boundary would result in transfers that exceed the limits deemed acceptable (see Table 1). Checkmark indicates the recommended policy option. Both mean annual temperature (MAT) and mean annual precipitation (MAP) transfers must be acceptable in order to sanction an increase in the seed planning unit (SPU) upper elevation boundary.*

	Transfer result				Recommended increase in SPU upper boundary		
	100-m increase in SPU upper boundary		200-m increase in SPU upper boundary				
Seed Planning Unit [a]	MAT	MAP	MAT	MAP	No change	100 m	200 m
Western redcedar low maritime south						√ [b]	
Coastal Douglas-fir low south							√
Coastal Douglas-fir sub-maritime	X		X		√		
Interior Douglas-fir Prince George							√
Interior Douglas-fir Quesnel Lakes							√
Interior Douglas-fir Cariboo Transition							√
Interior Douglas-fir Nelson low							√
Interior Douglas-fir Nelson high							√
Western hemlock maritime low south					√ [c]		
Western hemlock maritime high south					√ [c]		
Western larch Nelson low							√
Western larch East Kootenay							√
Interior lodgepole pine central plateau							√
Interior lodgepole pine Bulkely Valley							√
Interior lodgepole pine Prince George low							√
Interior lodgepole pine Thompson Okanagan low							√
Interior lodgepole pine Nelson low							√
Western white pine maritime	X	X	X	X	√		
Western white pine Kootenay Quesnel	X		X		√		
Sitka spruce maritime low south		X	X	X	√		
Interior spruce Prince George high		X		X	√		
Interior spruce Prince George low							√
Interior spruce Thompson Okanagan low							√
Interior spruce Thompson Okanagan high							√
Interior spruce East Kootenay							√
Interior spruce Nelson mid							√
Interior spruce Nelson high							√
Interior spruce Nelson low							√
Interior spruce BV							√
Yellow-cedar maritime south					√ [c]		

a For a list of Seed Planning Units see http://www.for.gov.bc.ca/hti/speciesplan/index.htm.

b While MAT and MAP transfer limits are not violated, increasing the upper elevation transfer limit may result in snowpress damage at higher elevations. Therefore, an increase of the upper elevation limit of only 100 m is recommended.

c While MAT and MAP transfer limits are not violated, increasing the upper elevation transfer limit may result in snowpress damage. Therefore, no change in transfer limit is recommended.

limit for coastal Douglas-fir will result in MAT and MAP transfer limit transgressions. While increases in the upper transfer limit would not result in MAT and MAP transgressions for western hemlock, there is uncertainty regarding potential snowpress damage with further upward movement. Therefore we recommend increasing the upper transfer limit by only 100 m for this species. Transfer limits should also not be altered for western white pine because transfer impacts could not be evaluated due to the inability to generate sufficient hypothetical transfers for analysis. Results of analyses of Class B seed transfer and recommendations are summarized in Table 3.

TABLE 3 *Results of Class B (wildstand seed) climate transfer distance analyses. "X" indicates that an increase in the upper elevation transfer limit would result in transfers that exceed the limit deemed acceptable (see Table 1). Checkmark indicates the recommended policy option. Both mean annual temperature (MAT) and mean annual precipitation (MAP) transfers must be acceptable in order to sanction an increase in the seed planning unit (SPU) upper elevation limit.*

	Transfer result						
	100-m increase in upper elevational transfer limit		200-m increase in upper elevational transfer limit		Recommended increase in upper elevational transfer limit		
Species [a]	MAT	MAP	MAT	MAP	No change	100 m	200 m
Ba						√	
Bl							√
Cw							√
Fdc		X		X	√		
Fdi							√
Hw					√ [b]		
Lw							√
Pli							√
Pw					√ [c]		
Py							√
Ss				X		√	
Sx							√
Yc							√

a Species codes: Ba = *Abies amabilis*; Bl = *Abies lasiccarpa*; Cw = *Thuja plicata*; Fdc = *Pseudotsuga menziesii* var. *menziesii*; Fdi = *Pseudotsuga menziesii* var. *glauca*; Hw = *Tsuga heterophylla*; Lw = *Larix occidentalis*; Pli = *Pinus contorta* var. *latifolia*; Pw = *Pinus monticola*; Py = *Pinus ponderosa*; Ss = *Picea sitchensis*; Sx = *Picea glauca* x *engelmannii*; Yc = *Chamaecyparis nootkatensis* (*Xanthocyparis nootkatensis; Callitropsis nootkatensis*).

b While MAT and MAP transfer limits are not violated, increasing the upper elevation transfer limit may result in snowpress damage. Therefore, no change in transfer limit is recommended.

c Insufficient data to evaluate.

Appendix 2 indicates that downward transfer of Class B seed transgresses the lower MAT transfer limit of all species. As with Class A seed, the modest degree of the transgressions, the conservative magnitude of the climate transfer ranges used, and the disruption in the seed supply that would be caused by an immediate increase in the lower transfer limit do not warrant increasing the lower elevational transfer distance of Class B seed. However, transfer of Class B amabilis fir seed more than 200 downward and western redcedar seed more than 300 m downward should be discouraged.

Standards for seed deployment are somewhat more liberal for superior provenances (i.e., B+ provenances) than for wildstand seedlots. Therefore, superior provenances were not examined in this analysis, and expanded transferability of B+ seed is not recommended.

Because of differences in the methods used to determine current Class A SPU elevational boundaries and Class B elevational transfer limits, transfers to the upper elevational limit may result in different climate transfer distances for Class A and B seed of the same species. Consequently, recommendations may differ for Class A and B seed of the same species.

While these analyses indicate that climates are suitable to expand the deployability of some orchard and wildstand seedlots, operators are still required to adhere to species selection guidelines described in provincial stocking standards: climatic suitability does not obviate the need for site (edaphic) suitability.

5 CONCLUSIONS

These analyses translate elevational transfer distances into climatic transfer distances to aid in evaluating climatic transfer associated with British Columbia's current geographic-based seed transfer system. In addition, the translation scheme provides an approach to develop and evaluate a mechanism for assisted migration within British Columbia's current seed transfer system. Moreover, these analyses provide a starting point to inform decisions regarding assisted migration in a future climate-based seed transfer system.

The recommendations provided in this document are limited to those that could be implemented quickly and relatively easily with the least disruption of seed supply. More comprehensive recommendations regarding assisted migration will accompany the climate-based seed transfer system when it is available.

Target transfer distances calculated in this report are based, in part, on estimates of future climate, which are imperfect due to uncertain future greenhouse gas emissions and GCM error. While we employed a range of future climate scenarios in calculating target transfer distances to account for this uncertainty, additional "buffering" of uncertainty may be achieved by increasing adaptive diversity (i.e., increasing the range of climate tolerances among seedlings) in plantations (Millar et al. 2007). This could be achieved by deploying, within the constraints of the seed transfer standards, multiple seedlots from various locations or elevations (i.e., seedlots with slightly different climatic tolerances). A similar strategy for assisting the migration of species and increasing the number of species within each management unit should also be explored with both experimental and empirical (modelling) approaches.

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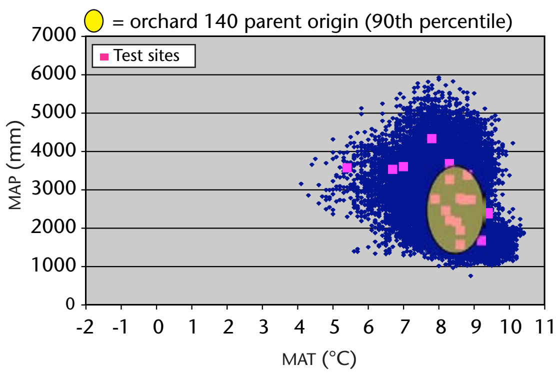
Appendix 1 Climate profile of Seed Planning Units and the progeny test sites used in calculating breeding values of parents used in orchards

