Forest Tree Genetic Conservation Status Report 2 Genetic Conservation Status of Operational Tree Species

Jodie Krakowski, Christine Chourmouzis, Alvin D. Yanchuk, David Kolotelo, Andreas Hamann, and Sally N. Aitken

2009

British Columbia
The Best Place on Earth

Ministry of Forests and Range
Forest Science Program

Forest Tree Genetic Conservation Status

Report 2 Genetic Conservation Status of Operational Tree Species

Jodie Krakowski, Christine Chourmouzis, Alvin D. Yanchuk, David Kolotelo, Andreas Hamann, and Sally N. Aitken

BRITISH COLUMBIA
The Best Place on Earth

Ministry of Forests and Range
Forest Science Program

Library and Archives Canada Cataloguing in Publication Data

Forest Tree Genetic Conservation Status Report 2: Genetic Conservation Status of Operational Tree Species / Jodie Krakowski ... [et al.].

(Technical report ; 054)
ISBN 978-0-7726-6225-5

1. to come

Citation

Krakowski, J., C. Chourmouzis, A.D. Yanchuk, D. Kolotelo, A. Hamann, and S.N. Aitken. 2009. Forest tree genetic conservation status report 2: genetic conservation status of operational tree species. Centre for Forest Conservation Genetics, Forest Genetics Council of British Columbia, and B.C. Min. For. Range, For. Sci. Prog. Victoria, B.C. Tech. Rep. 054. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr054.htm

Prepared by

Christine Chourmouzis
Sally N. Aitken
Andreas Hamann (present address: Department of Renewable Resources, University of Alberta, 739 General Services Building, Edmonton, Alberta T6G 2H1)
University of British Columbia
Centre for Forest Conservation Genetics
3041–2424 Main Mall
Vancouver, BC V6T 1Z4

and

Alvin D. Yanchuk
Jodie Krakowski
Ministry of Forests and Range
Research Branch
Box 9519 Stn Prov Govt
Victoria, BC V8W 9C2

and

David Kolotelo
Ministry of Forests and Range
Tree Improvement Branch
18793 32nd Ave
Surrey, BC V35 0L5

Copies of this report may be obtained, depending on supply, from:
Crown Publications, Queen's Printers
2nd Floor, 563 Superior Street
Victoria, BC V8W 9V7
TOLL FREE 1-800-663-6105
www.crownpub.bc.ca

For more information on Forest Science Program publications, visit
www.for.gov.bc.ca/scripts/hfd/pubs/hfdcatalog/index.asp

ABSTRACT

The native tree species of British Columbia provide a vast range of economic benefits and ecological services. Conserving genetic diversity in these species is critical for maintaining the ability of populations to adapt to new conditions, and for safeguarding genetic resources from which tree breeders can select to meet new challenges or objectives. Genetic conservation of forest trees is achieved in British Columbia for all indigenous species through the protection of populations *in situ* in parks and protected areas. The status of tree species *in situ* is documented in a companion report, *Forest tree genetic conservation status report 1:* In situ *conservation status of all indigenous British Columbia species* (Chourmouzis et al. 2009).

For species of economic importance that have genetic management and tree improvement programs, there are also extensive genetic resources archived *ex situ*, primarily in seed collections in long-term storage, and *inter situ*, in provenance and progeny trials. Historically, seed bank conservation samples have been obtained from the surplus remaining for each operational seedlot, after testing. Prior to December 2003, operational seedlots represented collections from over 50 individuals in an area. To support a more strategic acquisition strategy, subsequent collections focussed on obtaining at least three samples per target species within identified biogeoclimatic (BGC) zones. The strategy is to populate the full matrix of species-zone occurrences with at least three samples per cell for conservation collections. This represents a highly efficient, robust conservation approach: 100 grams of hybrid white spruce seed could contain up to 50,000 unique genotypes, and *ex situ* collections are not susceptible to climate change impacts, as genetic resources *in situ* and *inter situ* sites are; however, stocks must be periodically replenished because long-term storage may reduce seed viability.

This report summarizes the *in situ*, *ex situ*, and *inter situ* genetic conservation status of commercial forest tree species in British Columbia that have genetic management and tree improvement programs. These eight conifers have breeding programs supported by *inter situ* trials established for their respective seed planning zones (SPZs) and/or seed planning units (SPUs) identified for seed transfer and deployment of improved or select seed (Snetsinger 2004). Species with active breeding and testing programs are managed and developed using a combination of genecological research, provenance studies, and progeny studies (Ying and Yanchuk 2006).

This report expands on the assessments of Yanchuk and Lester (1996) and Hamann et al. (2004, 2005). These studies used comparable methodology (using the life history traits, forest inventory, protected areas, and utilization) to track *in situ* conservation status of conifers in British Columbia, and developed systems to prioritize species for conservation efforts. Changes between the previous assessment (Yanchuk and Lester 1996) and this assessment indicate where gaps still exist or where increased genetic conservation and habitat protection have been successful. This analysis has improved precision through the updated forest inventory database, Geographic Information System (GIS) platform, and quantification of effective population sizes (Ne) in reserves. Effective population size is the number of individuals contribut-

ing genes to the next generation of the population, based on an idealized set of population genetics assumptions.

The provenance and progeny trials assessed here include populations with phenotypically selected individuals (plus trees) and their progeny from a wide sample of the base populations of each species, and are often replicated in several sites, comprising an invaluable genetic resource. These are *inter situ* genetic conservation resources (Blixt 1994; Yanchuk 2001; Lipow et al. 2003) because they provide links between population genetic representation of wild reserves (*in situ*) and clone or seed bank collections (*ex situ*).

Species were ranked in terms of conservation priority using criteria adapted from Yanchuk and Lester (1996), and revised based on international (FAO et al. 2004) and regional information. Ranking criteria used by other programs that assessed plant species were also reviewed to compile the most current and representative set of standards to prioritize these species (IUCN 2001; COSEWIC 2006; NatureServe 2008[1]). Gaps in conservation can highlight areas to focus on for prioritization of *in situ* reserve establishment or management, *ex situ* seed collections, or *inter situ* representation.

