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Information Report
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2018

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Cat. no. Fo4-135/2018E-PDF
ISBN 978-0-660-30153-2

A pdf version of this publication is available through the Canadian Forest Service Publications website: http://cfs.nrcan.gc.ca/publications.

Editing: Paula Irving
Design and layout: Julie Piché

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Acknowledgements

The Canadian Wood Fibre Centre, Natural Resources Canada funded this report and associated fieldwork. Thanks to the staff at the Ministry of Forests, Lands, Natural Resource Operations and Rural Development in Terrace who provided us with advice and updated maps and helped us locate some of the sites in the Kalum District. We also thank Antoine Lalumière of the Canadian Wood Fibre Centre for extensive advice on and thorough edits of an earlier draft, which helped to significantly improve this report, and Richard Winder of the Pacific Forestry Centre for useful edits and advice. Thanks also to Cosmin Filipescu of the Canadian Wood Fibre Centre for supporting the project and guiding us on the road to publication.

Abstract

Although hundreds of off-site and exotic tree plantations have been established in British Columbia since the 1950s, there is a lack of current information on their survival and condition. In this report, we document the work undertaken to locate some of these plantations and assess their success. Sites selected were planted between 1958 and 1982 in the areas near Terrace and Campbell River. Fieldwork procedures followed Canada's National Forest Inventory (NFI) ground-sampling guidelines. The Table Interpolation Program for Stand Yield (TIPSY) was used to compare the growth and stocking of the off-site species with projected growth of local species and with their projected growth in their native habitat. Of 22 potential sites for the Terrace region, NFI plots were established in 7, limited assessments were done in 5, and 10 were either not found or inaccessible. Based on site index and radial growth, all species in our NFI plots exhibited greater diameter and height growth compared to the native species present and those modeled with TIPSY. Contribution to total basal area (BA) by off-site/exotic species ranged from 25% to over 90%. We visited five sites in the Campbell River area and established NFI plots in all of them. Although the off-site/exotic species comprised the bulk of the contributing BA on all sites, the leading native species, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), had larger diameters and heights than the pine species, whereas the native western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) also showed greater radial growth than the larch species. These initial findings suggest that further investigation of successful off-site and exotic plantations may provide useful information for reforestation and assisted migration while an investigation of wood quality and unique attributes of successful exotic plantation tree species may also reveal opportunities to expand and diversify British Columbia's wood fibre basket.

Résumé

Même si depuis les années 1950, on a planté des arbres exotiques dans des centaines de plantations et de sites naturels en Colombie-Britannique, nous manquons de données à jour sur leur survie et leur état. Dans ce rapport, nous donnons un aperçu des démarches pour trouver certains de ces sites et pour évaluer les résultats. On avait boisé les sites choisis entre 1958 et 1982, aux environs de Terrace et de Campbell River. Le travail sur le terrain était conforme au plan d'échantillonnage de l'Inventaire forestier national (IFN) du Canada. Nous avons utilisé la Table Interpolation Program for Stand Yield (TIPSY), pour comparer la croissance et la densité des espèces exotiques des sites naturels avec la croissance attendue des espèces indigènes et la croissance attendue dans l'habitat naturel. En ce qui concerne les 22 sites de Terrace, nous avons établi 7 parcelles d'observation fondées sur l'IFN, évalué sommairement 5 sites, alors que 10 sites étaient introuvables ou non accessibles. En se fondant sur l'indice de qualité du site et la croissance radiale des essences, les arbres de nos parcelles d'observation étaient plus hauts et plus gros que les espèces indigènes sur place et de celles modélisées au moyen de la TIPSY. La surface terrière occupée par les espèces exotiques des sites naturels allait de 25 à plus de 90 p. cent. Nous avons visité 5 sites de Campbell River et avons établi des parcelles d'observation fondées sur l'IFN dans chacun. Même si les espèces exotiques des milieux naturels couvraient la majeure partie de la surface terrière dans chaque site, le Douglas vert (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), l'essence indigène principale, était supérieur en hauteur et en grosseur que les pins, alors que la croissance radiale de la pruche de l'Ouest (*Tsuga heterophylla* (Raf.) Sarg.), était supérieure à celle des mélèzes. Ces premiers résultats démontrent qu'une étude plus poussée sur la survie des espèces exotiques introduites dans des plantations ou des sites naturels, pourrait fournir d'importantes données en faveur du reboisement et de la migration assistée, alors qu'une étude sur la qualité du bois et les caractéristiques particulières des espèces exotiques, pourrait également mettre en lumière les possibilités de développer et de diversifier davantage les produits forestiers de la Colombie-Britannique.

Key Points

- Starting in the 1950s, over 250 off-site and exotic plantations were established across the southern forest regions and in the Skeena Region of British Columbia.
- By the 1970s, approximately 35% had been classified as failures, but later assessments conducted in 1984/85 found that many of the plantations had survived and were growing favorably.
- Aside from a compendium prepared by the British Columbia Ministry of Forests, Lands, Natural Resources Operations and Rural Development of 119 plantations, which were initiated up to 1983, it seemed there was little information on the present state of these experimental sites.
- In this report, we document the results of fieldwork undertaken to locate some of these plantations and assess their present health and viability compared to native species.
- Of the 22 sites on the list of potential candidates in the Terrace region, NFI plots were established in 7, limited assessments were done in 5, and 10 were abandoned.
- Based on site index and radial growth alone, all off-site and exotic species in our Terrace NFI-sampled sites exhibited greater diameter and height growth compared to the native species on-site.
- In the Campbell River region of Vancouver Island, five plantations were found and NFI plots were established in all of them and although the off-site/exotic species comprised the bulk of the contributing basal area on all sites, the competing native Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco var. *menziesii*) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) exhibited superior height and/or radial growth.
- Further research is recommended as these abandoned sites could offer useful data, contributing to assisted migration decisions and providing opportunities to diversify British Columbia's forest products.

Mots-clés

- Depuis les années 1950, on a planté des arbres exotiques dans plus de 250 plantations et sites naturels dans les régions forestières méridionales et celles de Skeena en Colombie-Britannique.
- À l'horizon des années 1970, on considérait que c'était un échec dans environ 35 % des cas, mais des évaluations réalisées en 1984-85, révélaient que de nombreux arbres étaient toujours bien enracinés et poussaient vigoureusement.
- Mis à part un recueil d'informations statistiques sur les 119 sites établis jusqu'en 1983, élaboré au sein du ministère Forest, Lands, Natural Resources Operations and Rural Development de la Colombie-Britannique, il n'y avait guère d'information sur l'état actuel de ces sites expérimentaux.
- Dans ce rapport, nous donnons un aperçu du travail accompli pour localiser certains de ces sites, en vue d'évaluer l'état et la viabilité des essences exotiques par rapport aux espèces indigènes.
- Parmi les 22 sites de la région de Terrace, nous avons établi 7 parcelles d'observation fondées sur l'Inventaire forestier national (IFN), évalué sommairement 5 sites et en avons laissé 10 de côté.
- Selon l'indice de qualité du site et la croissance radiale des essences, tous les arbres exotiques de nos parcelles d'observation de Terrace étaient plus hauts et plus gros que les espèces indigènes du site.
- Nous avons trouvé 5 sites à Campbell River et avons établi des parcelles d'observation fondées sur l'IFN dans chacun. Même si les espèces exotiques des milieux naturels couvraient la majeure partie de chaque site, les espèces indigènes, comme le Douglas vert (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) et la pruche de l'Ouest (*Tsuga heterophylla* (Raf.) Sarg.), démontraient une plus grande croissance en hauteur et en grosseur.
- Nous recommandons des recherches plus poussées sur ces sites abandonnés, ce qui pourrait fournir d'importantes données en faveur de la prise de décisions sur la migration assistée et mettre en lumière des occasions de diversifier les produits forestiers de la Colombie-Britannique.

1. Introduction

Hundreds of off-site and exotic tree plantations have been established in British Columbia over the years by field foresters for private companies, universities, special groups, and governments with the initial objective of broadening the known species choices for reforestation. These long-term research installations could now provide valuable information on the success of certain species when planted outside their natural geographical range. Opportunities to diversify British Columbia's forest products may exist if exotic species are shown to have unique attributes such as rapid rate of growth, desirable silvicultural characteristics, or a quality of wood and fibre not found in native species. Moreover, although the initial purpose of the off-site plantations was not related to assisted migration, they could now contribute to practical forestry management decisions in the present day context of climate change concerns and associated ecological responses such as insect and disease outbreaks.

Evidence suggests that climate change could have significant effects on a wide range of species and ecosystems (Hamann and Wang 2006; Girardin et al. 2008; Reilly and Spies 2016). Predictions for western Canada are that the climate will be wetter and warmer in winter and hotter and drier in summer (Mote 2003) and that overall there will continue to be an increase in mean annual temperature (Abatzoglou et al. 2014). Some of the most economically important conifer species are expected to lose a large portion of their suitable habitat (Hamann and Wang 2006) and there has already been a widespread impact on British Columbia's plantations due to climate and associated climate-driven insect and disease outbreaks (Carroll et al. 2006; Hogg et al. 2008; Woods et al. 2005). Assisted migration, increasing stand resiliency, and reducing susceptibility to pests through genetic diversity may help to mitigate negative impacts on British Columbia's plantations. Increased research in this field is a key recommendation in a report produced by the British Columbia Ministry of Forests and Range (BCMFR 2006). Several studies have investigated the suitability of tree species to climate change and assisted migration, but these are mostly model based (Hamann and Wang 2006; Loehle and LeBlanc 1996; Nitschke and Innes 2008); there is little field-based information available on the actual long-term performance of off-site and exotic tree species in British Columbia, even though there is a network of established plantations that could provide such insights.

One major off-site and exotic tree plantation program established in the 1950s consisted of approximately 253 plantations located across the southern forest regions and in the Skeena Region of British Columbia. These ranged from 0.2 to 24 ha, and involved approximately 22 organizations including predecessors of the British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (BC MFLNRORD) and the Canadian Forest Service. The species used in this program were largely conifers but out of normal range, although various poplar species were also included. Seed sources were from British Columbia and other provinces throughout Canada, the United States, and other countries worldwide. Approximately 35% of these plantations were classified as failures on early examinations. The reasons for failure were diverse and included losses from browsing, frost, snow, suppression, flooding, drought, insects, and diseases. In some cases, losses might have been due to a lack of follow-up silviculture activity, such as brushing, rather than lack of capacity of the species to grow well. However, some plantations, varying between 4 and 38 years old, were determined to be healthy. A few of those assessed in the 1960s and early 1970s were re-examined by the Forest Insect and Disease Survey (FIDS) in 1984/85, primarily from a forest health perspective and many were found to be in good health and growing well (Wood 1984). A compendium consisting of 119 plantations, including many of the abovementioned, was prepared by the BC MFLNRORD (ca. 1984) and although it contains adequate information on species, location, and site, there is no information on site preparation, stock handling, planting methods, or follow-up silviculture activity. Limited metadata and associated climate data for some of these sites are also available in Winder (2017).