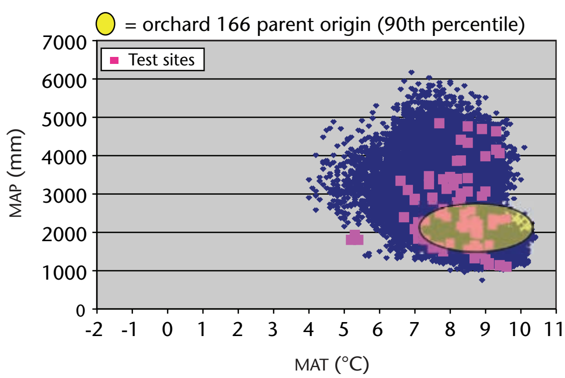
a) Western redcedar

Western redcedar low maritime south

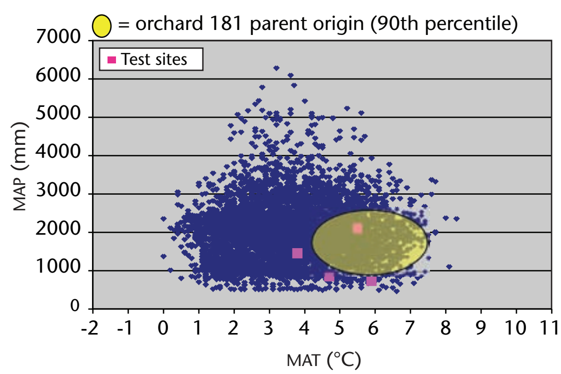


b) Coastal Douglas-fir

Coastal Douglas-fir low south

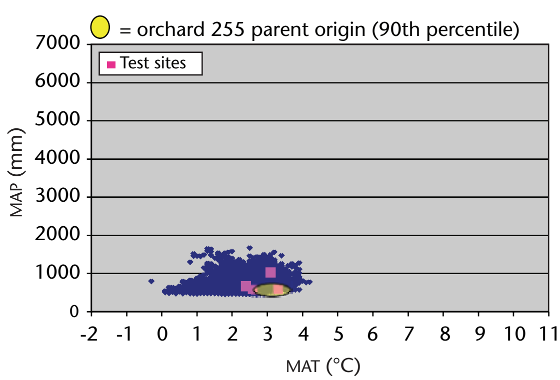


Coastal Douglas-fir sub-maritime

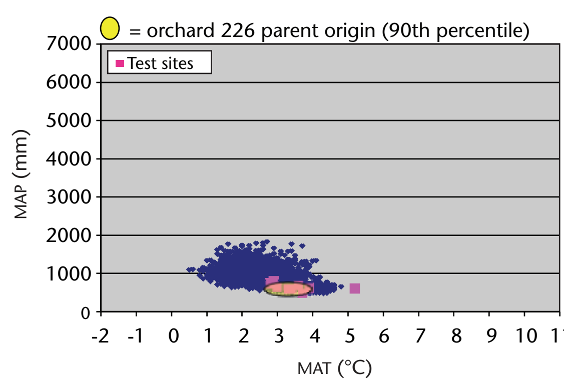


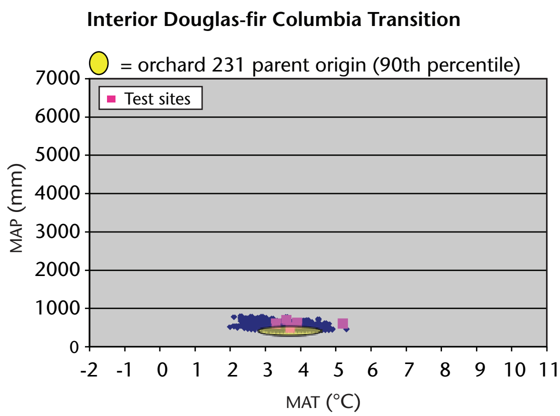
c) Interior Douglas-fir

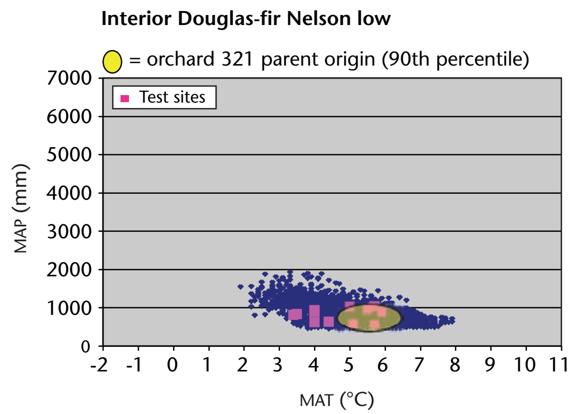
Interior Douglas-fir Prince George

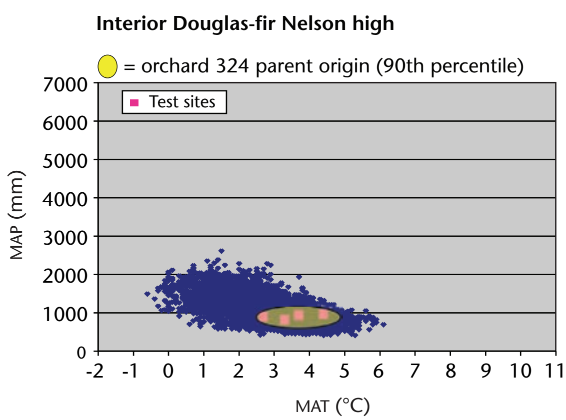


Interior Douglas-fir Quesnel Lakes

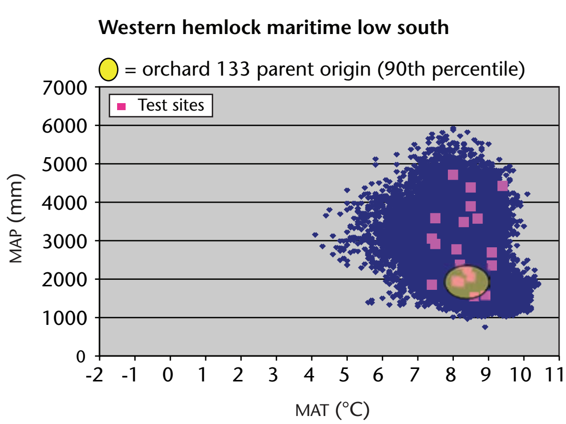


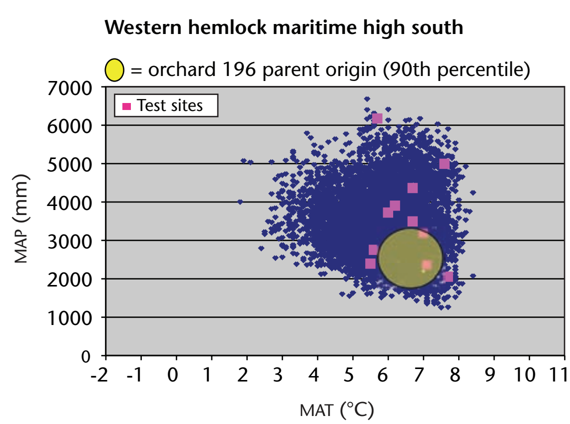




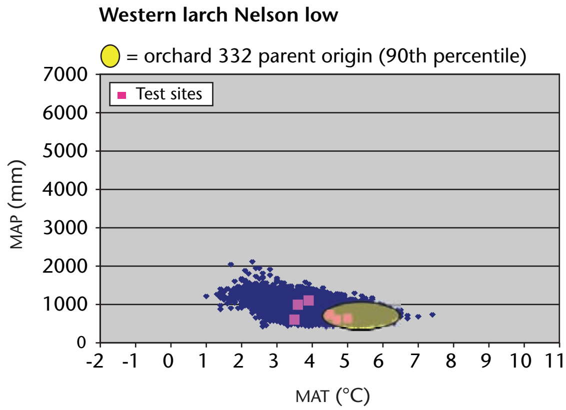


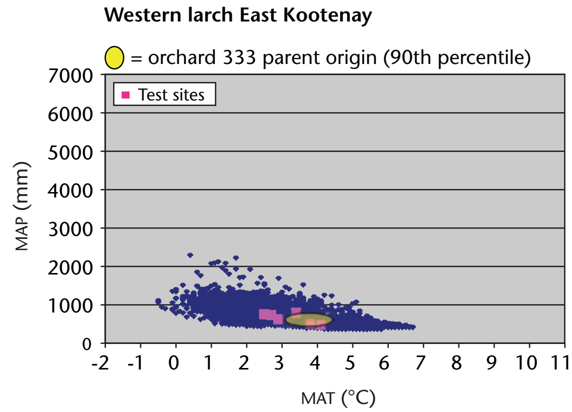
d) Western hemlock



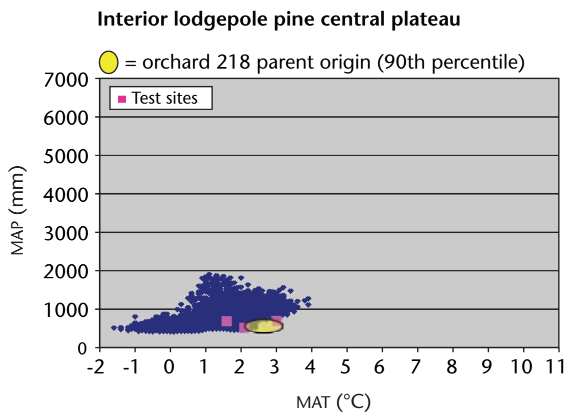


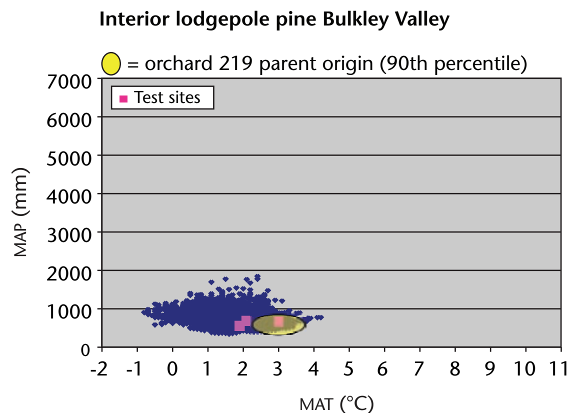
e) Western larch

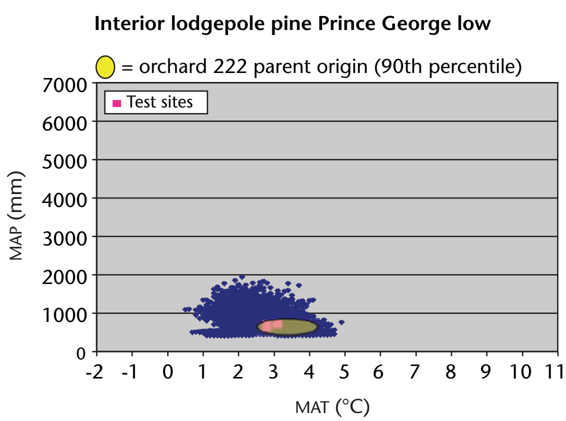


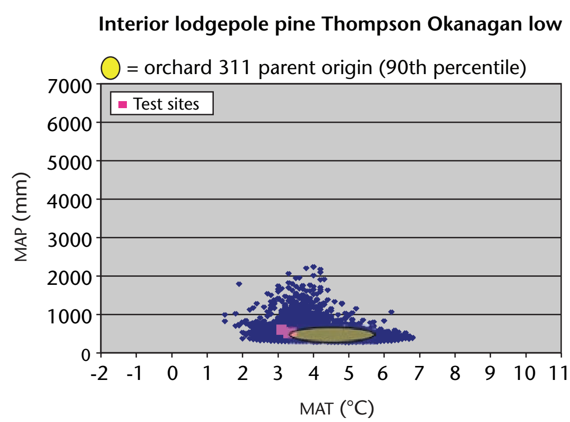


f) Interior lodgepole pine

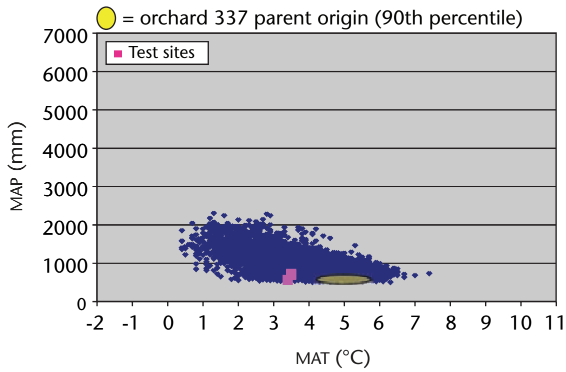






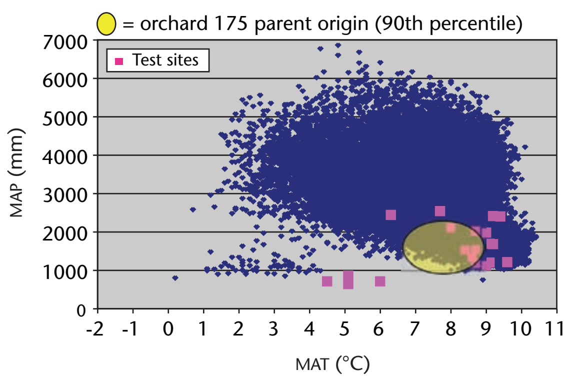