1 www.natureserve.org/explorer/ranking.htm (updated June 2008; accessed August 4, 2008)

ACRONYMS

BEC	Biogeoclimatic ecosystem classification
BGC	Biogeoclimatic

BGC zones

CDF	Coastal Douglas-Fir
CWH	Coastal Western Hemlock
ESSF	Engelmann Spruce–Subalpine Fir
ICH	Interior Cedar–Hemlock
IDF	Interior Douglas-Fir
MH	Mountain Hemlock
MS	Montane Spruce
SBPS	Sub-Boreal Pine–Spruce
SBS	Sub-Boreal Spruce
SWB	Spruce–Willow–Birch

F1	First generation progeny of controlled pollinations: full siblings sharing male (pollen) and female (seed) parents
MPB	Mountain pine beetle
Ne	Effective population size
PA	Protected area
SPU	Seed planning unit (may be subdivided into low and high elevations)

SPU list

BV	Bulkley Valley
CP	Central Plateau
CT	Cariboo Transition
EK	East Kootenay
KQ	Kootenay–Quesnel
M	Maritime
NE	Nelson
NEK	Nelson–Kootenay
NS(T)	Nass–Skeena (transition)
PG	Prince George
PGN	Prince George–Nelson
PR	Peace River
QL	Quesnel
SM	Submaritime
TO	Thompson–Okanagan

SPF	Spruce-pine-fir
SPZ	Seed planning zone
TSC	Tree seed centre
USDA	United States Department of Agriculture

CONTENTS

TABLES

FIGURES

For most species/seed planning unit combinations, there is adequate representation or protection in all categories: *in situ*, *inter situ*, and *ex situ* (Table 1). In some cases, either marginal protection levels or large discrepancies between inventory mapping methods warrant ground-truthing or verification using additional sources of data.

For a few species and SPUs (e.g., Sitka spruce outside the Maritime SPU, hybrid white spruce in the Peace River high and Nelson SPUs, and yellow-cedar), *ex situ* protection is currently weak. Other species/SPU combinations (e.g., western larch Nelson high SPU, many lodgepole pine high-elevation SPUs) lack *inter situ* representation. These species may not have identified top-priority conservation concerns *in situ* when analyzed by biogeoclimatic (BGC) zone (Chourmouzis et al. 2009). In some cases this is because an SPU may include differing proportions of two or more BGC zones. Since all of these species are fairly abundant and the SPUs represent the core of a species' distribution, verification rather than additional conservation is initially recommended.

Ex situ gaps can be rectified by collecting seedlots in the identified SPU. For species whose seeds deteriorate relatively rapidly in storage, particularly western hemlock and western redcedar, collections should be monitored for germination capacity and periodically replenished.

Where *in situ* gaps are identified, it is recommended that the analysis be updated considering protected areas established since 2002. The list of protected areas compiled in the report on *in situ* genetic conservation status (Chourmouzis et al. 2009) likely contains sufficiently large populations of these species and should be considered a good starting point for field verifying species abundance. The results would also provide a candidate list of areas to prioritize for additional *in situ* protection.

Where there is a gap in *inter situ* representation, each species/SPU combination must be evaluated separately due to the high cost of establishing and maintaining these trials. In some cases, *inter situ* trials are already planned for the near future. In other cases, such as lodgepole pine, while some SPUs are not well represented, genotypes are conserved in *inter situ* trials for adjacent SPUs, and the health of trees on these sites will require careful monitoring (e.g., mortality due to pests or diseases). Generally, these populations are often well protected *in situ* and *ex situ*, so barring a disaster that decimates populations throughout an SPU (e.g., mountain pine beetle), obtaining and establishing new field plantings with additional genotypes from well-adapted populations should be evaluated on a case-by-case basis.

Based on their *in situ*, *inter situ*, and *ex situ* conservation status, species and species/SPU combinations were assigned priorities based on a set of criteria adapted from those used by national and international agencies. These criteria can be used to allocate resources for additional genetic conservation activities.

TABLE 1 *Conservation status summary: ✓ protection adequate, ✗ increased protection required, ? verification required. Numbers are effective population size (Ne) of locally adapted genotypes in designated primary* inter situ *trials (number of sites in parentheses) for each seed planning unit (SPU).*

Species	SPU	*In situ*	*Ex situ*	*Inter situ*
Western redcedar	Cw M h	✓	✓	0
	Cw M l	✓	✓	102 (4)
	Cw SM	✓	✓	0
Douglas-fir	Fdc M h	✓	✓	78 (2)
	Fdc M l	✓	✓	1042 (8)
	Fdc SM	✓	✓	874 (1)
	Fdi CT	?	✓	1200 (1)
	Fdi EK	✓	✓	1864 (2)
	Fdi NE h	✓	✓	961 (2)
	Fdi NE l	✓	✓	1024 (1)
	Fdi PG	✓	✓	1440 (2)
	Fdi QL	✓	✓	840 (2)
Western hemlock	Hw M h	✓	✓	72 (2)
	Hw M l	✓	✓	359 (2)
Western larch	Lw EK	?	✓	1147 (2)
	Lw NE h	?	✓	0
	Lw NE l	✓	✓	1393 (6)
Lodgepole pine	Pli BV h	?	✓	0
	Pli BV l	✓	✓	1229 (1)
	Pli CP h	✓	✓	0
	Pli CP l	✓	✓	1131 (3)
	Pli EK h	?	✓	0
	Pli EK l	?	✓	0
	Pli NE h	✓	✓	0
	Pli NE l	✓	✓	1190 (3)
	Pli NS h	?	✗	0
	Pli NS l	?	✓	585 (2)
	Pli PG h	✓	✓	1053 (2)
	Pli PG l	✓	✓	1248 (2)
	Pli PR h	?	✓	0
	Pli PR l	✓	✓	0
	Pli TO h	✓	✓	0
	Pli TO l	✓	✓	1755 (3)
Western white pine	Pw KQ	?	✓	300 (6)
	Pw M	?	✗	936 (2)
Sitka spruce & hybrids	Ss M	✓	✓	1326 (13)
	Sxs NS	?	✓	0
	Sxs SM	✓	✓	0
Hybrid white spruce	Sx BV l	?	✓	679 (1)
	Sx EK	✓	✓	421 (1)
	Sx NE h	✓	✓	660 (1)
	Sx NE l	✓	✓	304 (1)
	Sx PG h	✓	✓	1237 (2)
	Sx PG l	✓	✓	2500 (4)
	Sx PR h	?	✗	874 (5)
	Sx PR l	✓	✓	555 (1)
	Sx TO h	✓	✓	0
	Sx TO l	✓	✓	0
Yellow-cedar	Yc M	✓	✓	156 (4)