In this report, we document the results of fieldwork undertaken to locate some of these plantations and assess their present health and viability compared to the surrounding native species. The main objectives were

- to determine the locations and accessibility of sites;
- to assess the survival, growth, and condition of the subject species;
- to compare the observed growth of native species within or adjacent to the site to that of the off-site/exotics species; and
- to compare the observed growth of the subject species to that of the local commercial species as projected by the Table Interpolation Program for Stand and Yield (TIPSY) and to the expected growth of the off-site species in their native environments as projected by TIPSY.

Budgetary, time, and practical limitations guided the decision to focus on plantations located near Terrace in the Skeena Forest Region's Kalum Timber Supply Area (TSA), and on Vancouver Island in and around the Coast Forest Region's Campbell River district (Figure 1). The Prince Rupert Compendium provided detailed planting information and excellent maps for the Terrace sites. We selected the Campbell River sites because they were readily accessible and reasonably close to the Canadian Forest Service laboratory in Victoria. Although assorted *Populus* spp. were planted, we decided to focus on conifers due to their superior commercial value. We also gave priority to British Columbia species as these off-site plantations might provide practical opportunities for future reforestation challenges caused by climate change. Further criteria for site selection included a condition of 'okay' to 'excellent' in the last FIDS report assessment and the availability of maps.

For clarity in this report, we refer to native British Columbia species planted outside their accepted climate envelopes as "off-site species" and species not native to British Columbia as "exotic species."

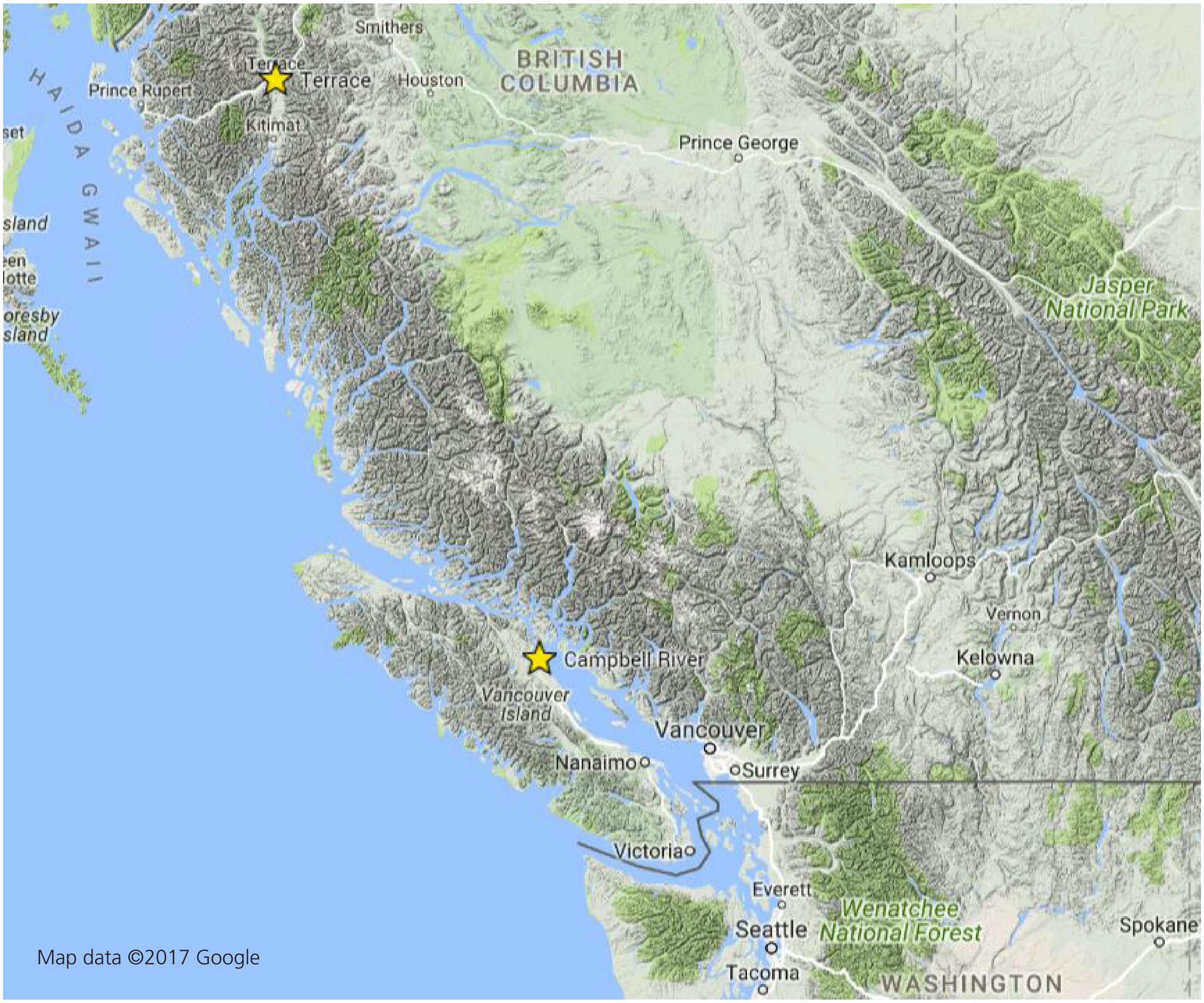

Figure 1. British Columbia showing general location of sites. Map data ©2017 Google.

2. Methods

The sites included in this study were planted between 1958 and 1982. The Terrace plots were assessed in the summer of 2015 and the Campbell River plots in the spring of 2016. All were in the Coastal Western Hemlock Biogeoclimatic Zone. They were mostly in subzone wet submaritime of the Kalum TSA and subzone moist maritime in the Campbell River region, and mostly flat with elevations ranging between 100 and almost 400 m (Tables 1and 4). Although the BC MFLNRORD Prince Rupert exotic plantations records included maps indicating a general location of most of the Terrace plantation blocks, there were no GPS locations available and the maps were outdated. Similarly, most of the Campbell River sites were located using original maps from The FIDS Collection of Exotic Plantations in British Columbia. For the sites that did not have location information, the Long-Term Research Installation Catalogue (LTRIC) was used to estimate the location. Many of the sites were inaccessible due to road abandonment or deactivation and in some cases, no trees were found, thus the site location could not be confirmed. Once a plantation was positively located and identified in the field, geographic coordinates were recorded using a GPS.

The field assessments procedure followed Canada's National Forest Inventory (NFI) Ground Sampling Guidelines (CanNFI 2008) method for 'Large Tree Plots.' Thus, once a stand was found, if it was larger than 0.04 ha and there were sufficient survivors of the subject species to capture at least five individuals in a plot, an 11.28-m radius circular plot (0.04 ha) was established and assessed according to the guidelines. In instances where the area was too small or where only a few scattered individuals survived, sampling was limited to four to six heights and diameters (Diameter at Breast Height (DBH)) of subject species and several heights and diameters of the representative local species.

Site indices for the NFI-assessed sites were determined using a site index (SI) calculator for Windows, Site Tools version 4.0 (Province of British Columbia 2015). Calculations of heights were based on NFI field procedures: the largest diameter tree in the plot was measured regardless of species, the largest diameter tree of the leading species in each quadrant was measured, and the largest diameter tree of the second leading species was selected from each quadrant. In each plot, this yielded an average height from four or five trees from each of two species. SI information was not available for some of the exotic species, thus *Larix occidentalis* Nutt. (western larch) was used in place of *L. decidua* Mill. (European larch) and *L. kaempferi* (Lamb.) Carrière (Japanese larch) while *Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm. (lodgepole pine) was used to estimate an SI for *P. resinosa* Ait. (red pine). Average age at breast height was determined for each of these species by taking one 5-mm core sample per tree.

The Table Interpolation Program for Stand and Yield (TIPSY) software version 4.3 was used to compare the growth and stocking (mean height, quadratic mean diameter (QMD), site basal area (BA), and stem density) of the off-site species with projected growth of local species and with the potential growth in their native habitat. Since TIPSY was developed for British Columbia species, this was not carried out for the exotic species surveyed. Because there was no information available on site preparation, operational adjustment factors (OAFs), species composition at the time of establishment, or ongoing data on the survival, growth, and condition of these plantations, the inputs in TIPSY could not be adjusted to reflect the study characteristics. Thus, for all the sites, default site indices and OAFs were applied and stands were assumed to be 100% pure.

3. Results and Discussion

3.1 Kalum Timber Supply Area

3.1.1 Sampling

Of the 22 sites on the list of potential candidates for the Terrace region, NFI plots were established in 7, limited assessments were done in 5, and 10 were abandoned. Table 1 outlines the results of the initial site assessment and some of the basic information available in the ministry records.

Table 1. Assessment summary of sites located in the Kalum Timber Supply Area. Dark gray entries indicate that an NFI plot was established; light gray indicates limited sampling; no fill indicates no sampling was done for various reasons (see Comments/observations column) (adapted from BC MFLNRORD ca. 1984, unpublished report).

Site	Longtitude	Latitude	Species	Common name	Origin	Yr planted	Elevation (m)	Aspect	Slope (%)	No. trees planted	Area (ha)	Comments/ observations
Fc–10	–	–	*Pseudotsuga menziesii* var. *menziesii*	Coastal Douglas-fir	Kemano, BC	1982	168–198	S	–	425	0.50	Site not found. New road work not indicated on older maps.
Fc–11	128°28′38.6″	54°17′46.3″	*Pseudotsuga menziesii* var. *menziesii*	Coastal Douglas-fir	Kemano, BC	1982	335–640	S	10	21 950	16.00	Good diameter growth but lots of competition (*Tsuga heterophylla*, *Alnus* spp.)
Fc–9	–	–	*Pseudotsuga menziesii* var. *menziesii*	Coastal Douglas-fir	Kemano, BC	1982	244–288	S	–	3150	5.00	Site not found. Road deactivated approximately 6 km from location.
Fc–13	–	–	*Pseudotsuga menziesii* var. *menziesii*	Coastal Douglas-fir	Upper Dean River area, BC	1982	244–288	S	–	4450	7.00	Site not found. Roaddeactivated approximately 6 km from location.
Fc–14	–	–	*Pseudotsuga menziesii* var. *menziesii*	Coastal Douglas-fir	Kemano, BC	1982	244–518	S	–	14 800	17.00	Site not found. Road deactivated approximately 6 km from location.
Fi–5	128°49′41.5″	54°46′05″	*Pseudotsuga menziesii* var. *glauca*	Interior Douglas-fir	E. Kootenay, BC	1959	259	flat	0	3000	1.86	Generally good growth, poor growth in wet areas, *Adelges* throughout (1968, 2015), some root rot, lots of leaners (minor).
Le–6	128°47′50.9″	54°42′29.4″	*Larix decidua*	European larch	Niedersachsen, W. Germany	1961	213	flat	0	1170	1.21	Excellent growth, good survival, wavy form, forks common (2015).
Le–8	128°51′19″	54°48′48″	*Larix decidua*	European larch	Schlitz, W. Germany	1964	213	W	5	3400	4.45	Good growth but few survivors, heavy competition with *Pinus contorta*.