Interior lodgepole pine Nelson low

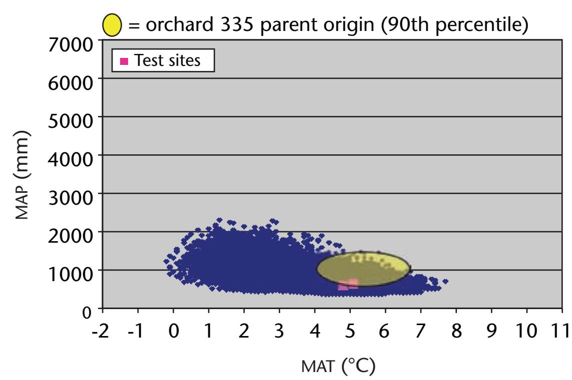


g) Western white pine

Western white pine maritime

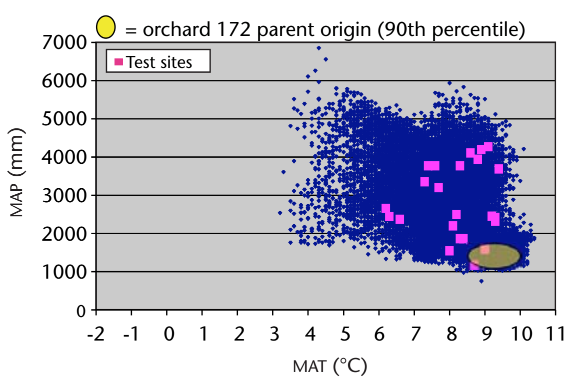


Western white pine Kootenay Quesnel



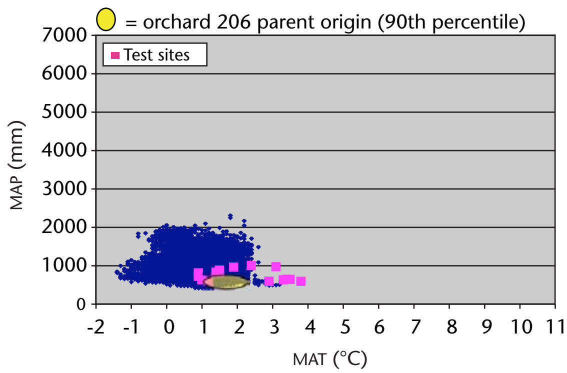
h) Sitka spruce

Sikta spruce maritime low south

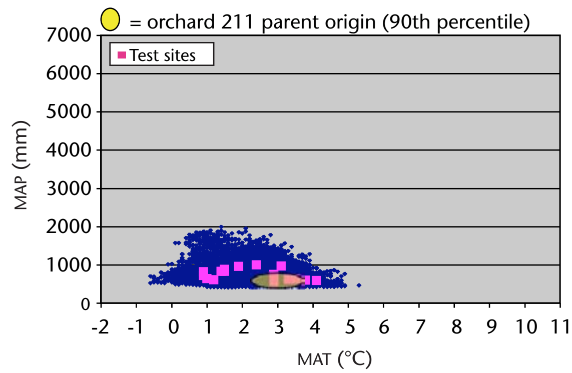


i) Interior spruce

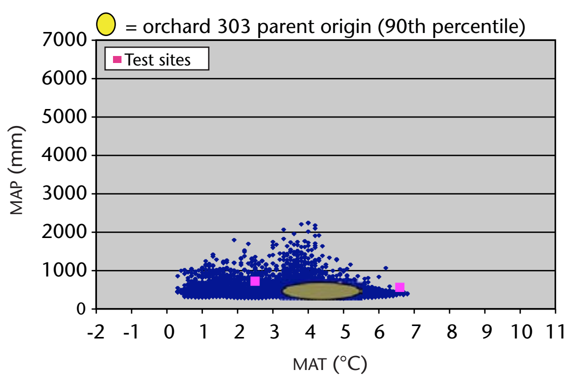
Interior spruce Prince George high



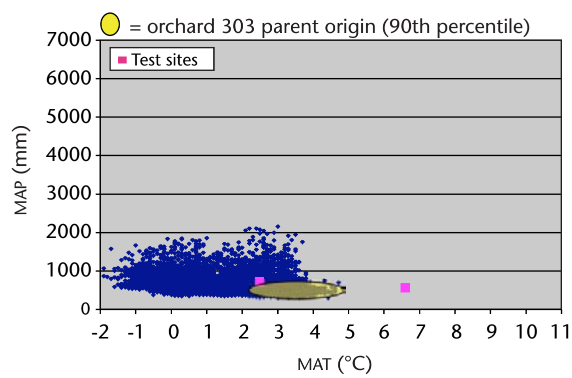
Interior spruce Prince George low



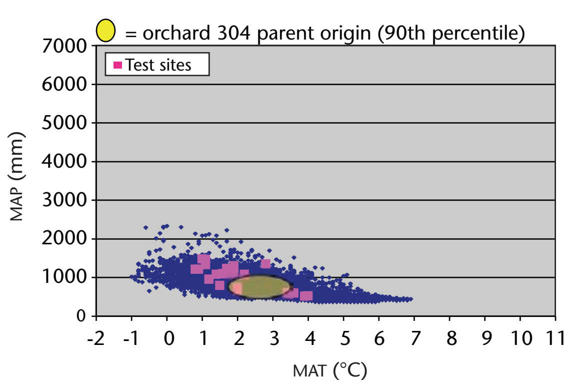
Interior spruce Thompson Okanagan low



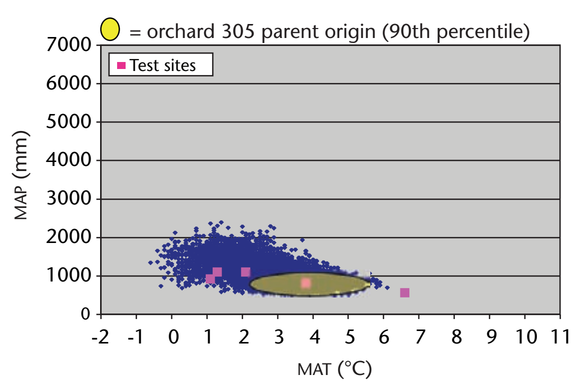
Interior spruce Thompson Okanagan high



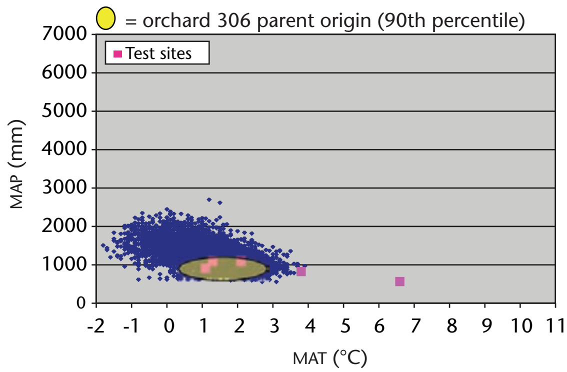
Interior spruce East Kootenay



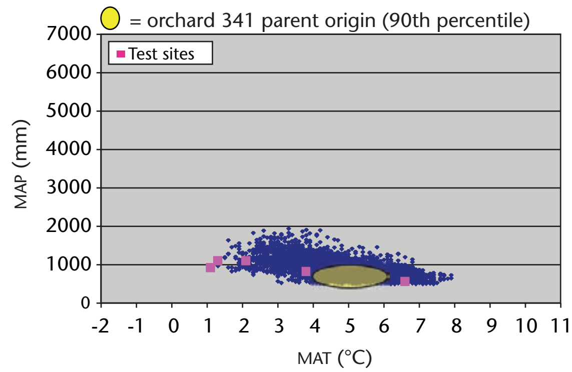
Interior spruce Nelson mid



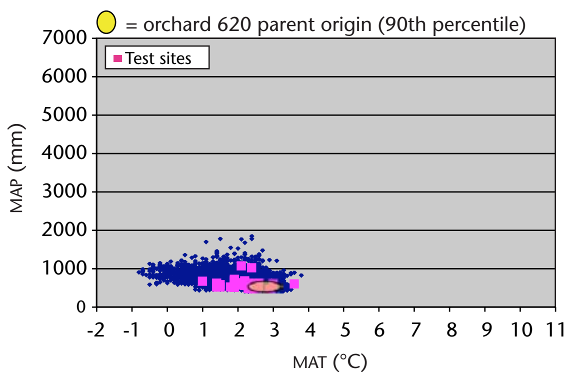
Interior spruce Nelson high



Interior spruce Nelson low

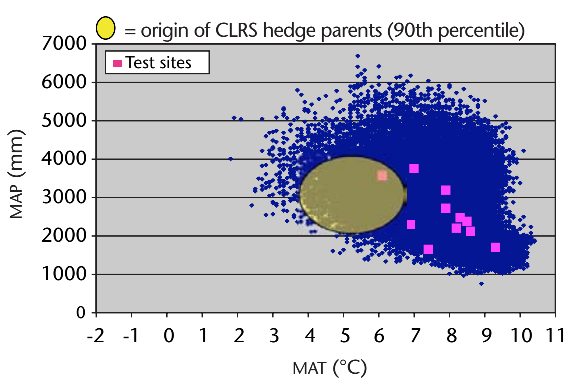


Interior spruce Bulkley Valley

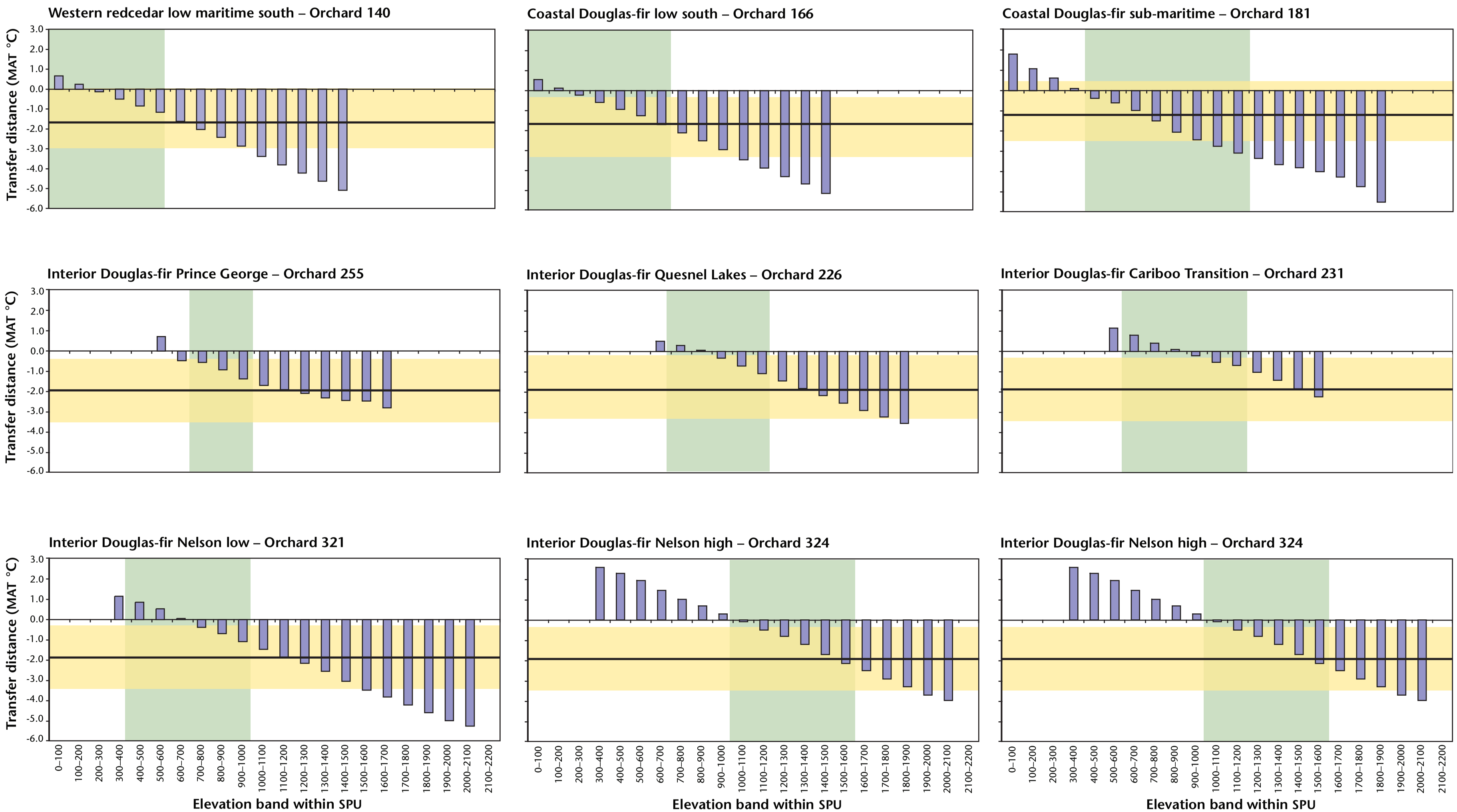