2.1 Overview

A summary of the genetic conservation priority ranking is presented first, followed by a description of the genetic conservation status of each species. Background information on the autecology, management, and market factors affecting each species is summarized, with harvest and regeneration data gathered from appendices and tables in provincial government annual reports (BCMOF 2003, 2004, 2005; BCMFR 2006, 2007). Forest health and economic issues were also reviewed in the context of their potential impacts on genetic diversity and management implications.

2.2 Conservation ranking

Given British Columbia's large and diverse land mass and biodiversity, we need to prioritize species for conservation. Resources are limited, so ensuring that they are used most effectively is integral to good stewardship of the forest genetic resources (FAO et al. 2004). To this end, various ranking schemes have been developed. deGrammont and Cuarón (2006) evaluated 25 systems of categorizing and ranking threatened species; while most of these systems focus solely on species at risk, some aspects of their analyses can inform prioritization of more common species using similar factors. For this assessment, the criteria of Yanchuk and Lester (1996) were used for an initial prioritization of species and, in conjunction with new sources of data, have yielded a set of parameters well suited to prioritize species relatively objectively.

The following criteria were considered for ranking species (Table 2):

- provincial and national status rankings (S and G ranks from NatureServe and/or British Columbia Conservation Data Centre database and *Species at Risk Act* schedules)
- abundance: expected and actual census size
- range: geographic distribution and ecological niche
- threats: risk of population reduction via disturbance or forest health agents
- resilience: ability to recover former distribution and abundance following disturbance (includes regeneration capacity)
- proportion of range and/or genetic diversity protected (includes *in situ, inter situ,* and *ex situ*)
- population trends and factors: demographic and/or anthropogenic

Although provincial and national status rankings assign high priority to threatened and endangered species, all of the commercial species included here are fairly common, and none is listed provincially or federally. Thus, this criterion had no weight influencing the remaining six criteria used to rank species, but this could change should conditions or the list of species being ranked change. Threats to species or unique populations (e.g., pest-resistant localized populations, virulent disease causing range-wide decline) were also considered when estimating a species' rank. Potential impacts of climate change were considered where there was adequate confidence in the data for a given species or region, depending on the context and category. For instance, studies may indicate with relatively high confidence that a species will become maladapted over much of its current range as a result of climate change, or that severity of pest outbreaks may increase in certain areas. (See rankings and notes in Table 2.)

TABLE 2 *Criteria used to rank species for conservation priority by different agencies*

Yanchuk and Lester (1996)	IUCN (2001; 2003)	COSEWIC (2006)	NatureServe (2008)	This study
subnational ranking	ranks at global and global/regional scales	ranks at national scale considering subnational factors	ranks at global, national, and subnational scales	1. provincial and federal ranking for threatened and endangered species[a]
commonness	small, declining, and/or severely fluctuating population/ subpopulation(s)	small, declining, and/or severely fluctuating population/ subpopulation(s)	number and condition of populations	2. commonness/ abundance
range extent	range extent	range extent	range extent	3. range extent
natural regeneration	probability of extinction in the wild	probability of extinction in the wild	population size	4. resilience to capacity disturbance
current protection status	rapid, major population decline	population decline rate and causes	protected and managed populations	5. current protection status: *in, inter, ex situ*
inter situ conservation	population fragmentation	habitat niche narrowness	short- and long-term trends	6. population trends and factors: demographic and/or anthropogenic
economic value		species-specific considerations	threats	7. threats
		potential and impacts of rescue from extra-regional populations	intrinsic vulnerability (sensitivity, the inverse of resilience)	
			habitat niche narrowness	

a None of the species considered here are listed provincially or federally as they all have secure and/or abundant status. Rankings for these species are not directly comparable to priority rankings for rare, threatened, or endangered species as they take into account different factors.

The ranking of protection status was based on the percentage of the species' range protected. For *inter situ* protection we considered the representation and status of primary trials. *Ex situ* status was evaluated based on the number of samples and their distribution relative to the species' range. If a particular population is restricted to a narrow geographic or ecological niche, this may impose constraints on migration and adaptation, elevating its ranking; however, detailed quantitative information was not seen as critical to assigning ranks at this stage, since all commercial British Columbia tree species are abundant.

Each species was assigned a value for each of the six criteria for conservation ranking, from 1 (most at risk, narrowest range, rarest, most sensitive to disturbance, least protected, etc.) to 3 (most common, most abundant, most widespread, adequate protection, least sensitive to disturbance, etc.). Values for each species were summed across categories to yield an aggregate unweighted ranking, then re-ranked from minimum to maximum between the lowest score and the highest score, so that the species with the rank of 1 received the lowest score and would be assigned the highest priority. Species with the same score received the same rank.

2.3 *In situ* conservation

To determine protection levels of commercial species in their natural habitat, the methodology of Hamann et al. (2004) was used. The number of protected areas containing effective population sizes (Ne) ≥1000 (corresponding to a census population size of roughly 5000 mature trees) (Lande and Barrowclough 1987; Yanchuk 2001) in each SPU at a confidence level of 95% was calculated based a species' presence and frequency in botanical inventory plots. The number of protected areas was also calculated in a similar way using the forest cover database. The *in situ* protection estimates based on the latter method were plotted on the maps documenting conservation for each species.