Table 1 *(Continued)*

Site	Longtitude	Latitude	Species	Common name	Origin	Yr planted	Elevation (m)	Aspect	Slope (%)	No. trees planted	Area (ha)	Comments/ observations
Lj–1	128°50′22″	54°43′13″	*Larix kaempferi*	Japanese larch	–	1958	274	flat	0	900	1.10	Good survival and growth. Some basal scarring.
Lj–3	–	–	*Larix kaempferi*	Japanese larch	Niedersachsen, W. Germany	1964	213	–	–	2500	3.64	Extremely poor survival. Competition from *Abies grandis*.
Lw–1	128°48′2.9″	54°42′29.2″	*Larix occidentalis*	Western larch	N.W. Montana, USA	1967	213	flat	0	1500	1.60	Excellent survival and growth, some snow and game damage.
Pr–1	128°49′42.1″	54°43′27.3″	*Pinus resinosa*	Red pine	–	1959	275	E	5	85	0.04	High survival, growing well.
Pr–2	128°49′50″	54°43′27″	*Pinus resinosa*	Red pine	–	1962	244	E	5	4000	3.60	Good growth and fair survival on microsites. Variable site with *Pinus contorta* and *Populus* spp. as notable competitors.
Ps–3	128°49′42.1″	54°43′27.9″	*Pinus sylvestris*	Scots pine	–	1961	275	E	5	85	0.08	Very poor growth and survival. Most of the few survivors badly mangled probably due to snow press.
Ps–10	128°40′58.5″	54°09′55.2″	*Pinus sylvestris*	Scots pine	Finland	1981	107–152	SE	variable	200	0.20	Originally doing well on ‘screefed’ spots (1973). Few survivors and poor growth (2015) due to snow press and competition from *Tsuga heterophylla* and *Abies* spp.
Py–1	–	–	*Pinus ponderosa*	Ponderosa pine	–	1957	213	NE	10	–	0.04	Site found but no survivors probably due to suppression.
Py–2	128°49′42.7″	54°43′26.8″	*Pinus ponderosa*	Ponderosa pine	–	1961	275	E	5	135	0.08	Good growth, low survival probably due to early suppression from *Populus* spp.
Py–6	128°47′31.5″	54°42′10″	*Pinus ponderosa*	Ponderosa pine	–	1965	152	flat	0	9250	6.30	*Good* growth. Survival poor due to *Pinus contorta* competition and poor spacing (1973). Some snow damage.
Sn–2	128°50′56″	54°48′58″	*Picea abies*	Norway spruce	Austria	1971	152	flat	0	1850	1.20	Survival and growth quite variable, forking common possibly due to weevil.
Sn–4	–	–	*Picea abies*	Norway spruce	Denmark	1974	–	flat	0	1101	3.36	Site not found. Road deactivated and bridge removed.
XP–146	–	–	*Pseudotsuga menziesii* var. *glauca*	Interior Douglas-fir	E. Kootenay, BC	1959	290	E	1	3000	1.86	Site not found. No maps—estimated location using LTRIC* information and descriptions in FIDS Collection.
XP-225	–	–	*Pinus ponderosa*	Ponderosa pine	–	1961	366	S	2	135	0.81	Site not found. No maps—estimated location using LTRIC* information and descriptions in FIDS Collection.

* The LTRIC (Long-Term Research Installation Catalogue) is a web tool that functions as a searchable catalogue of long-term forest research sites, studies, and projects (https://ca.nfis.org/applications_eng.html).

3.1.2 Site Index

Some minor differences in SI between local and off-site/exotic species can be seen in Figure 2. In all but one case, the off-site/exotic species had a higher SI than that of the native species observed in the plantations; however, the differences were relatively small and results were based on a limited sample size. The only instance where the SI of the native species was higher than that of off-site/exotic species was in the red pine/poplar combination, which was also the only instance where we observed the presence of a hardwood species as the leading native species.

3.1.3 Annual Radial Growth

Coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco. var. *menziesii*) radial growth, derived from the increment core samples collected, was higher than western hemlock (*Tsuga heterophylla*

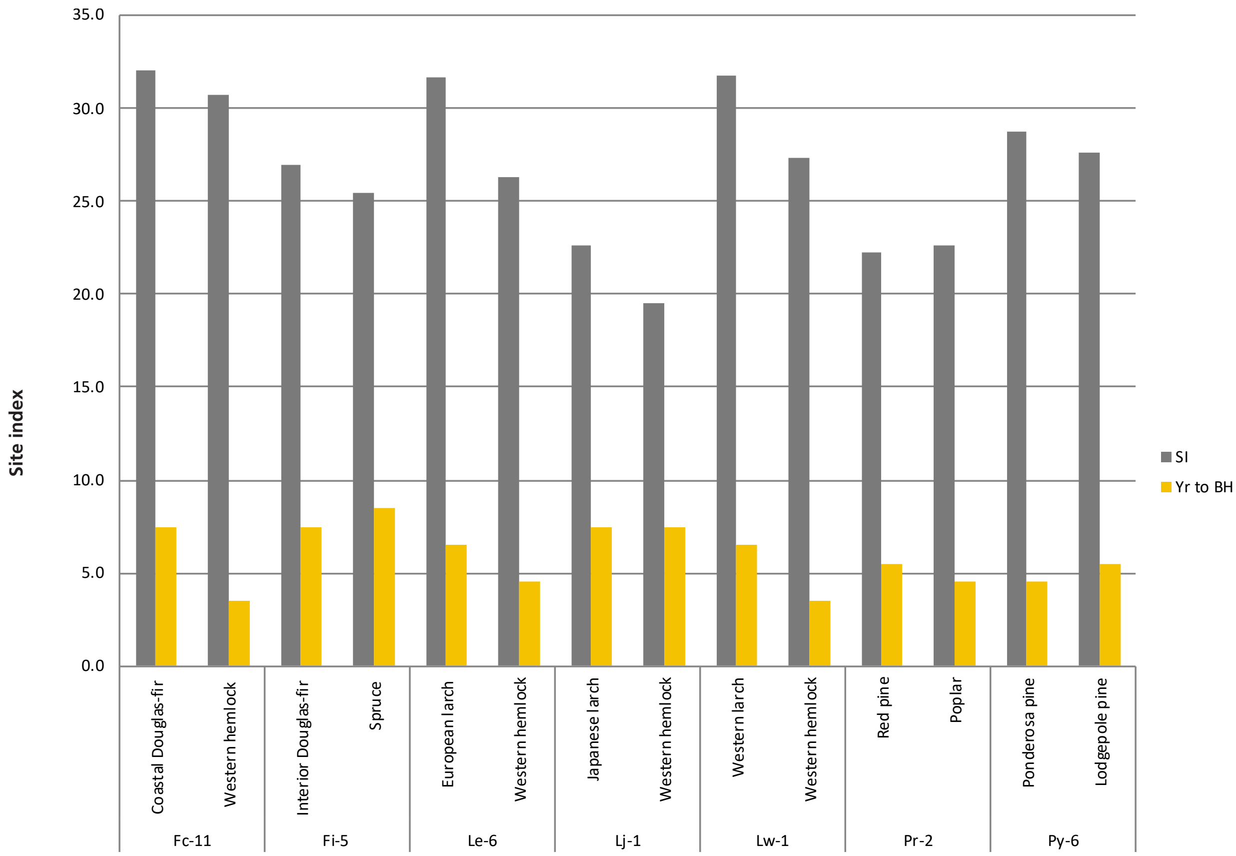

Figure 2. Site Index (SI) and years to breast height (1.3 m) of the off-site/exotic species (left), and leading native species (right) at the seven NFI-sampled sites near Terrace, British Columbia.

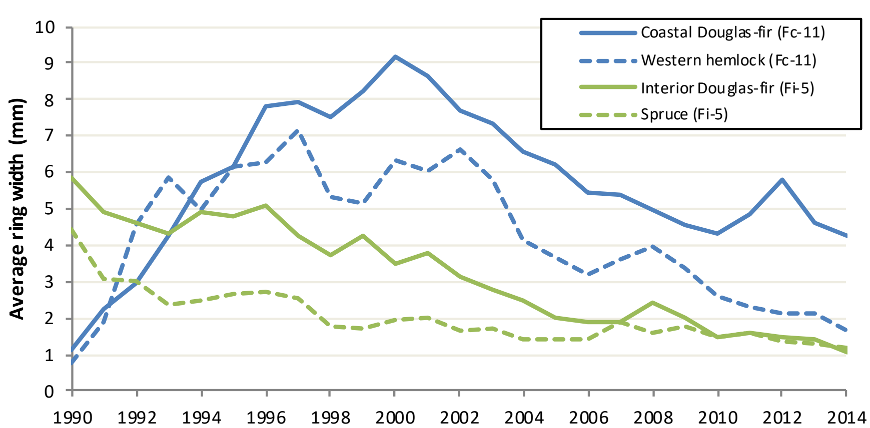

Figure 3. Average radial growth of Douglas-fir varieties compared to on-site native species at sites Fc-11 and Fi-5. Bold lines represent off-site species and dashed lines represent native species.

(Raf.) Sarg.) at the same site, and better than all species on all sites (Figure 3). Early radial growth of interior Douglas-fir (*P. menziesii* var. *glauca* (Beissn.) Franco) was high but steadily declined over time and in the last 7 years has approximately matched the surrounding native spruce species (a hybrid spruce species that we were unable to identify) in incremental growth.

Western larch had the highest annual radial growth rate of all larches (Figure 4) while Japanese larch had the smallest annual incremental growth through the entire time period shown; however, it was observed that the Lj-1 site conditions might have been poor and this was supported by the obtained SI (Figure 2). European larch showed incremental growth similar to the hemlock on the same site throughout the entire time represented by Figure 4. At these three sites, the native western hemlock sampled exhibited overall annual growth as large or larger than all the larch species.

Red pine seemed to perform moderately well in radial growth at the two sites assessed (Figure 5), showing incremental growth similar to the native poplar at one site and lodgepole pine at the other site. Ponderosa pine (*Pinus ponderosa* Dougl. ex P. & C. Laws.) also appeared to perform well at both sites Figure 5), although more recently at site Py-6 the native lodgepole pine demonstrated greater radial growth.