j) Yellow-cedar

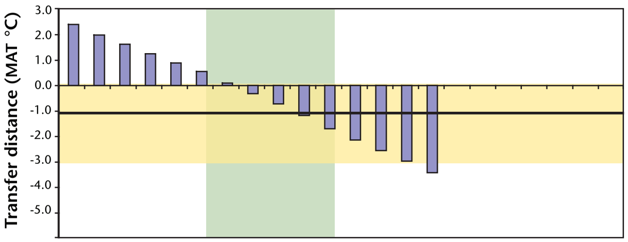
Yellow-cedar maritime south



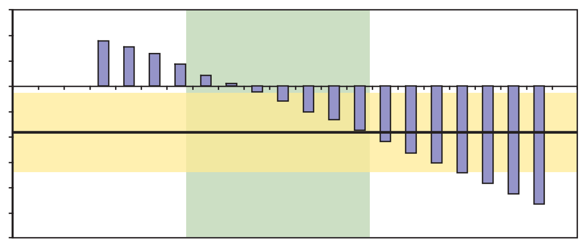
APPENDIX 2 Average mean annual temperature distance that orchard seed is transferred for 100-m elevation bands for 30 seed planning units (SPUs) in British Columbia. Horizontal line and yellow rectangle represent recommended transfer distance target and range, respectively. Green rectangle represents current SPU upper and lower elevation boundaries.



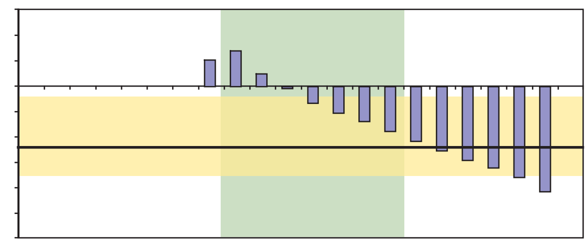
Western hemlock maritime high south – Orchard 196



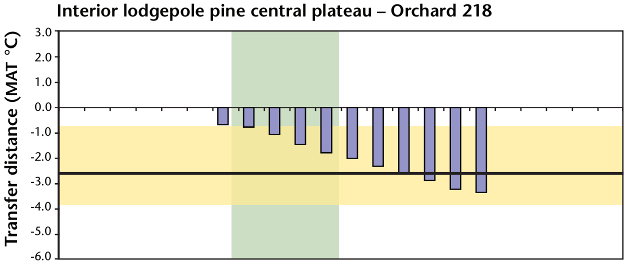
Western larch Nelson low – Orchard 332



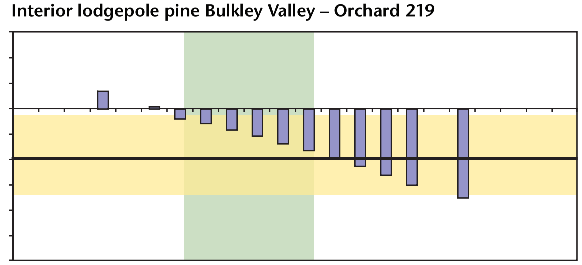
Western larch East Kootenay – Orchard 333



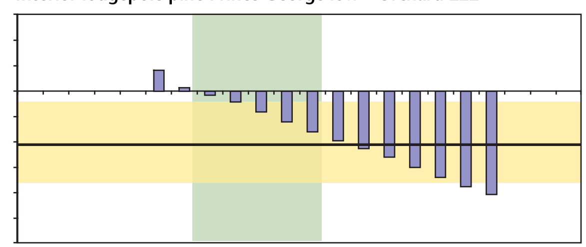
Interior lodgepole pine central plateau – Orchard 218



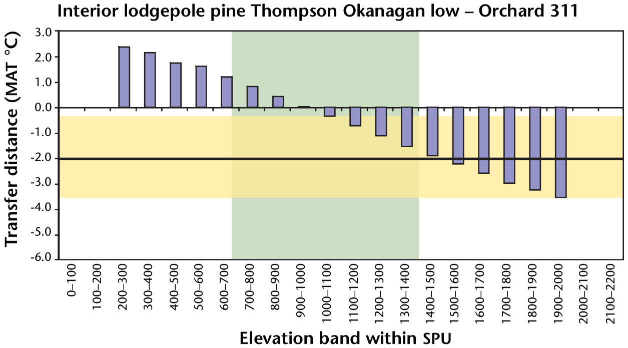
Interior lodgepole pine Bulkley Valley – Orchard 219



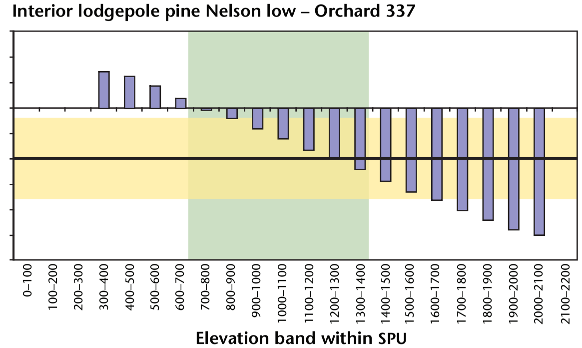
Interior lodgepole pine Prince George low – Orchard 222