The botanical inventory, which is supported by tens of thousands of biogeoclimatic ecosystem classification (BEC) plots, was screened for accuracy, and plots with substantial spatial or species anomalies were excluded from the analysis. The forest cover inventory database used in this analysis was in use prior to the introduction of the current standard Vegetation Resource Inventory, which consists of aerial photo interpretation followed by systematic stratified or random field sampling for adjustment. Ground-truthing is recommended where the two methods produce very inconsistent results or if either suggests that protection levels are below the threshold of three separate protected areas per SPU with Ne of 1000.

2.4 *Ex situ* conservation

A summary of inventory at the Tree Seed Centre (TSC) for seed held in long-term storage for conservation purposes was generated and summarized by SPU. Where seedlot geographic origin was identified as inaccurate, either the provenance and species identification were corrected using available data (e.g., collection reports with geographic co-ordinates) or the entry was discarded. A minimum sample of 1000 viable seeds with three samples per SPU, based on periodic viability testing conducted by the TSC, was considered the threshold for adequate genetic conservation.

Living trees in clone banks are also *ex situ* collections; however, they are clone archives or breeding arboreta and the numbers are relatively low compared to seed banks. (We are currently documenting these by species and SPU.) In most cases clonal archives exist at only a single site, but provide a valuable source of viable material for rapid testing and propagation, even though genotypic representation will tend to be much smaller than *ex situ* seed collections for a given SPU.

2.5 *Inter situ* conservation

A primary objective of an *inter situ* genetic resource is to conserve genetic variation in a more dynamic state than *ex situ* seed collections because they capture local gene pools undergoing natural selection in a common environment and under current climate conditions; also, trials are maintained and measured periodically. Not all traditional common garden trials qualify as *inter situ* trials. For example, provenance tests, although they represent a broad range of genetic variation within a species, often include many non-local populations (from outside the currently delineated SPU). While this is of great value for many research purposes, particularly the development of seed transfer guidelines and selecting populations to accommodate changing climates, the conservation objective is to represent the natural variability within a panmictic "local population" (defined here as the SPU). The quantitative and conceptual framework for the conservation of adaptive genetic variation, as well as for the capture of low-frequency alleles (which can be approximated from the tables presented below), is more fully documented by Yanchuk (2001). *In situ* and *inter situ* installations are experiencing current climates under field conditions that impose a more stringent "land race" type of selection than do managed clone bank sites, reflecting regional-scale environmental selection. Sites selected as key *inter situ* reserves contain a large range of genetic diversity and adaptive potential within each geographic and climate zone that presently delineates the SPU. For a few species that show relatively little genetic differentiation among populations (e.g., western white pine), provenance trials can also be utilized as *inter situ* installations. *Inter situ* sites were prioritized based on the following criteria: 1) population size sufficient to contain a large sample of the adaptive genetic variation of the gene pool of the SPU; 2) condition of the trial in terms of health, survival, and age; and 3) access and status with respect to immediate threats from development. Results from primary trials are reported here.

Inter situ trials have additional value in that they are key sources of information about the population genetic variation and adaptive traits that cannot be quantified with the same degree of accuracy in a natural population. These data are used to support decision making for reforestation and restoration, and may be used to produce seed. Such trials persist for decades, and provide a wide range of data, as well as opportunities to appropriately change allele frequencies and population mean values of adaptive traits in future generations by selecting trees from these populations to contribute to the next generation through seed or pollen.

Peripheral portions of species' ranges are not usually included in SPUs (for reforestation and management). The core portions of species' ranges most often contain genotypes that are best adapted to current conditions, especially on productive sites with the highest growth potential. While the peripheral populations may contain important alleles and phenotypes, these are often considered "off site" for management purposes (i.e., not economical or well adapted to the site at present). Peripheral populations may be subject to strong environmental selection pressure at the margin of a species' ecological niche, and affected disproportionately by gene flow from adjacent "core" populations. As such, the genetic conservation of peripheral populations is being addressed by *in situ* conservation measures addressed elsewhere (Chourmouzis et al. 2009)

Ne is nearly always less than the actual (census) population size, except where controlled pollinations or clonal reproduction allow the exact count of how parents contribute to the next generation. Biological constraints reduce the actual numbers of parents contributing gametes. For open-pollinated (OP) trials with fewer than 20 progeny per family, 3.2 was used as a multiplier for the number of half-sib families. If there were 20 or more progeny per family, 3.9 was the multiplier[2] because individuals were selected from unrelated, distant individuals. For instance, a 100-family OP trial of species in the

[2] $$\text{Ne} = \text{multiplier} \times (\text{\# of families}) \times \left(\frac{1}{\sum \begin{pmatrix}\text{female gametic} \\ \text{contribution}^2\end{pmatrix} + \sum \begin{pmatrix}\text{male gametic} \\ \text{contribution}^2\end{pmatrix}} \right)^{-1}$$

Pinaceae was assumed to have Ne ~396. Although it is likely that many more than four trees have pollinated a single tree, the Ne of the reference population represented by an OP collection from 100 different males of equal proportion has Ne ~3.9, increasing to a maximum of 4 with an infinite number of pollen parents. Hence, each OP parent tree was treated as an independent sample of the reference population to estimate approximate levels of genetic variation present in trials for planning purposes. Full-sib or polycrossed families, when denoted as key installations, have Ne values calculated based on the number of unrelated parents used in the test.

In some cases, natural stand seed planning zones (SPZs) are recognized for management purposes where there are currently no formal SPUs designated due to a lack of testing (e.g., western redcedar in the Interior). For species in this circumstance, *in situ* and *ex situ* collections are the main conservation vehicles where *inter situ* trials have only recently been established or are planned. Target areas containing well-adapted populations for all three conservation vehicles are likely to change as we develop a better understanding of future climate con-ditions, and as seed transfer guidelines become more climate-based.

3 RANKING SPECIES CONSERVATION PRIORITY

3.1 Status in British Columbia

Species were ranked by both overall provincial status (Table 3) and by SPU (Table 4) based on the criteria in Table 2. The provincial rank for all species was identical (not at risk), so this category was excluded from Tables 3 and 4. The species are relatively abundant and widespread in British Columbia (compared to many minor species), leading to a limited spread of the rank values with the ranks being roughly tied to the extent of the species' range and the proportion in protected areas.