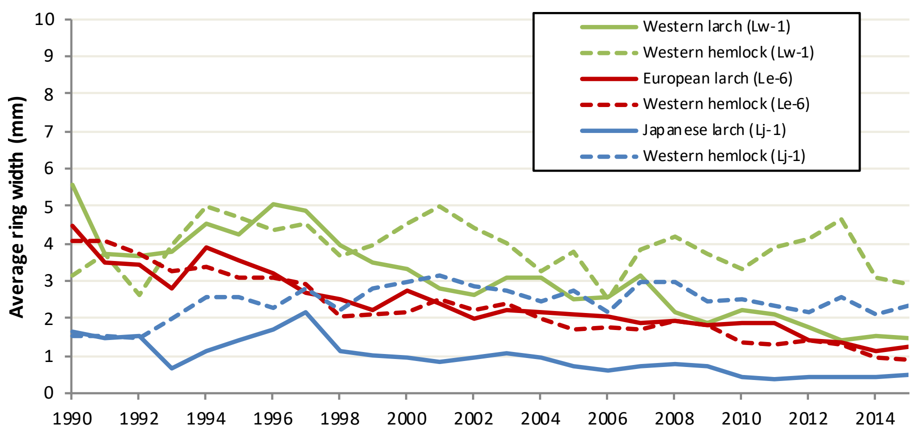

Figure 4. Average radial growth of larch species compared to on-site native species at sites Le-6, Lj-1, and Lw-1. Bold lines represent off-site/exotic species and dashed lines represent native species.

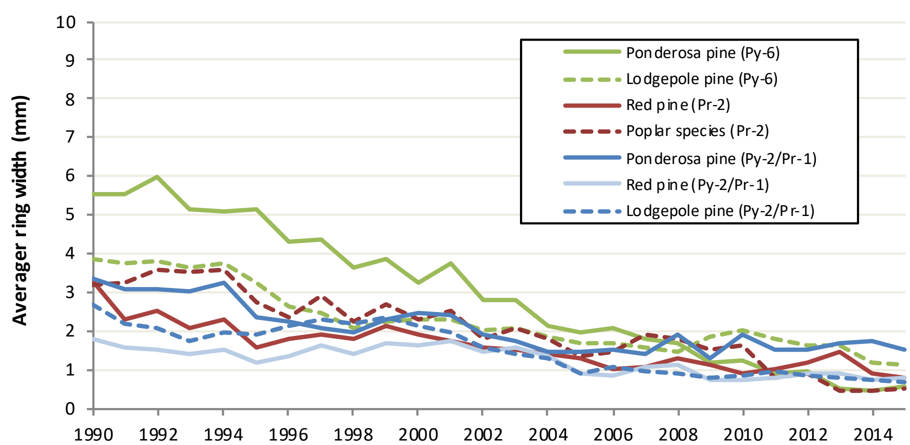

Figure 5. Average radial growth of pine species compared to on-site native species at sites Pr-2, Py-2/Pr-1, and Py-6. Bold lines represent off-site/exotic species and dashed lines represent native species.

3.1.4 Comparison of Basal Area, Tree Density, Diameter at Breast Height, and Height of Subject and Local Native Trees

In the coastal Douglas-fir plot (Fc-11), five species were measured, and the Douglas-firs represented 43% of the BA (Table 2). An estimated 375 Douglas-firs/ha were outnumbered by smaller red alder and western hemlock which appeared to present negligible competition for the Douglas-fir; height growth marginally surpassed that of the other species on-site, but DBH growth was exceptional compared to that of the western hemlock, western redcedar (*Thuja plicata* Donn ex D. Don), red alder, and the spruce species (Figure 6). Although this is a younger plantation compared to many of the other sites (1982 compared to the 1950s and 1960s), some of the DBHs were well over the 30-cm range with an average DBH of 26 cm; this is 32% larger than the next leading species on this site, the native western hemlock (Figure 6).

At 65.1 m^2/ha, the interior Douglas-fir at site Fi-5 had the largest BA per hectare of all the NFI- surveyed plots, with the firs representing 58% of that BA (Table 2). The codominant species growing on this site, a spruce species (possibly a hybrid species), was comparable in both number of live trees (22 spruce trees compared to 21 Douglas-fir trees) and height (23.5-m mean height for the spruce *vs*. 23.2 m for the Douglas-firs), but the mean diameters (DBH) of the firs were over 16% greater than the spruce (Figure 7).

Surviving western larch at the Lw-1 site were somewhat scattered, though sufficiently numerous to yield a viable plot containing several species, where they contributed 54% to the total BA (Table 2) due mainly to a larger average DBH and taller heights than all other species in the plot (Figure 8).

Although over 9000 ponderosa pine seedlings were planted at the Py-6 site, there was relatively low survival at the time of this assessment. This may be partly due to poor planting conditions, as well as snow and larger-scale mortality over time due to competition from brush and fast-growing lodgepole pine neighbors. Ponderosa pine represented only 24% of the total BA (Table 2) and, although diameters were larger (Figure 9) and tree form was good, the lodgepole pine were taller and this might continue to negatively affect growth of ponderosa pine on this site over time. Although competition appears to have been the leading cause of mortality, surviving ponderosa pine seemed to be growing well on this site.

In a mixed stand (Le-6), where western hemlock was the most common species, the exotic European larch had a larger average DBH and height and comprised 63% of the total BA (Table 2 and Figure 10). The exotic species plantation (Lj-1), Japanese larch, also grew well in height and DBH compared to the other species found on this site; high survival and good form were noticed on this small 1.1-ha plantation. The larch comprised 91% of the present total BA (Table 2) in the sampled plot; however, this was the oldest site sampled and had the second lowest total BA measured. The trees were the tallest and had the largest diameters on this site but were much smaller (in height and DBH) than their counterparts the western larch and European larch measured on the other sites in the region (Figures 8, 10, and 11). It is unclear now if this is related to site or species composition.

Red pine, the third exotic species surveyed, had a smaller average DBH and height than its neighboring native species at the Pr-2 site and was also the smallest of all the exotic species assessed, but it still comprised over 47% of the site's total BA (Table 2). Although survival was higher than in other plots, several suppressed trees in the plot negatively affected average height and DBH. Surviving codominant trees had good form, although some forking was observed; a few codominant trees, some intermediate trees, and the live suppressed trees were damaged with bent and broken stems, possibly by snow. As both the poplar and lodgepole pine were taller than the red pine (Figure 12), the latter might become increasingly suppressed in the long term.

Table 2. Site density (trees per hectare) and contributing basal area of Terrace off-site and exotic species . Data extrapolated from NFI Large Tree Plot information and include all live standing species sampled.

Site	Off-site/exotic species	Age	No. trees	Trees/ha (initial)	Trees/ha 2015	BA (m^2/ha)	No. trees (other species)	Trees/ha 2015 (other species)	BA (m^2/ha) (other species)
Fc-11	Coastal Douglas-fir	33	15	850	375	21.7 (43%)	55	1375	29.2 (57%)
Fi-5	Interior Douglas-fir	56	21	1600	525	38.0 (58%)	22	550	27.1 (42%)
Le-6	European larch	54	10	967	250	35.5 (63%)	17	425	20.6 (37%)
Lj-1	Japanese larch	57	26	818	650	34.0 (91%)	8	200	3.4 (9%)
Lw-1	Western larch	48	7	938	175	18.5 (54%)	17	425	15.5 (46%)
Pr-2	Red pine	54	25	1111	625	28.5 (47%)	34	850	31.6 (53%)
Py-6	Ponderosa pine	50	5	1468	125	10.6 (24%)	17	425	33.1 (76%)

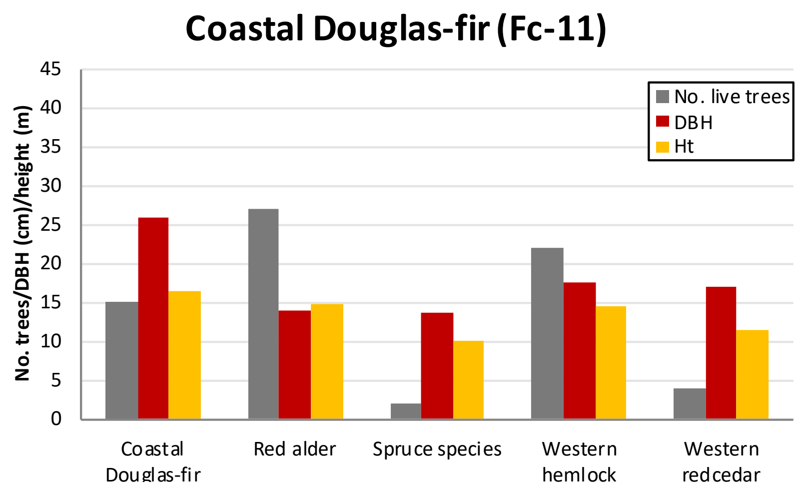

Figure 6. Coastal Douglas-fir (Fc-11) site results of NFI Large Tree Plot sampling.

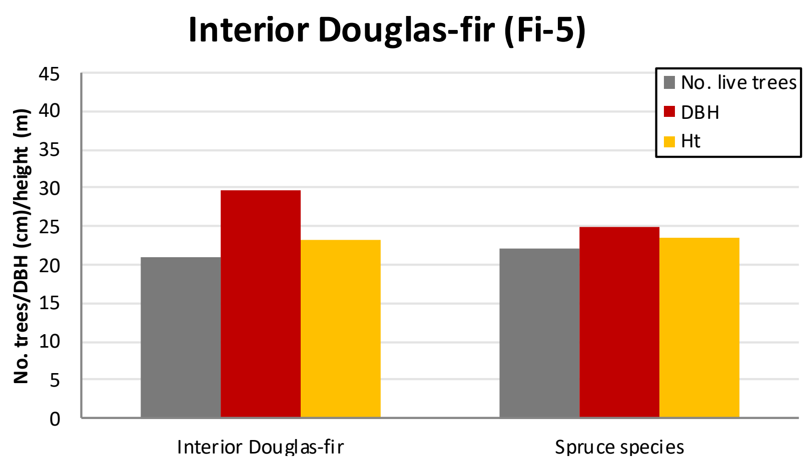

Figure 7. Interior Douglas-fir (Fi-5) site results of NFI Large Tree Plot sampling.

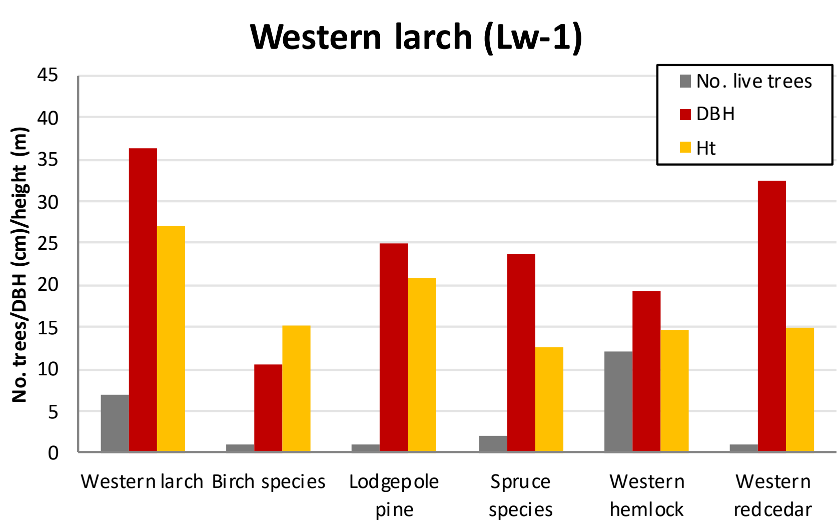

Figure 8. Western larch (Lw-1) site results of NFI Large Tree Plot sampling.