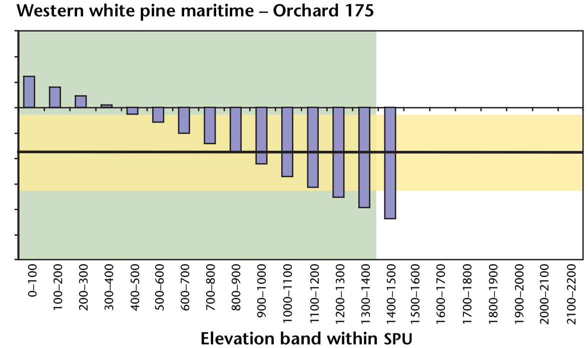
Interior lodgepole pine Thompson Okanagan low – Orchard 311

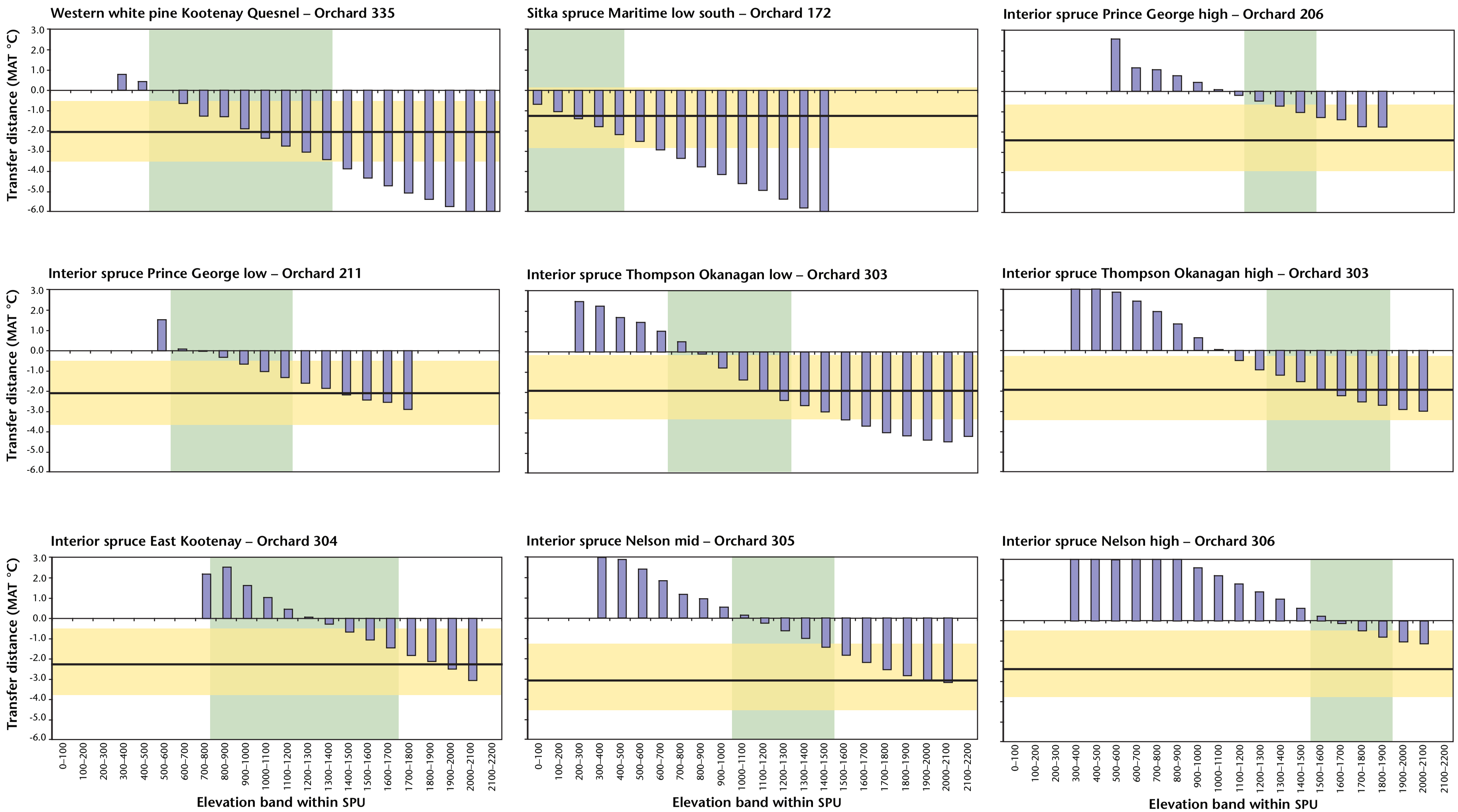


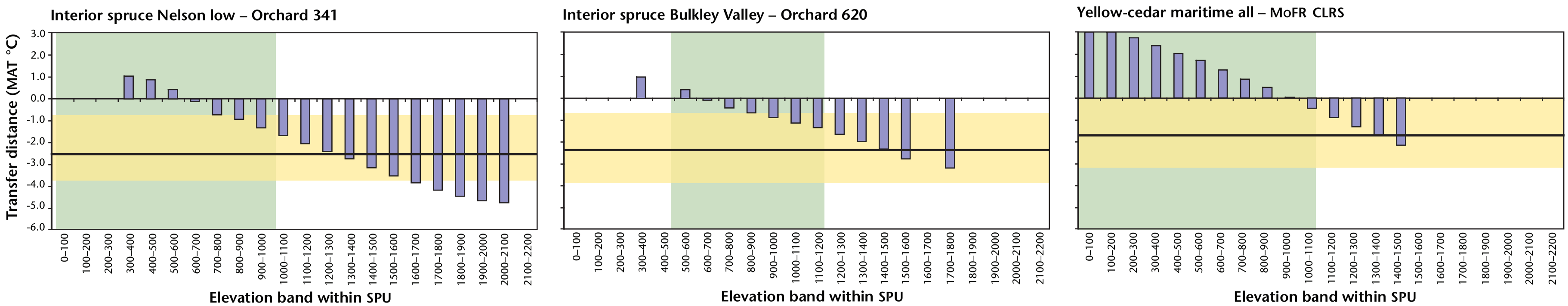
Interior lodgepole pine Nelson low – Orchard 337



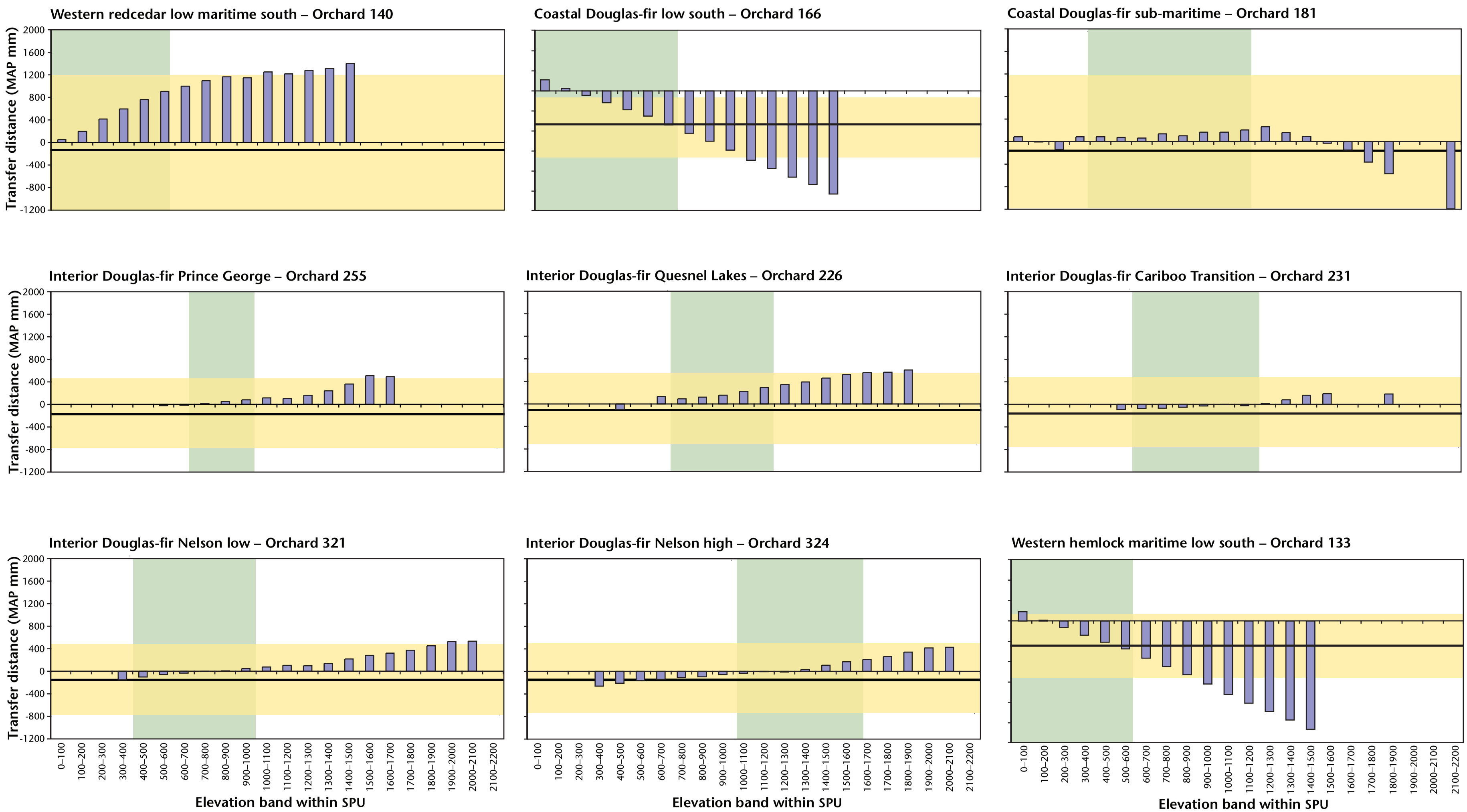
Western white pine maritime – Orchard 175