TABLE 3 *Species conservation priority ranking by species, based on criteria in Table 2*

				Protection status						
Species	**Abundance**	**Range**	**Resilience**	***In situ***	***Inter situ***	***Ex situ***	**Trends**	**Threats**	**Total**	**Rank**
Pw	1	2	2	1	2	3	2	1	17	1
Sxs/Ss	2	1	3	3	2	3	3	2	19	2
Yc	2	2	1	3	3	2	2	3	21	3
Pli	3	3	3	3	2	3	1	2	23	4
Lw	2	2	3	2	3	3	3	3	24	5
Hw	3	3	3	3	3	3	2	3	26	6
Sx	3	3	3	3	3	2	3	3	26	6
Cw	3	3	3	3	3	3	3	3	27	7
Fdc	3	3	3	3	3	3	3	3	27	7
Fdi	3	3	3	3	3	3	3	3	27	7

3.2 Status by Seed Planning Unit

In Table 4, a more complex picture emerges when species are evaluated by SPU, which can provide more targeted guidance for genetic conservation and management by geographic area.

TABLE 4 *Species conservation priority ranking by species/SPU combination, based on criteria in Table 2*

Species/ SPU	B.C. rank	Abundance	Range	Resilience	Protection status: *In situ*	*Inter situ*	*Ex situ*	Trends	Threats	Total	Rank	Comments
Pw M	3	1	3	2	1	2	3	2	2	19	1	white pine blister rust and limited replanting
Pli NS h	3	1	3	3	1	1	1	3	3	19	1	uncommon in this SPU and lacking adequate protection
Lw NE h	3	2	2	2	2	1	3	3	3	21	2	uncommon in this SPU; require ground-truthing of in situ protection
Pw KQ	3	2	3	2	2	2	3	2	2	21	2	white pine blister rust and limited replanting
Sx TO l	3	1	3	2	3	1	3	3	2	21	2	spruce beetle outbreak in dry limits of range
Yc M	3	2	3	2	3	3	2	2	3	23	3	yellow-cedar decline on north/central coast, regeneration capacity limited; harvested volumes/areas not typically replanted to same species
Lw EK	3	2	2	2	2	3	3	3	3	23	3	require verification of in situ protection
Ss M	3	2	3	2	3	3	3	2	2	23	3	forest management practices reducing abundance: areas harvested not replanted to Sitka spruce due to weevil
Sxs SM	3	2	2	2	3	2	3	3	3	23	3	forest management practices reducing abundance: replanting to other species because of weevil
Sx NE h	3	1	3	3	3	1	3	3	3	23	3	uncommon in this SPU
Sx NE l	3	1	3	3	3	1	3	3	3	23	3	uncommon in this SPU; likely to increase in abundance with climate change
Sx PR h	3	3	3	3	2	1	2	3	3	23	3	limited ex situ reserves; expected to increase in abundance with climate change
Sx TO h	3	2	3	3	3	1	3	3	2	23	3	less common in this SPU
Cw M h	3	3	3	2	3	1	3	3	3	24	4	forest management practices on north and central coast reducing abundance without creating conditions for regeneration
Fdi CT	3	3	3	2	2	3	3	2	3	24	4	likely to reduce with climate change: increased fire and drought, limited seed bank
Fdi QL	3	3	2	3	3	1	3	3	3	24	4	less common in this SPU
Sxs NS	3	2	2	2	3	3	3	3	3	24	4	forest management practices reducing abundance: replanting to other species because of weevil (less severe impacts than SM SPU)
Pli BV h	3	3	3	3	2	1	3	3	3	24	4	
Pli EK h	3	3	3	3	2	1	3	3	3	24	4	
Pli EK l	3	3	3	3	2	1	3	3	3	24	4	
Pli NE h	3	2	3	3	3	1	3	3	3	24	4	
Pli PR h	3	2	3	3	3	1	3	3	3	24	4	
Pli PR l	3	2	3	3	3	1	3	3	3	24	4	

TABLE 4 *Continued*

Species/ SPU	B.C. rank	Abundance	Range	Resilience	Protection status *In situ*	*Inter situ*	*Ex situ*	Trends	Threats	Total	Rank	Comments
Cw M l	3	3	3	2	3	3	3	3	2	25	5	increasing summer drought limiting in drier habitats
Cw SM	3	3	3	3	3	1	3	3	3	25	5	
Fdi NE h	3	2	2	3	3	3	3	3	3	25	5	less common in this SPU
Lw NE l	3	3	2	2	3	3	3	3	3	25	5	
Sx BV l	3	2	3	3	2	3	3	3	3	25	5	
Pli CP h	3	3	3	3	3	1	3	3	3	25	5	
Pli NS l	3	2	3	3	2	3	3	3	3	25	5	
Pli TO h	3	3	3	3	3	1	3	3	3	25	5	
Hw M h	3	3	3	3	3	2	3	3	3	26	6	
Fdc M h	3	3	3	3	3	2	3	3	3	26	6	
Fdi PG	3	3	2	3	3	3	3	3	3	26	6	
Sx EK	3	2	3	3	3	3	3	3	3	26	6	
Sx PG h	3	2	3	3	3	3	3	3	3	26	6	
Hw M l	3	3	3	3	3	3	3	3	3	27	7	
Fdc M l	3	3	3	3	3	3	3	3	3	27	7	
Fdc SM	3	3	3	3	3	3	3	3	3	27	7	
Fdi EK	3	3	3	3	3	3	3	3	3	27	7	
Fdi NE l	3	3	3	3	3	3	3	3	3	27	7	
Sx PG l	3	3	3	3	3	3	3	3	3	27	7	
Sx PR l	3	3	3	3	3	3	3	3	3	27	7	
Pli BV l	3	3	3	3	3	3	3	3	3	27	7	
Pli CP l	3	3	3	3	3	3	3	3	3	27	7	
Pli NE l	3	3	3	3	3	3	3	3	3	27	7	
Pli PG h	3	3	3	3	3	3	3	3	3	27	7	
Pli PG l	3	3	3	3	3	3	3	3	3	27	7	
Pli TO l	3	3	3	3	3	3	3	3	3	27	7	