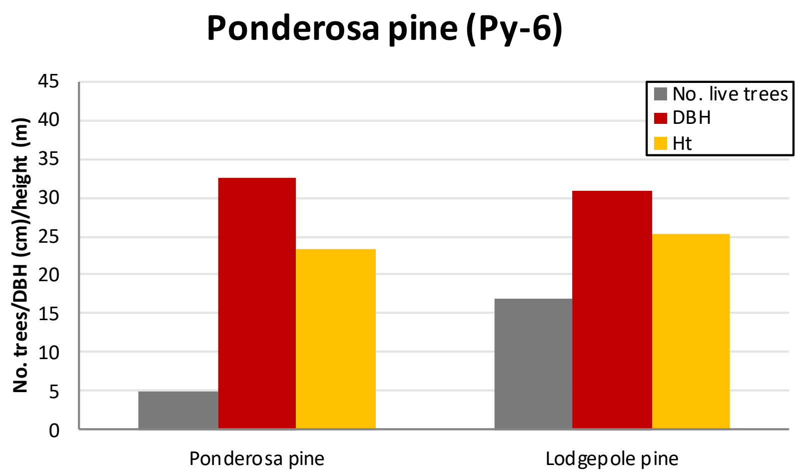

Figure 9. Ponderosa pine (Py-6) site results of NFI Large Tree Plot sampling.

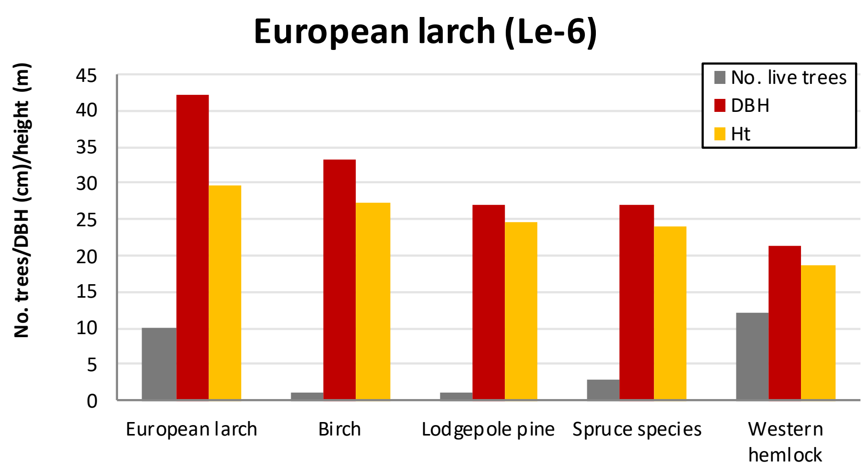

Figure 10. European larch (Le-6) site results of NFI Large Tree Plot sampling.

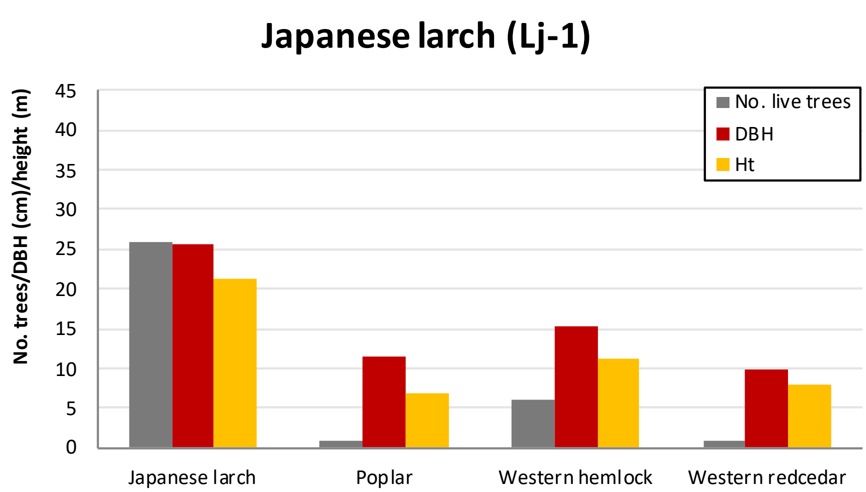

Figure 11. Japanese larch (Lj-1) site results of NFI Large Tree Plot sampling.

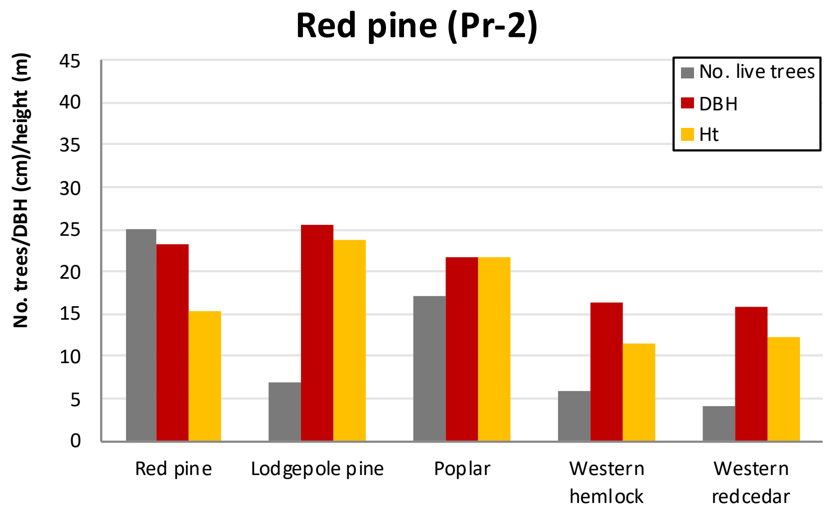

Figure 12. Red pine (Pr-2) site results of NFI Large Tree Plot sampling.

Of the five sites surveyed in limited capacity due to low survival, the diameters and heights of the European larch, ponderosa pine, and red pine surpassed the growth of the other species on- site (Table 3); however, the Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) did not fare as well (Table 1) with the Scots pine having particularly small diameters and heights when compared with the surrounding native species, both at Ps-10 (Table 3) and Ps-3.

Table 3. Diameters and heights for sites with poor survival and limited sampling.

Site	Species common names	Species scientific names	DBH (cm)	Ht (m)
Le-8	European larch	*Larix decidua*	31.7	21.0
	Lodgepole pine	*Pinus contorta*	27.3	22.2
Ps-10	Scots pine	*Pinus sylvestris*	15.0	9.9
	Balsam fir	*Abies balsamea*	20.3	13.6
	Western hemlock	*Tsuga heterophylla*	28.5	17.5
Py-2/Pr-1	Ponderosa pine	*Pinus ponderosa*	37.3	26.3
	Red pine	*Pinus resinosa*	29.3	21.9
	Lodgepole pine	*Pinus contorta*	27.2	24.3
Sn-2	Norway spruce	*Picea abies*	22.1	15.8
	Lodgepole pine	*Pinus contorta*	26.1	20.0
	Western redcedar	*Thuja plicata*	24.6	15.1

3.1.5 TIPSY Comparison of Final Density, Mean Height, Basal Area, and Quadratic Mean Diameter

We used the TIPSY software to compare the tree density, mean heights, BA, and QMD of the subject trees to that of three common native species: amabilis fir (*Abies amabilis* (Dougl. ex Loud.) Dougl. ex J. Forbes), lodgepole pine, and western hemlock. We also used TIPSY to project an estimate of these same growth parameters for the subject trees in their respective native habitats.

The interior Douglas-fir trees on the assessed site had the best results compared to both the other species native to the region and to Douglas-fir in its native habitat; it achieved greater height and QMD than the TIPSY estimates for the native species, and a larger site BA than that projected by TIPSY for Douglas-fir in the southern interior region of Kamloops. The BA was smaller than the Terrace species due to a decrease in the stems per hectare from approximately 1600 trees/ha at planting to 525 trees/ha at the time of our assessment (Figure 13).

Similarly, the ponderosa pine, western larch, and coastal Douglas-fir trees on the assessed sites achieved greater heights and QMDs than the modeled TIPSY Terrace species and the TIPSY species in their native habitats. All of them also had lower overall site BAs due to a decrease in stems per hectare from planting to the time of assessment (Figures 14–16).

The assessed European larch trees also achieved greater heights and QMDs than the modeled TIPSY Terrace species (Figure 17). The Japanese larch yielded slightly better results regarding heights and QMD than the Terrace native tree TIPSY projections and again had a lower BA due to a decrease in stems per hectare (Figure 18). Since Japanese and European larches are not British Columbia species, TIPSY growth projections were not available.

Of all the tree species assessed in the Terrace area, the red pine had the worst growth results compared to the trees modeled using TIPSY (Figure 19). But even this species almost matched the estimated heights and diameters of the Terrace natives and, like all the other plantations we visited in this region, had a lower site BA due to mortality.

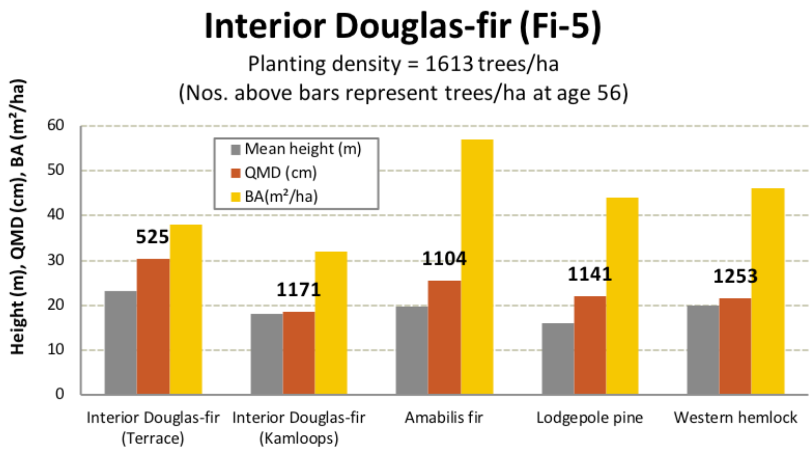

Figure 13. Comparison of the Terrace interior Douglas-fir mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace species and interior Douglas-fir in their native range.

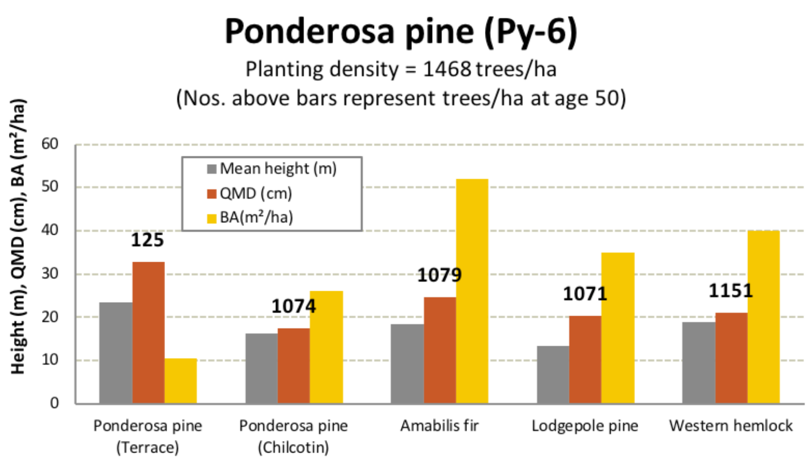

Figure 14. Comparison of Terrace ponderosa pine mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace species and ponderosa pine in their native range.