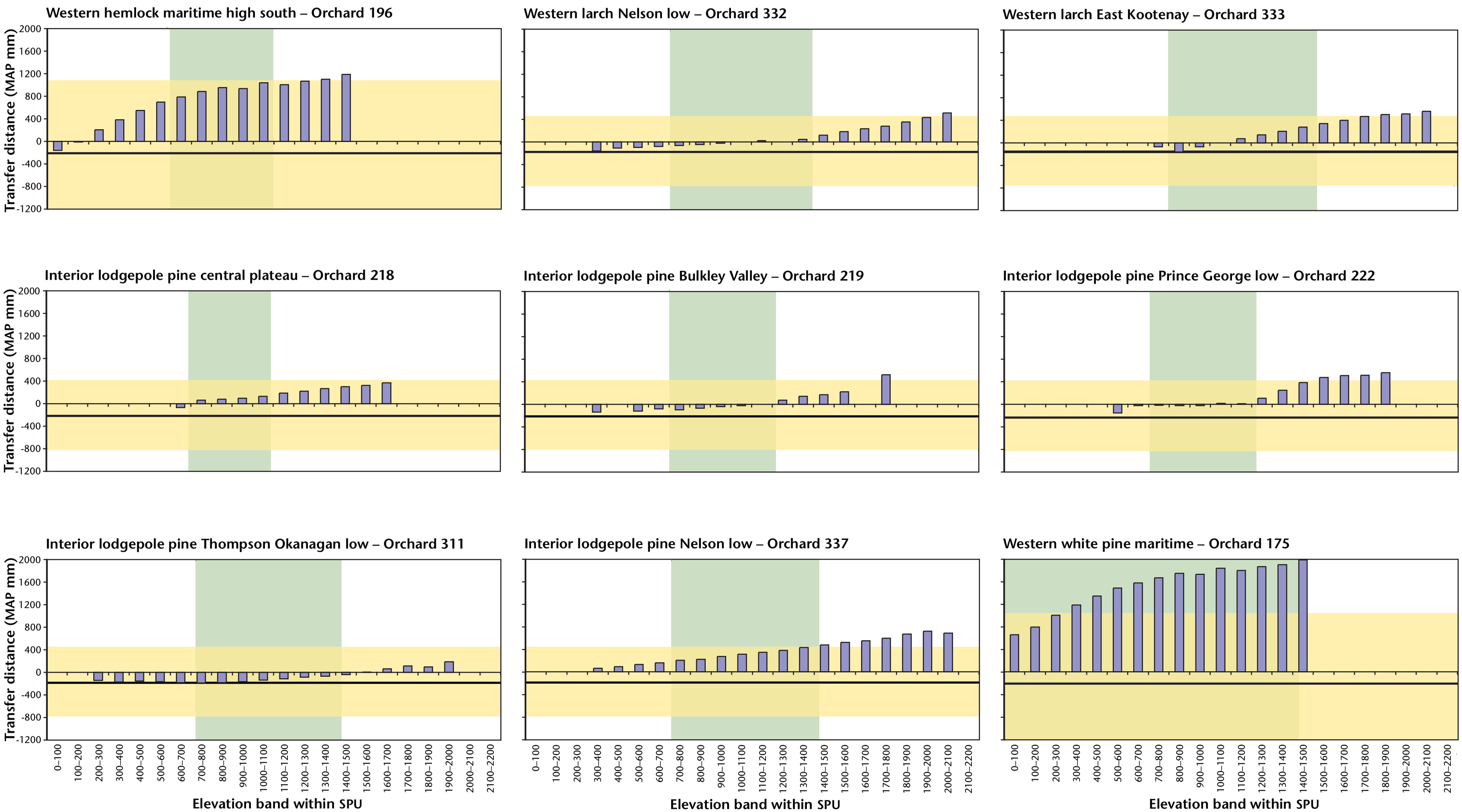



Western white pine Kootenay Quesnel – Orchard 335
Sitka spruce Maritime low south – Orchard 172
Interior spruce Prince George high – Orchard 206
Interior spruce Prince George low – Orchard 211
Interior spruce Thompson Okanagan low – Orchard 303
Interior spruce Thompson Okanagan high – Orchard 303
Interior spruce East Kootenay – Orchard 304
Interior spruce Nelson mid – Orchard 305
Interior spruce Nelson high – Orchard 306
Transfer distance (MAT °C)
3.0 2.0 1.0 0.0 -1.0 -2.0 -3.0 -4.0 -5.0 -6.0
0–100 100–200 200–300 300–400 400–500 500–600 600–700 700–800 800–900 900–1000 1000–1100 1100–1200 1200–1300 1300–1400 1400–1500 1500–1600 1600–1700 1700–1800 1800–1900 1900–2000 2000–2100 2100–2200
Elevation band within SPU

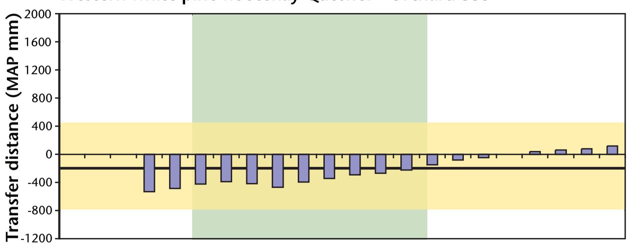

Interior spruce Nelson low – Orchard 341
Interior spruce Bulkley Valley – Orchard 620
Yellow-cedar maritime all – MoFR CLRS
Transfer distance (MAT °C)
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
0–100
100–200
200–300
300–400
400–500
500–600
600–700
700–800
800–900
900–1000
1000–1100
1100–1200
1200–1300
1300–1400
1400–1500
1500–1600
1600–1700
1700–1800
1800–1900
1900–2000
2000–2100
2100–2200
Elevation band within SPU

APPENDIX 3 Average mean annual precipitation distance that orchard seed is transferred for 100-m elevation bands for 30 seed planning units (SPUs) in British Columbia. Horizontal line and yellow rectangle represent recommended transfer distance target and range, respectively. Green rectangle represents current SPU upper and lower elevation boundaries.

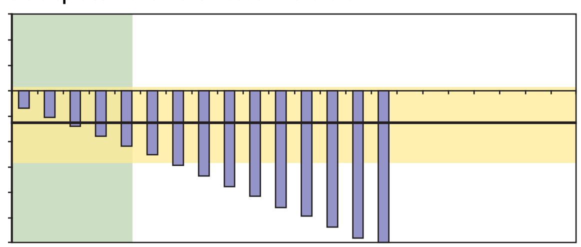



Western hemlock maritime high south – Orchard 196
Western larch Nelson low – Orchard 332
Western larch East Kootenay – Orchard 333
Interior lodgepole pine central plateau – Orchard 218
Interior lodgepole pine Bulkley Valley – Orchard 219
Interior lodgepole pine Prince George low – Orchard 222
Interior lodgepole pine Thompson Okanagan low – Orchard 311
Interior lodgepole pine Nelson low – Orchard 337
Western white pine maritime – Orchard 175
Transfer distance (MAP mm)
2000
1600
1200
800
400
0
-400
-800
-1200
0–100
100–200
200–300
300–400
400–500
500–600
600–700
700–800
800–900
900–1000
1000–1100
1100–1200
1200–1300
1300–1400
1400–1500
1500–1600
1600–1700
1700–1800
1800–1900
1900–2000
2000–2100
2100–2200
Elevation band within SPU

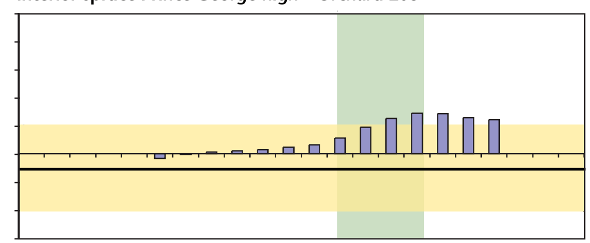
Western white pine Kootenay Quesnel – Orchard 335



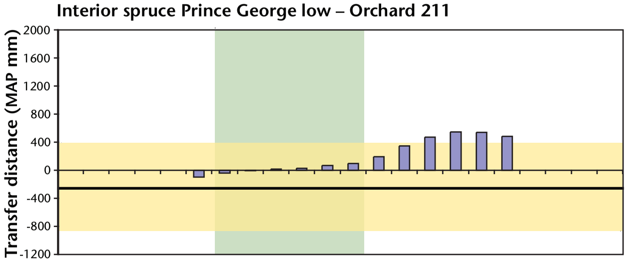
Sitka spruce Maritime low south – Orchard 172



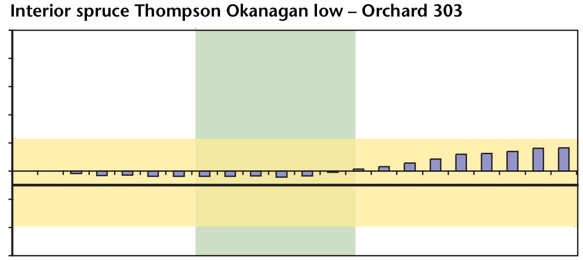
Interior spruce Prince George high – Orchard 206



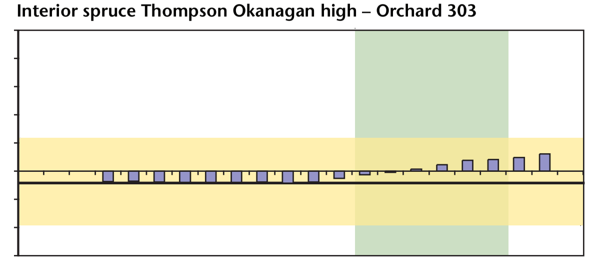
Interior spruce Prince George low – Orchard 211