4.1 Overview

Western redcedar is a long-lived conifer that is largely resistant to disease and decay. It prefers moisture-receiving sites, extending up the coast to Alaska and in the Interior in the ICH zone and adjacent zones in the Kootenays and Rocky Mountain Trench. This tree has immense cultural importance for British Columbia First Nations—its wood was used for a range of applications from house poles to canoes, and the fibrous bark and roots were woven into clothing, baskets, rope, and other items. The oil is rendered for a non-timber forest product, and the foliage is also an important commercial product for the floral industry. Cavity-nesting species often use western redcedar for nest sites. Western redcedar is the provincial tree of British Columbia, symbolizing many of the cultural, economic, and aesthetic values associated with the forest.

Western redcedar regenerates abundantly on any seedbed, but survival is highest on mineral soil. It is very shade-tolerant, often subsisting in the canopy of a pioneer stand for decades or longer. Western redcedar has evolved a very high tolerance to inbreeding and self-fertilization, but has relatively low levels of genetic diversity. This likely resulted from a glacial bottleneck in small refugia that purged much of its genetic load (O'Connell et al. 2001). It can also reproduce asexually through layering, and cuttings root easily. The minute seeds are extremely abundant, but viability decays relatively quickly, making this species a challenge for seed storage. This species can be induced to flower in as little as 2 years from germination, providing a unique model for research on selection for various traits (Russell and Ferguson 2008). Western redcedar is relatively recently domesticated: second-generation trials are established in British Columbia, the only jurisdiction with an improvement program. Major traits currently of interest in the redcedar breeding program include growth and yield, heartwood durability, and deer-browse resistance based on foliar monoterpene concentrations. This indeterminate species is extremely plastic, facilitating relatively wide seed transfer and adaptation over a range of sites. There are currently three coastal SPUs, and none designated in the Interior, where natural stand seed planning zones (SPZs) are used. Plantings of western redcedar have ranged over the past 5 years from 8 to 10 million seedlings annually, while the reported harvest volume has fluctuated between 5 and 8 million m^3.

The major pests of redcedar include leaf blight caused by the fungal agent *Didymascella thujina* (E.J. Durand) Maire (formerly *Keithia*), mammal browse, heart rot decay associated with mechanical injury, moderate to low windthrow incidence, and abiotic stress due to growing-season drought, flooding, and snow and freezing damage in coastal populations. It is very susceptible to mortality caused by fire, which is very infrequent in western redcedar habitat. Typical regeneration dynamics result in multi-layered stands with single-tree to small group disturbances caused by windthrow or high water table. Redcedar has an intermediate root system comprised of a network of moderately deep roots but lacking a taproot.

The wood of western redcedar is reddish, soft, highly resistant to decay, and aromatic. It can be used for structural poles and timbers, crossbeams, shakes, furniture, ornamental and artisan woodwork, fencing, poles, and decking. Waste is commonly processed into mulch. The wood of old-growth western redcedar is of far higher value than second-growth due to the former's tight grain, higher density, large knot-free sections, and greater proportion of heartwood. Butt swell is pronounced, especially in old trees.

4.2 *In situ* protection levels

All SPUs and populations of this species are adequately represented *in situ* with six to 41 protected areas (PAs) containing Ne ≥1000 (Table 5). There is no recognized interior SPU for redcedar, resulting in a potential gap in protection documented in this analysis. There is a good range of protected areas that meet the *in situ* criteria, but not in the small disjunct population in the Cranbrook–Fernie area, which is likely genetically similar to nearby populations inhabiting similar climates (J. Russell, B.C. Min. For. Range, Res. Br., pers. comm., Sept. 2008). National parks appear to comprise a substantial portion of protected areas containing adequate western redcedar populations over large, contiguous areas (Figure 1).

4.3 *Inter situ* protection levels

The only *inter situ* trials for western redcedar are in the Maritime low SPU, containing Ne >100 with selections occurring across four sites (Table 5). The numbers are relatively low because most of the material originated from polycross testing of the first-generation parent trees in the SPU. Maritime high and Submaritime SPUs represent gaps in the *inter situ* network of genetic conservation and genetic resource management, although they are represented in a range of provenance trials that have not been included here due to their high proportion of populations from beyond the climatic amplitude of British Columbia (e.g., California, Oregon, Alaska). While there are also no *inter situ* trials in the Interior, comprehensive collections have been made and several field tests will be established in 2009 that contain *inter situ* resources.

4.4 *Ex situ* protection levels

The range of SPUs and BGC zones both show good levels of *ex situ* seed collections for this species in its core habitat (Table 5, Figure 1). Numbers are sufficient but low for some ecosystems, including drier and peripheral Interior habitats (not currently within an SPU) in the IDF and SBS. This species is genetically and phenotypically quite homogeneous and phenotypically plastic; it remains to be determined whether collections from the margins of the range would capture additional adaptive variation.

4.5 Conservation status summary

Western redcedar is adequately protected in core *ex situ* and *in situ* locations, although additional seed collections from peripheral populations in the Interior would provide a more comprehensive set of baseline samples. Seed for this species must be periodically replaced due to deteriorating viability in long-term storage. *Inter situ* representation in primary trials is only marginal for the Maritime low SPU, and completely absent for the other coastal SPUs. Administratively, genetic resource management for this species would be greatly enhanced by developing interior SPUs, where the effects of climate change are expected to be considerable. Results from provenance and genecological studies should be utilized to delineate appropriate units.