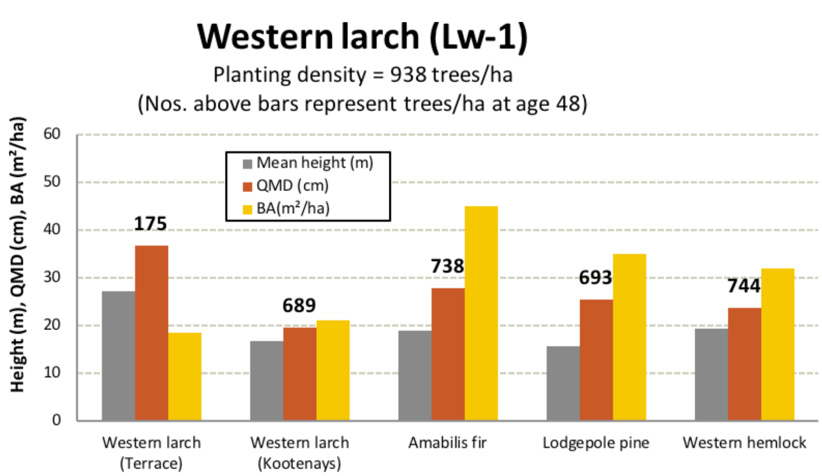

Figure 15. Comparison of Terrace western larch mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace species and western larch in their native range.

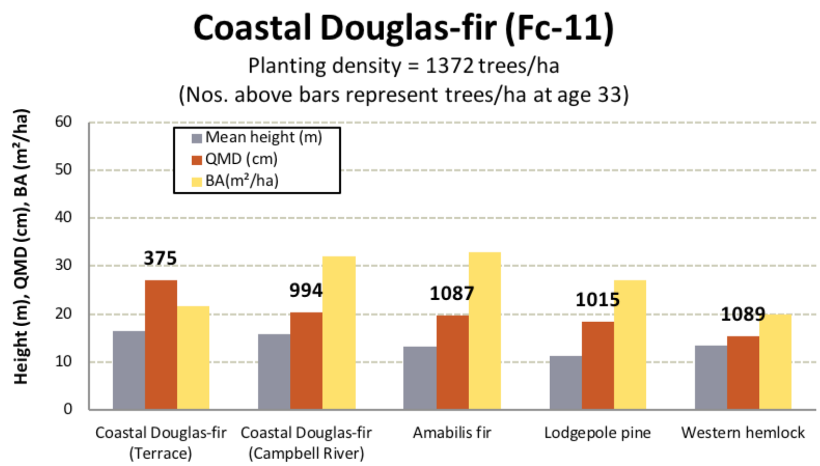

Figure 16. Comparison of Terrace coastal Douglas-fir mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace species and coastal Douglas-fir in their native range.

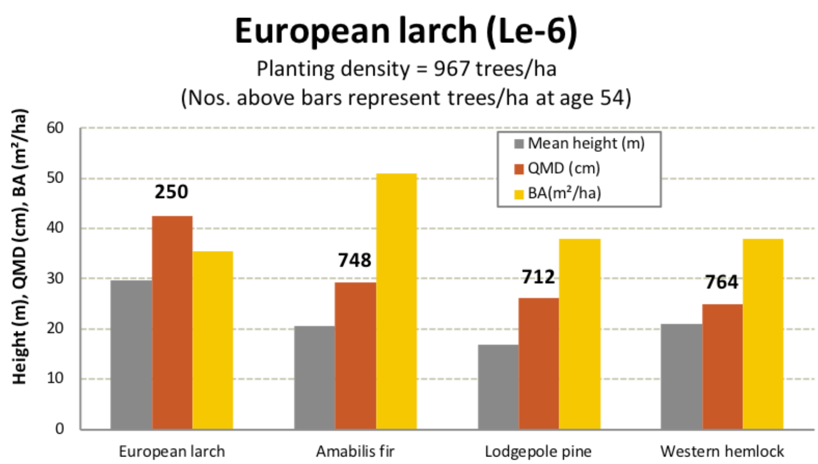

Figure 17. Comparison of Terrace European larch mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace native species.

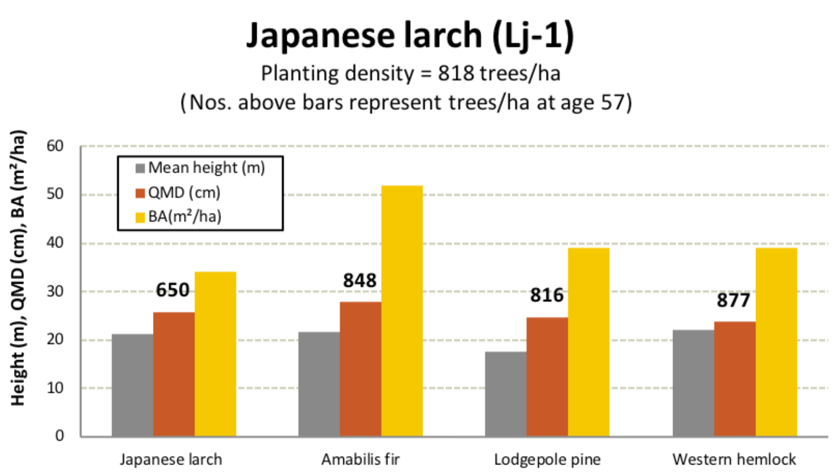

Figure 18. Comparison of Terrace Japanese larch mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace native species.

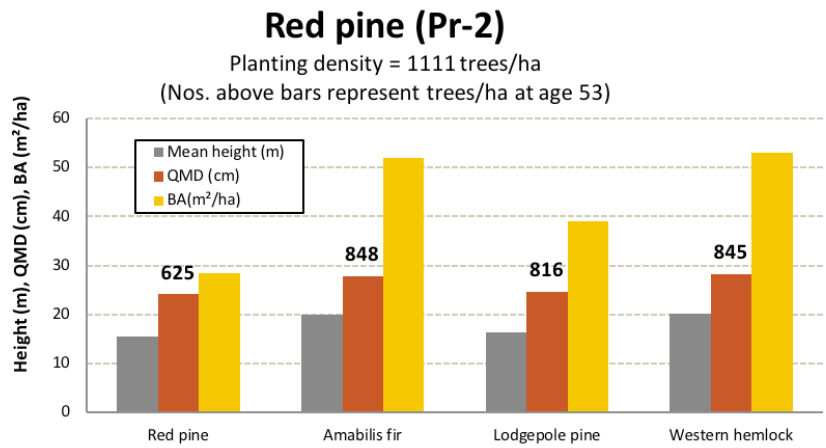

Figure 19. Comparison of Terrace red pine mean height, QMD, and BA to TIPSY-modeled scenarios of Terrace native species.

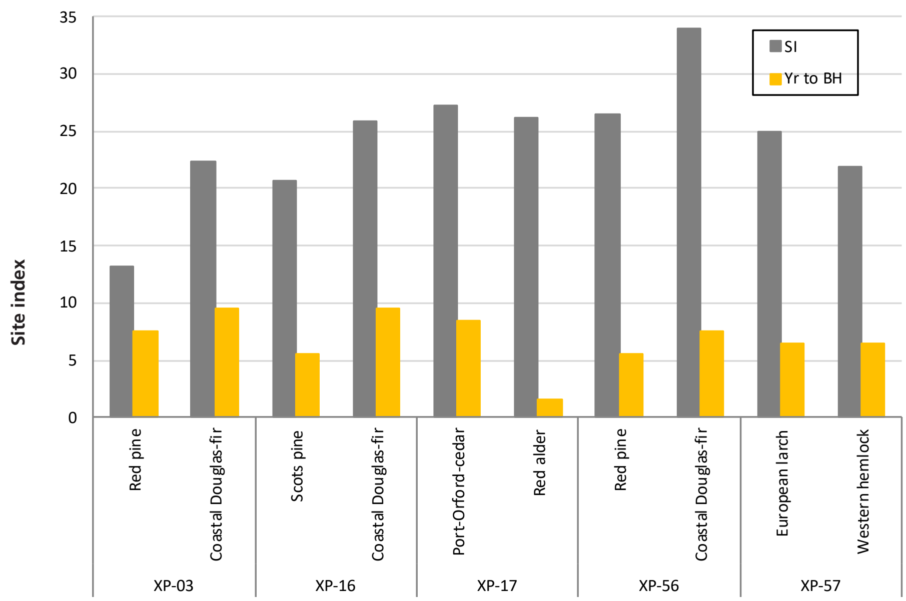

Figure 20. Site Index (SI) and years to breast height (1.3 m) of the off-site/exotic species (left), and leading native species (right) at the five NFI-sampled sites near Campbell River, British Columbia.

Table 4. Assessment summary of sites located in the Campbell River area (PFC archival materials, Forest Insect Disease Survey (FIDS) Collections, Series 05: Exotic Plantations in British Columbia. Files 001-254. 1956-1983).

Site	Longtitude	Latitude	Species	Common name	Origin	Yr planted	Elevation (m)	Aspect	Slope (%)	No. trees planted	Area	Comments/ observations
XP-3	124°58′10.49″	49°32′23.64″	*Pinus resinosa*	Red pine	Pembroke, Ontario, Canada	1954	383	S	42	5000	2.4	Good survival and growth
XP-16	125°14′20.08″	49°50′4.34″	*Pinus sylvestris*	Scots pine	Sweden	1952	134	flat	0	–	0.1	Good survival and growth
XP-17	125°14′34.48″	49°49′55.99″	*Chamaecyparis lawsoniana*	Port-Orford-cedar	Portland, Oregon, USA	1953	115	flat	0	–	0.3	Good survival and growth
XP-56	125°44′6.83″	50°12′32.08″	*Pinus resinosa*	Red pine	–	1951	144	flat	0	4050	2	Good survival and growth
XP-57	125°44′0.17″	50°12′36.25″	*Larix decidua*	European larch	–	1951	133	flat	0	1800	0.4	Good survival and growth

3.2 Campbell River

3.2.1 Sampling

We visited five sites in the Campbell River area (Table 4) and established NFI plots in all of them. Unfortunately, two of those five had no record of original planting density which did not allow for an estimate of survivorship or a TIPSY comparison.