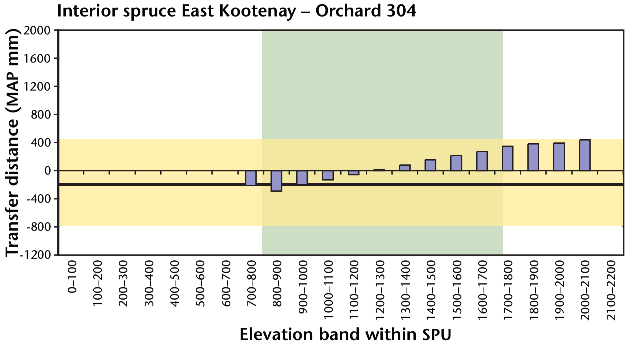
Interior spruce Thompson Okanagan low – Orchard 303



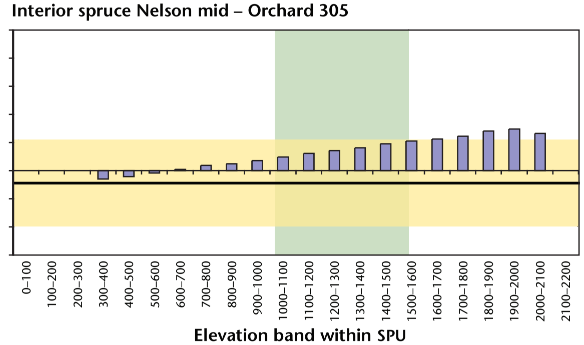
Interior spruce Thompson Okanagan high – Orchard 303



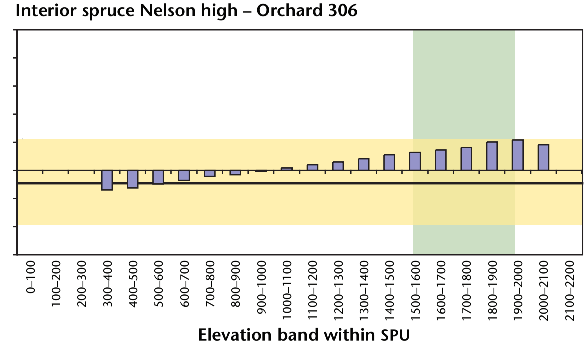
Interior spruce East Kootenay – Orchard 304



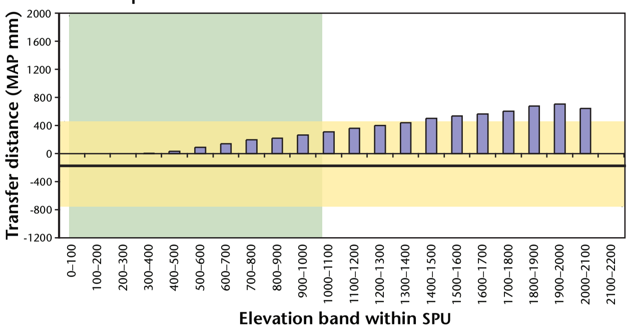
Interior spruce Nelson mid – Orchard 305



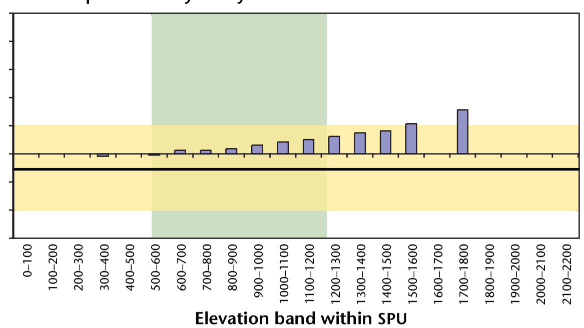
Interior spruce Nelson high – Orchard 306



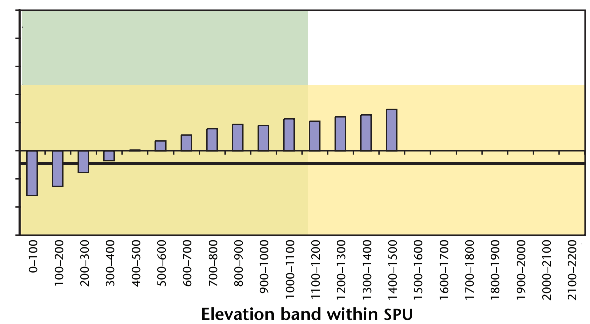
Interior spruce Nelson low – Orchard 341



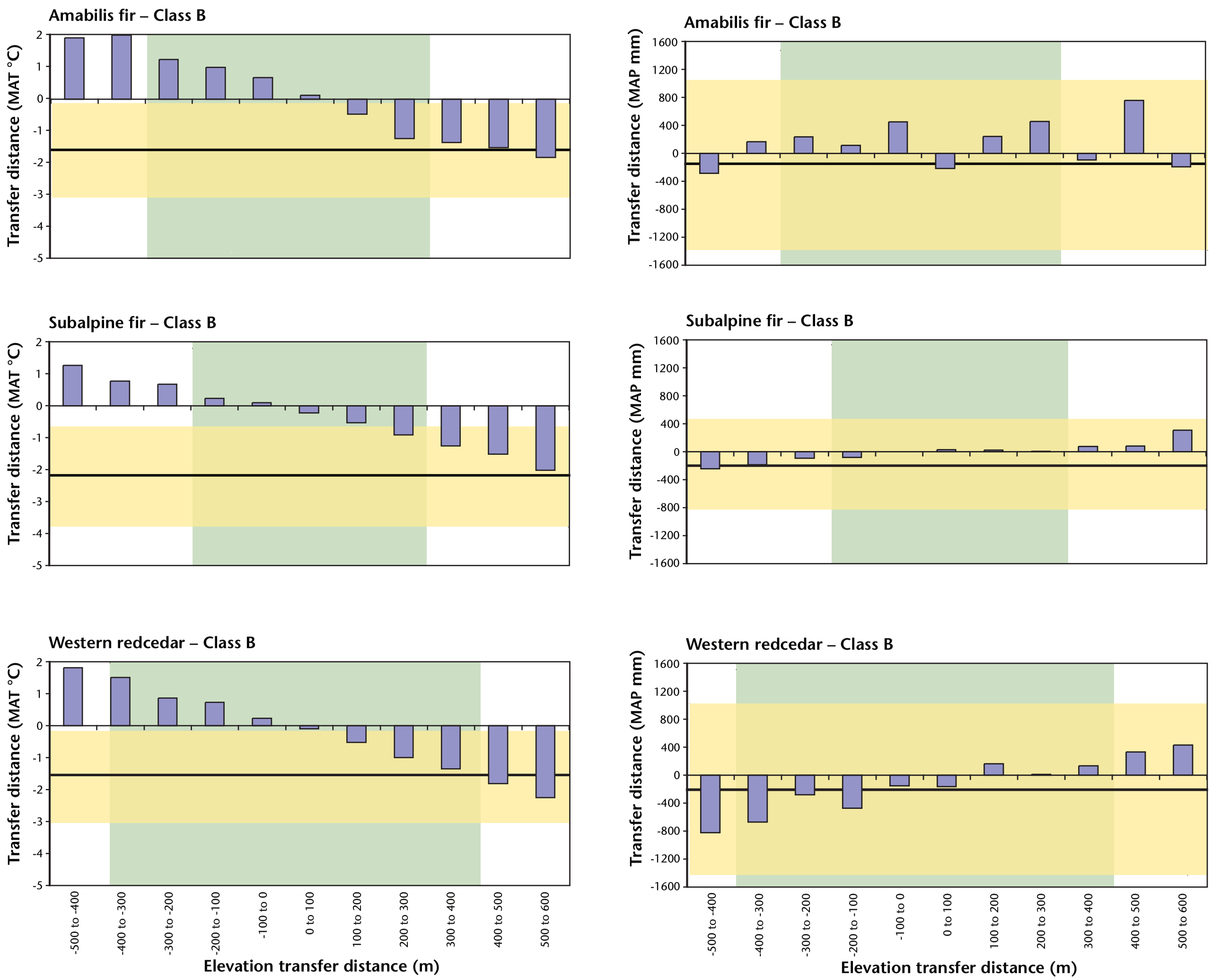
Interior spruce Bulkley Valley – Orchard 620