TABLE 5 *Conservation status of western redcedar including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Cw M h	3.51	0.47	13.49	≥10	41	19	0
Cw M l	0.90	0.06	6.70	≥3	6	93	102 (4)
Cw SM	3.47	0.44	12.68	≥5	31	40	0
Total	7.88	0.97	12.31	≥18	78	152	102 (4)

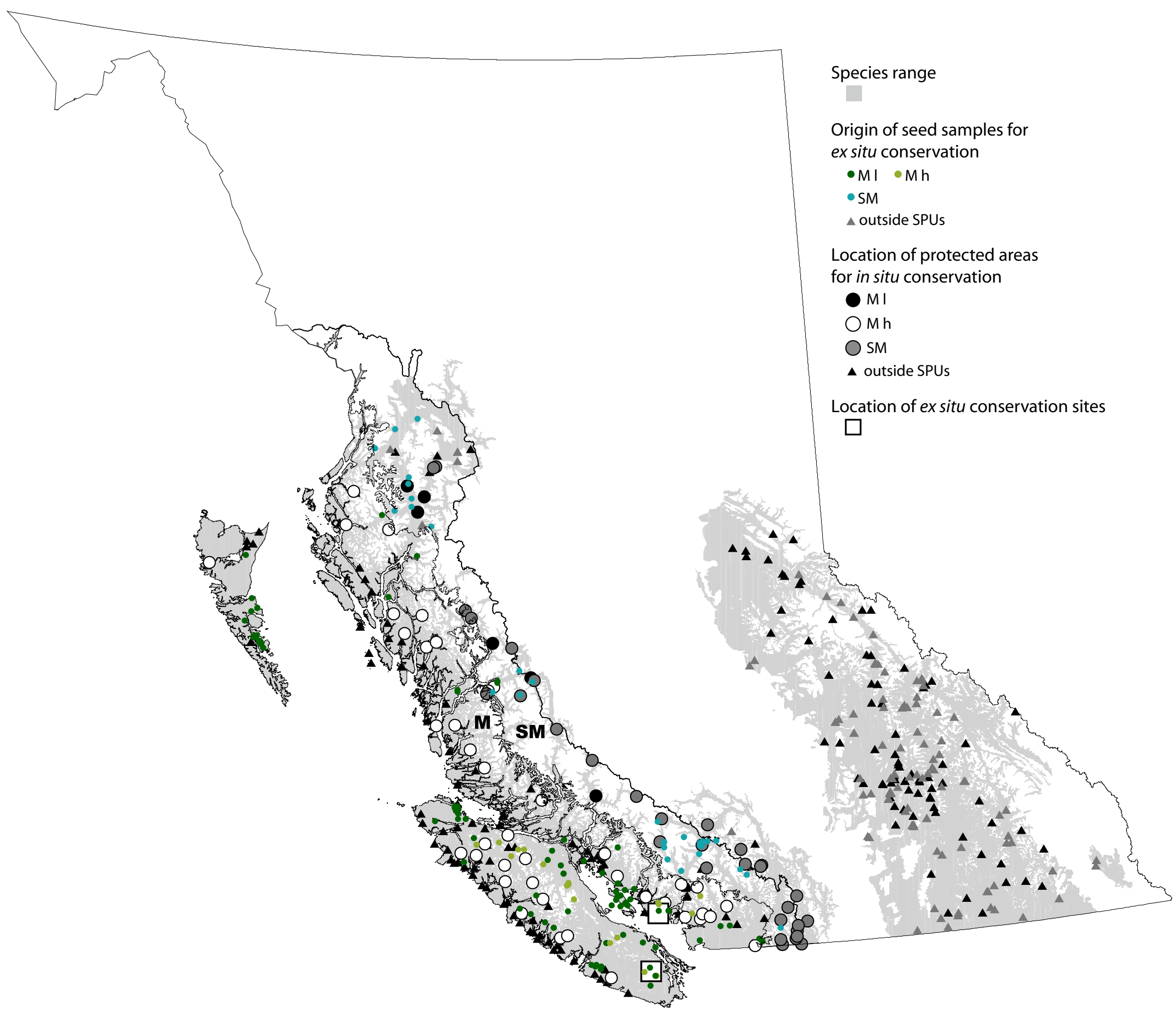

FIGURE 1 *Map of* in situ, inter situ, *and* ex situ *protection for western redcedar in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

5 Fdc – COAST DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* VAR. *MENZIESII* (MIRBEL) FRANCO)

5.1 Overview

Coast Douglas-fir is typically a pioneer species and a climatic climax species in the dry CDF zone, although long-lived veterans occur throughout drier variants of the CWH zone in mature forests. Coast Douglas-fir hybridizes with interior Douglas-fir where they are sympatric; hybrids are intermediate between the two varieties with respect to morphology and physiology. The coastal variety has been the subject of over half a century of tree improvement research; breeding and testing are in the third generation. Material in the improvement program includes genotypes from co-operating agencies in Washington and Oregon. This species can tolerate a wide range of edaphic conditions and belongs to many plant associations, but is only moderately tolerant of snowpack and low temperatures. Douglas-fir is an adaptive generalist on the Coast where it regenerates most often to even-aged stands after large-scale disturbances such as hurricanes or when rare stand-replacing fires expose substantial mineral seedbeds. In the CDF zone, root rot (particularly *Armillaria ostoyae* (Rom.) Herink.) is a major disturbance agent, leaving patchy stand structure. Large snags and veterans often provide nest sites for Bald Eagles and other raptors. A long history of land use, including forestry and residential development, has reserved few old-growth stands of Douglas-fir to the present.

Harvest of coast Douglas-fir ranged from 5 to nearly 8 million m^3 in the past 7 years, while 5 to 7 million seedlings were planted. The major trait for coast Douglas-fir breeding is growth and yield; however, wood quality traits, particularly density and—more recently—modulus of elasticity, are emerging as key traits for selection. Wood density and related traits typically have a significant, inverse relationship with diameter growth, so various index selection and sublining breeding programs have been implemented to simultaneously capitalize on these antagonistic traits. Stem form is also incorporated in selection. Climate change is not expected to have a major effect on coast Douglas-fir and other predominantly maritime taxa, where the prevailing oceanic influence moderates extremes, and where the extent of climate change is predicted to be much smaller than in the Interior (Spittlehouse 2008).

Coast Douglas-fir wood markets and utilization are similar on the Coast and in the Interior; however, high-grade and large, sound logs command a considerable premium for coast Douglas-fir in the specialty market. Some intensively managed stands are on their third rotation.