3.2.2 Site Index

Native coastal Douglas-fir was observed growing in three of the five plantations visited. In all instances, the Douglas-fir SI was significantly greater than all the neighboring off-site/exotic species assessed in this study, ranging from 22% (XP-56) to 42% (XP-03) greater than the introduced species SIs. The reverse was observed for the European larch, which had an SI approximately 12% greater than the native western hemlock. The Port-Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) had an SI that was marginally greater than the native red alder (Figure 20).

3.2.3 Annual Radial Growth

Port-Orford-cedar was the only exotic species that exhibited greater radial growth than its neighboring native species, showing consistently as large or larger annual radial growth than red alder in the last 15 years (Figure 21). It was also the only site assessed where the leading native species was a hardwood. The native Douglas-fir and western hemlock had greater annual radial growth than the exotic red pine, Scots pine (Figure 22), and European larch (Figure 23).

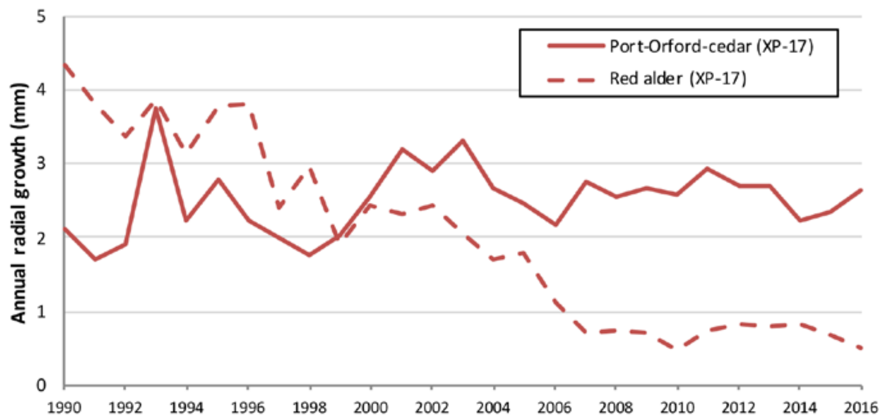

Figure 21. Average radial growth of Port-Orford-cedar compared to on-site native species at site XP-17.

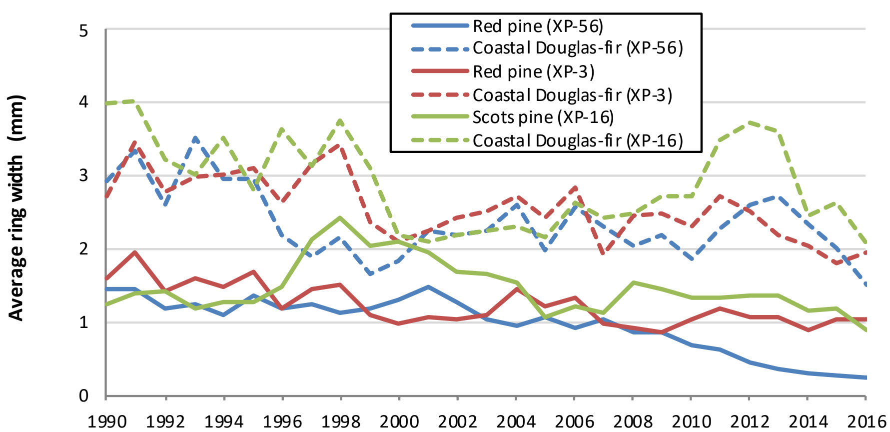

Figure 22. Average radial growth of pine species compared to on-site native species at site XP-3 (green), XP-16 (red), and XP-56 (blue). Off-site/exotic species represented by bold lines.

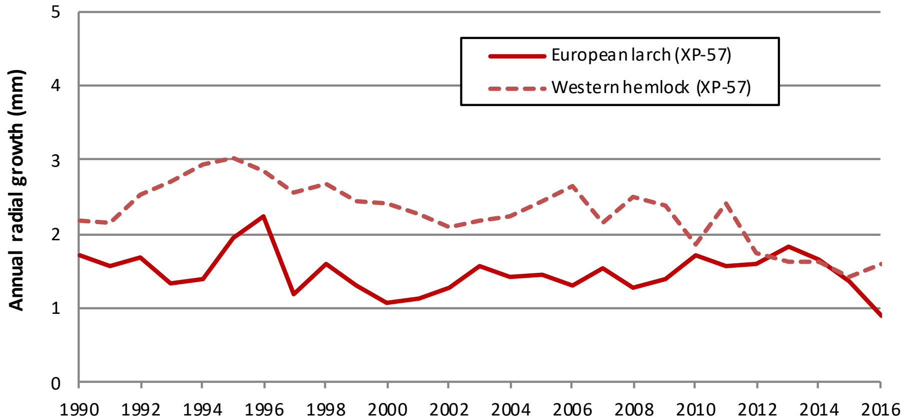

Figure 23. Average radial growth of European larch compared to on-site native species at site XP-57.

Table 5. Site density (trees per hectare) and basal area (BA, m^2/ha) of Campbell River off-site and exotic species. Data extrapolated from NFI Large Tree Plot information and include all live standing species sampled.

Site	Off-site/ exotic species	Age	No. trees	Trees/ha (initial)	Trees/ ha 2016	BA (m^2/ha)	No. trees (other species)	Trees/ha 2015 (other species)	BA (m^2/ha) (other species)
XP-03	Red pine	61	50	2083	1250	31.7 (80%)	9	225	8.0 (20%)
XP-16	Scots pine	64	38	–	950	34.1 (96%)	1	25	1.4 (4%)
XP-17	Port-Orford-cedar	63	16	–	400	36.2 (66%)	11	225	18.7 (34%)
XP-56	Red pine	65	26	2025	650	37.3 (78%)	2	150	10.7 (22%)
XP-57	European larch	65	23	4500	575	31.9 (87%)	4	100	4.6 (13%)

3.2.4 Comparison of Basal Area, Tree Density, Diameter at Breast Height, and Height of Subject and Local Native Trees

Unlike the Terrace counterparts, the exotics we measured in the Vancouver Island plots comprised the bulk of the BA in all instances (Table 5). At 64 years old, the 950 stems/ha of Scots pine were estimated to represent 96% of the site's BA, even though the Douglas-fir on the same site were 25% taller and 19% larger in diameter (Figure 24). Similar results were observed at both red pine sites. With an initial planting density of 2083 stems/ha (Table 5), the survival of the red pine at the XP-03 site was estimated to be approximately 60% and represented 80% of the stand's BA (Table 5). However, the Douglas-fir diameters and heights were considerably larger (Figure 25) for trees that were of similar ages according to our core samples—47 years at breast height for the fir, compared to 52 years for the pine. The other red pine stand (XP-56) followed a similar pattern. Although pine density dropped from 2025 to 650 trees/ha, the species still represented approximately 78% of the stand's BA, but the few Douglas-firs on-site were almost twice as tall and considerably larger in diameter (Figure 26).

The Port-Orford-cedars had the lowest contribution to the site's BA, which nonetheless was still high at 66% (Table 5), whereas height and DBH growth marginally exceeded that of competing red alder (Figure 27). The European larch also represented a large percentage of the site's BA (Table 5) and both the height growth and DBH exceeded that of the neighboring Douglas-fir and western larch (Figure 28).

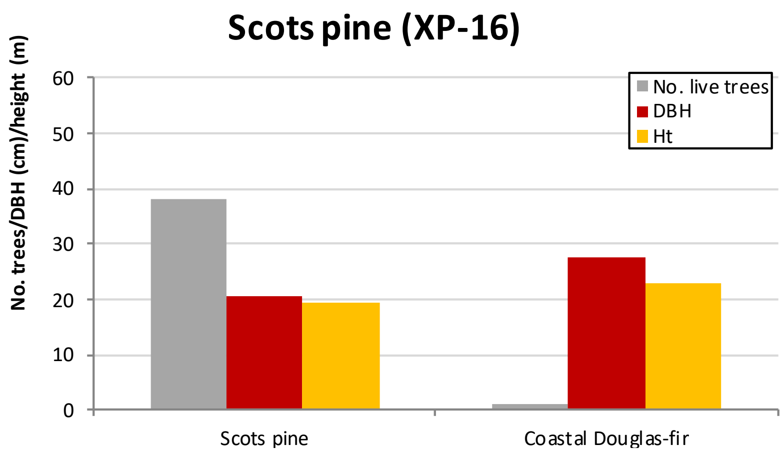

Figure 24. Scots pine (XP-16) site results of NFI Large Tree Plot sampling.

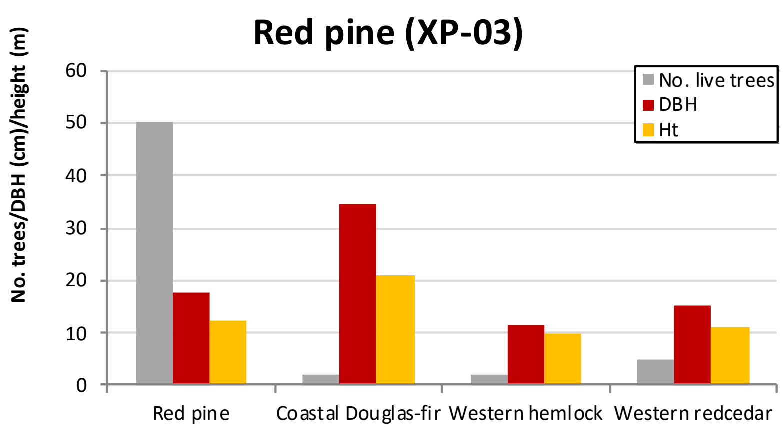

Figure 25. Red pine (XP-03) site results of NFI Large Tree Plot sampling.

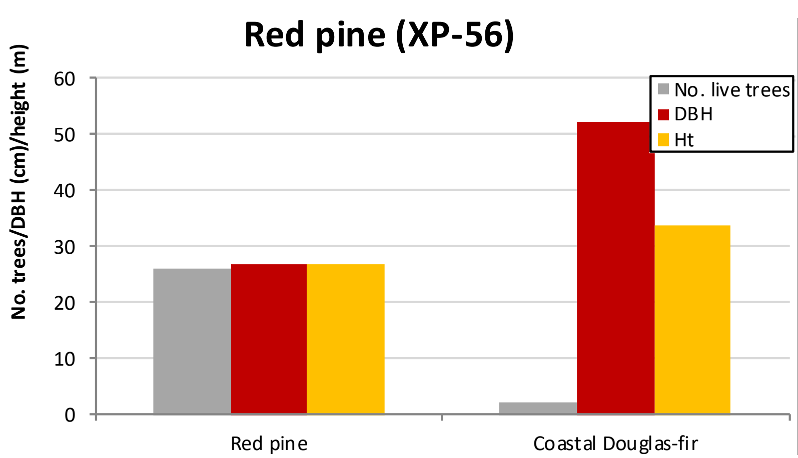

Figure 26. Red pine (XP-56) site results of NFI Large Plot sampling.