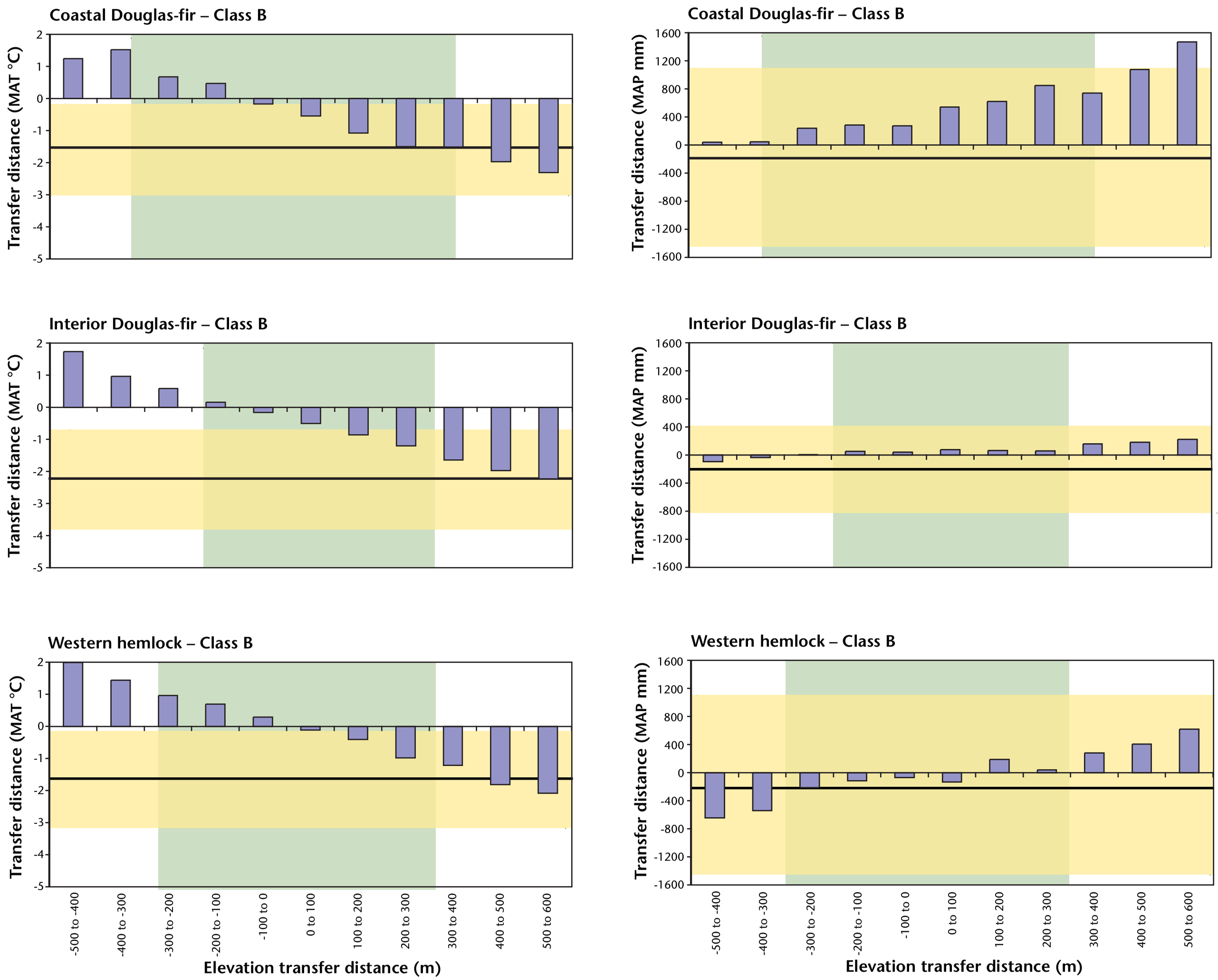


Yellow-cedar maritime south – MoFR CLRS



APPENDIX 4 Average mean annual temperature distance that wildstand (Class B) seed is transferred for 100-m elevation bands for 12 commercial species in British Columbia. Horizontal line and yellow rectangle represent transfer distance target and range, respectively. Green rectangle represents current elevational transfer limits.

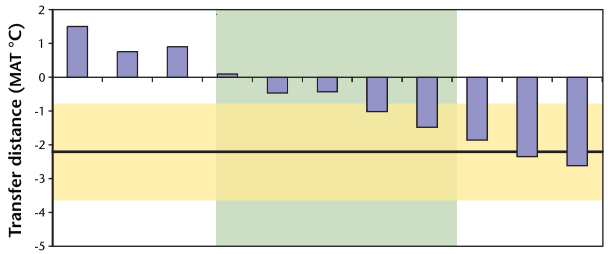




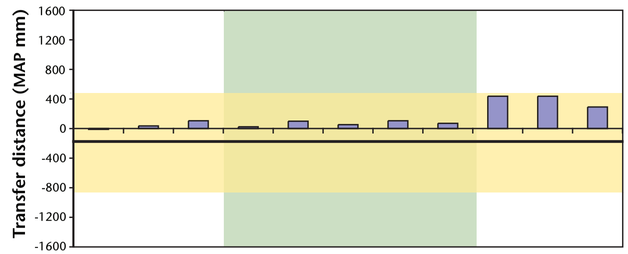
Coastal Douglas-fir – Class B
Transfer distance (MAT °C)
Coastal Douglas-fir – Class B
Transfer distance (MAP mm)
Interior Douglas-fir – Class B
Transfer distance (MAT °C)
Interior Douglas-fir – Class B
Transfer distance (MAP mm)
Western hemlock – Class B
Transfer distance (MAT °C)
Western hemlock – Class B
Transfer distance (MAP mm)
-500 to -400
-400 to -300
-300 to -200
-200 to -100
-100 to 0
0 to 100
100 to 200
200 to 300
300 to 400
400 to 500
500 to 600
Elevation transfer distance (m)

APPENDIX 4 continued

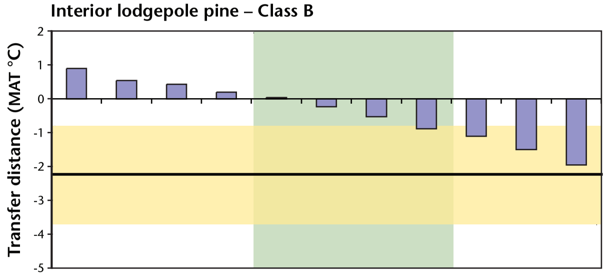
Western larch – Class B



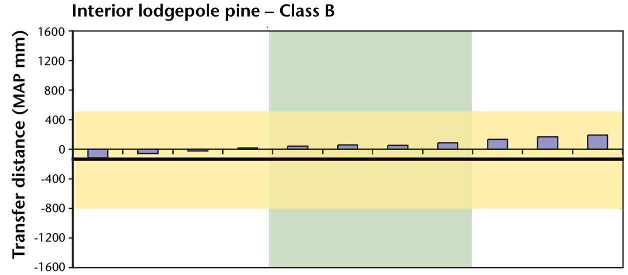
Western larch – Class B



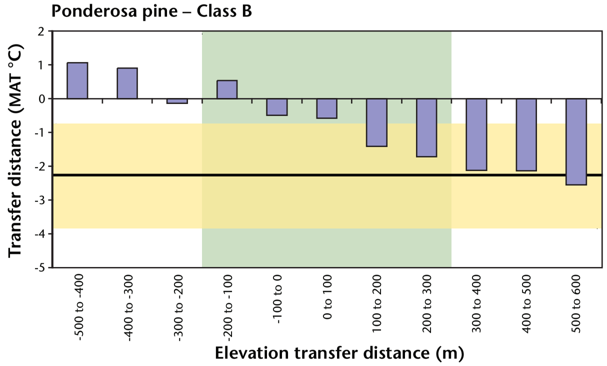
Interior lodgepole pine – Class B



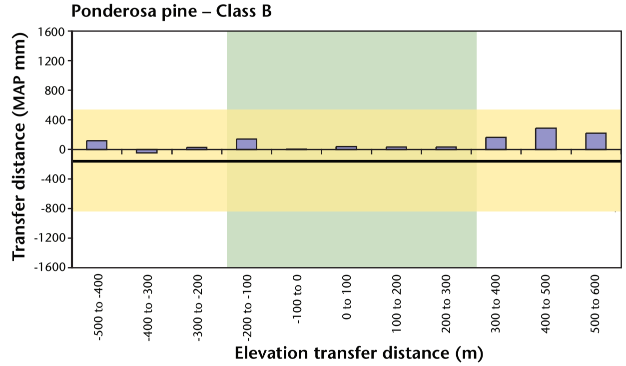
Interior lodgepole pine – Class B



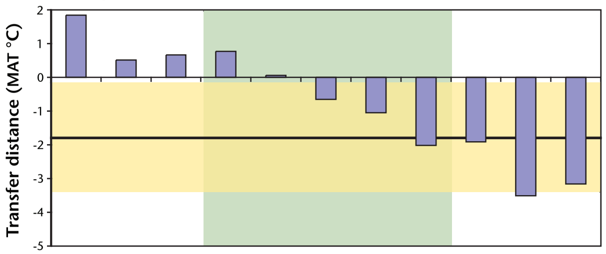
Ponderosa pine – Class B



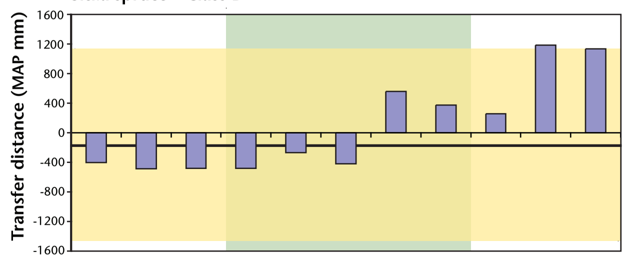
Ponderosa pine – Class B



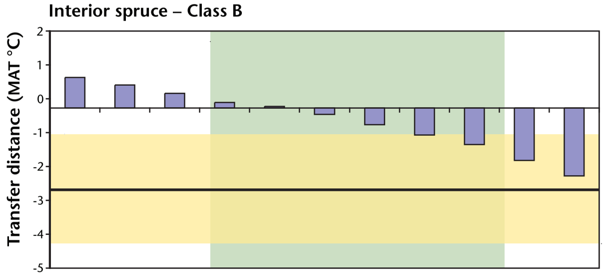
Sitka spruce – Class B



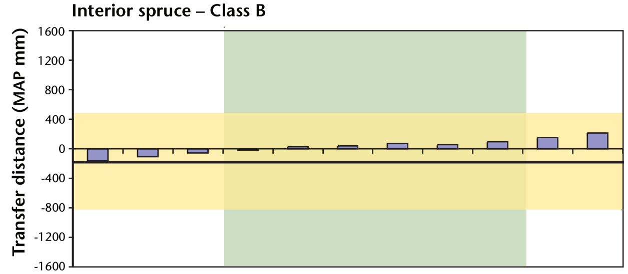
Sitka spruce – Class B



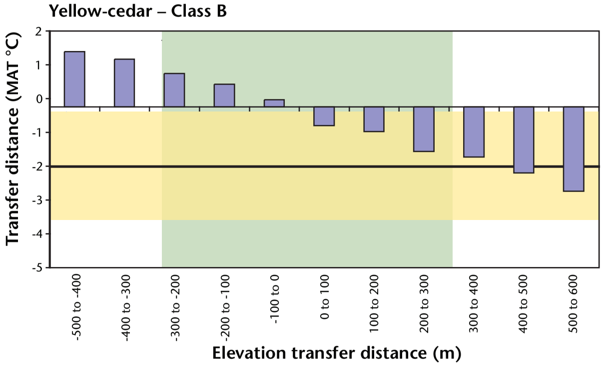
Interior spruce – Class B



Interior spruce – Class B



Yellow-cedar – Class B



Yellow-cedar – Class B