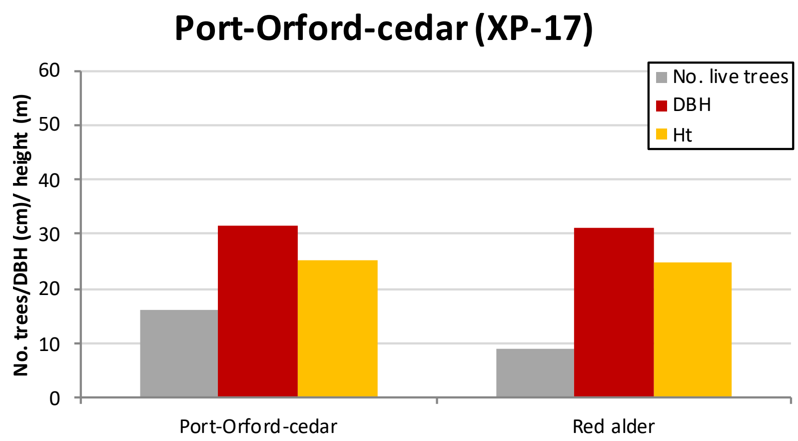

Figure 27. Port-Orford-cedar (XP-17) site results of NFI Large Plot sampling.

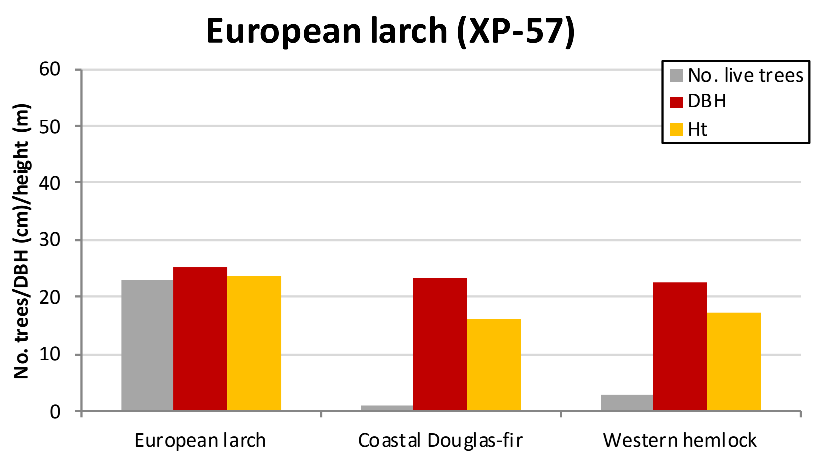

Figure 28. European larch (XP-57) site results of NFI Large Plot sampling.

3.2.5 TIPSY Comparison of Final Density, Mean Height, Basal Area, and Quadratic Mean Diameter

The goal of the following TIPSY outputs was to compare the projected growth of native species given the same planting density and time to grow as the exotic species planted in the Campbell River area. Unfortunately, no initial planting densities were available for the Port-Orford-cedar or the Scots pine plantations so the following graphs only summarize the TIPSY outputs for the European larch and both red pine plantations. Not surprisingly, the TIPSY projections for both red pine sites follow the same trend since their initial planting densities and ages are similar (Figures 29 and 30). Although the western redcedar growth projected using TIPSY had the greatest site BA due to greater survival, the Douglas-fir had marginally greater mean diameter and height. Red pine growth and final BAs were the lowest at the XP-3 site compared to the modeled growth of the four native species projected using TIPSY (Figure 29). Although the height and BA at the XP-56 site were greater than the amabilis fir and the western redcedar and comparable to the Douglas-fir and western hemlock, survival was poor compared to that projected for the native species, resulting in significantly lower BA (Figure 30). The TIPSY outcomes suggest that, given similar growth conditions, the native western redcedar and Douglas-fir would fare better in terms of both survival and growth than the red pine. The European larch was planted at a density of 4500 trees/ha and surpassed all the competitors in diameter and all but one (western redcedar) in height, but once again, the survival and thus the BA at age 65 were far lower than those of all the native species modeled (Figure 31). According to the TIPSY outputs, the native cedar would fare best under this planting regime.

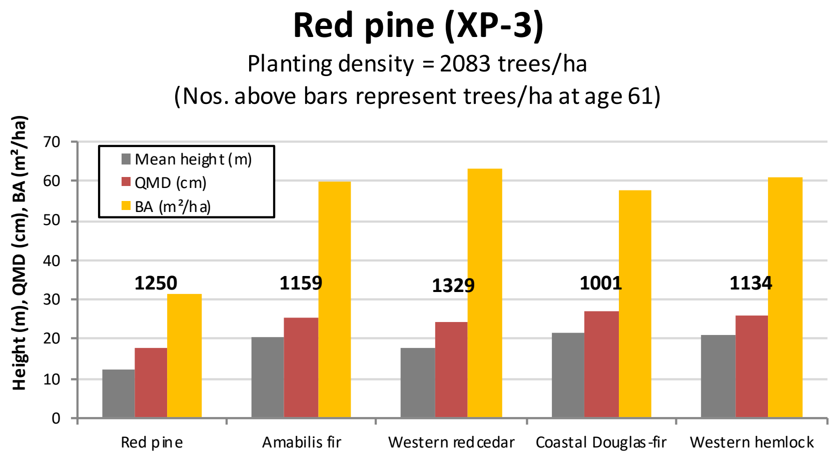

Figure 29. Comparison of Campbell River red pine mean height, QMD, and BA to TIPSY-modeled scenarios of native species.

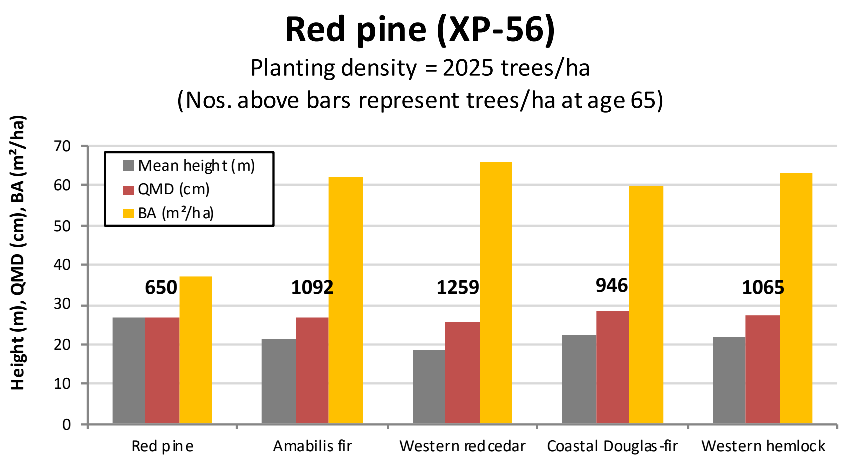

Figure 30. Comparison of Campbell River red pine mean height, QMD, and BA to TIPSY-modeled scenarios of native species.

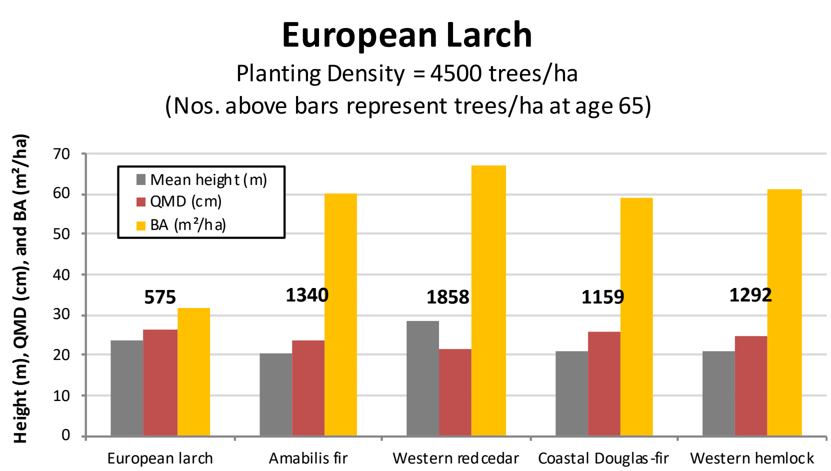

Figure 31. Comparison of Campbell River European larch mean height, QMD, and BA to TIPSY-modeled scenarios of native species.

4. Conclusions

All available information must be used to assist provincial decision makers and forest managers to plan for and adapt to the impacts of climate change on the province's forest resources (BCMFR 2006). This initial assessment of long-term plantations in British Columbia's interior and coastal regions suggests that it is possible to successfully establish some off-site and exotic tree species outside their current geographical ranges.

In the Kalum TSA, based on SI and radial growth alone, all species in our NFI-sampled sites exhibited greater diameter and height growth compared to the native species on-site. Even at the sites where survival was poor, DBH and heights were nonetheless as good as or better than the native species for all species except for Scots pine and Norway spruce. Contribution to total BA by off-site/exotic species ranged from 25% for the ponderosa pine to over 90% for the Japanese larch. Red pine and ponderosa pine were the least successful, although observations and modeled outcomes suggest that these pines survived and grew well early on and may fare better long term if not planted neighboring lodgepole pine. Both fir species and all the larches performed exceedingly well compared to native species sampled and those modeled with TIPSY. Based on growth alone, all the sites surveyed in this study could have high yields from these off-site and exotic species. Survival appears to be the limiting factor and could be improved through site preparation, seed lot selection, and consideration of species composition at establishment as well as using appropriate silvicultural treatments such as early vegetation control. A previous assessment of similar sites in northwest British Columbia also concluded that Douglas-fir (interior and coastal varieties) and western larch could grow at rates that are as good as or exceeding that of the local species (LePage and McCulloch 2011).

In the Campbell River area of Vancouver Island, only five sites were assessed. Unlike the Terrace counterparts, the off-site/exotic species comprised the bulk of the contributing BA on all sites due to the large number of stems per hectare. But the leading native species, Douglas-fir, exhibited far greater diameter and height growth than the pines at the three sites sampled, whereas the native western hemlock had greater radial growth than the larch. The Port-Orford-cedar had greater radial growth than the red alder and similar heights and DBH, but we were not able to assess survival or make projections using TIPSY due to lack of information; it is difficult to draw any conclusions concerning Port-Orford-cedar. Our observations, and inferences on SI, radial growth and the three TIPSY-generated projections, suggest that the native Douglas-fir and western hemlock have potential for greater survival than the red pine, Scots pine, and European larch and at the very least match, if not surpass, the growth of these exotic species in this region.

These conclusions are based on a narrow sampling of available sites and a basic assessment of survival, growth, and condition of the subject species compared to the surrounding native species. Yet these initial findings suggest that, especially in the Kalum TSA, further investigation of successful off-site and exotic plantations may provide useful guidelines for future reforestation efforts and assisted migration in the face of changing climatic patterns. Further investigation is recommended and should include a climate comparison between origin and study sites, and a measure of seedlings recruitment. Good survival and growth may indicate superior pest and disease resistance; thus studies on insect and disease resistance of the plantation species compared to the native provenance may also prove useful. Finally, an investigation of wood quality and unique attributes of successful exotic plantation tree species may also reveal opportunities to expand and diversify British Columbia's wood fibre basket.

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