5.2 *In situ* protection levels

Coast Douglas-fir is well protected for the most part. The Maritime low SPU has been heavily affected by development and intensive resource utilization, particularly along lower-elevation valley bottoms, and has only 7.8% of its area protected (Table 6, Figure 2). The botanical and forest inventories both confirm that this variety has adequate representation (Table 6).

5.3 *Inter situ* protection levels

All SPUs have some representation in *inter situ* installations with Ne between 78 and 1024, most of which are replicated across multiple sites, except the Maritime high SPU, which has a low Ne (78) due to the full-sib crossing design (Table 6). Increasing the number of genotypes and trials in this SPU may be warranted to evaluate the effects of environmental factors and stressors at higher elevations that are expected to occur with climate change. There are many other trials with thousands of families not included in this inventory that could be considered backup *inter situ* installations.

5.4 *Ex situ* protection levels

All SPUs, and a diverse range of habitats across the SPUs, have abundant seed in *ex situ* collections (Figure 2).

5.5 Conservation status summary

Coast Douglas-fir is well represented in *ex situ* seed collections and *in situ* protected areas—except within the CDF zone and southern portions of the CWH zone—yielding a lower level of protection in the Maritime low SPU. All SPUs have sufficient *ex situ* collections that represent all BGC zones supporting Douglas-fir. Increasing representation in *inter situ* trials for the Maritime high SPU would support the delineation of seed transfer and reforestation guidelines for this SPU.

TABLE 6 *Conservation status of coast Douglas-fir including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			*In situ*		*Ex situ*	*Inter situ*
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Fdc M h	1.91	0.25	13.04	≥5	24	17	78 (2)
Fdc M l	4.63	0.36	7.78	≥10	98	138	1042 (8)
Fdc SM	2.32	0.41	17.51	≥3	32	33	874 (1)
Total	8.86	1.02	11.51	≥18	154	188	1994 (11)

6 Fdi – INTERIOR DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* VAR. *GLAUCA* (BEISSN.) FRANCO)

6.1 Overview

The interior variety of Douglas-fir occupies a pioneer niche throughout much of the southern half of interior British Columbia, except in the IDF zone where it is a climatic climax. In mesic to drier habitats, Douglas-fir stand dynamics sustain an uneven-aged structure with multiple canopy layers, and the primary disturbance agent is relatively frequent, low-intensity, stand-maintaining fires. Its thick bark is an adaptation to this disturbance mechanism. Relative to the coastal variety, interior Douglas-fir is more tolerant of shade (to shade-requiring for regeneration), drought, cold, and snowpack. Seed and cone pests are major biotic factors affecting interior Douglas-fir; mature and veteran trees support populations of Douglas-fir bark beetle and occasionally mistletoe. *Armillaria ostoyae* is a moderately frequent root rot pathogen affecting this variety, and *Phellinus weirii* (Murr.) R.L. Gilb. also is relatively widespread in the southern Interior. Douglas-fir tussock moth (*Orgyia pseudotsugata* McD.) can damage and even kill trees by defoliation on drier sites. Spruce budworm (*Choristoneura occidentalis* Freeman) periodically affects current-year foliage, but rarely causes mortality. Interior Douglas-fir is a commercial species primarily on summer-drought sites. Forest harvesting, fire history, and land use conversion have left few old-growth stands of Douglas-fir, replacing them with more homogeneous, densely stocked stands with smaller trees today than were there a century ago.

Harvest of interior Douglas-fir varied from 3.2 to 5.6 million m^3 annually over the past 5 years, with plantings ranging from 8.5 to 15 million seedlings per year. The primary objective of most Douglas-fir breeding is accelerated growth and yield, with stem form and wood quality important secondary traits. The second generation of testing is currently under way, with a wide-ranging series of trials, including screening for *Armillaria* resistance (Jaquish et al. 2007). Impacts of climate change on Douglas-fir are projected to be significant in terms of forest ecology, productivity, disturbance regimes, abiotic stressors, and health. Hamann and Wang (2006) predicted that the climatic niche of interior Douglas-fir should shift northward substantially over the next rotation as a result of climate change; recent predictions using improved models forecast greatly expanded habitat across the Interior of British Columbia (T. Wang, Univ. British Columbia, pers. comm., Aug. 2008).

The wood of Douglas-fir is moderately strong and durable, with a straight grain, low taper, and little tendency for dimensional lumber to warp or check. Stands tend to be readily available in terms of proximity to transportation corridors. Its homogeneous straight bole and taproot facilitate operations and manufacturing. On richer sites this species can achieve high yields, making it a preferred species for reforestation. Primary uses are lumber and plywood, with veneer and secondary manufactured products such as flooring, furniture, and cabinetry also comprising a substantial market share.

6.2 *In situ* protection levels

While the Quesnel SPU has a high proportion of its area protected, other interior Douglas-fir SPUs range from only 1 to 7%, well short of the provincial benchmark of 12% (Table 7). The botanical inventory estimates that all other SPUs have adequate representation; however, the forest cover data show that all SPUs, including the Cariboo Transition, have at least three protected areas with Ne >1000. This discrepancy warrants ground-truthing in the Cariboo Transition, East Kootenay, and Quesnel SPUs.

6.3 *Inter situ* protection levels

All SPUs are well represented with Ne between 800 and 1567, most of which are replicated across multiple sites (Table 7).

6.4 *Ex situ* protection levels

All SPUs are adequately represented in *ex situ* collections (Figure 2). Moreover, when apportioned across BEC zones, seeds from the full range of habitat types were included.

6.5 Conservation status summary

Interior Douglas-fir is well represented in *ex situ* collections and *in situ* protected areas, except for the Cariboo Transition, which requires ground-truthing to confirm adequate population sizes in protected areas; the East Kootenay and Quesnel SPUs should also be verified. Regardless, all SPUs have sufficient *inter situ* trials that represent the range of habitats and administrative units supporting operational interior Douglas-fir deployment.

TABLE 7 *Conservation status of interior Douglas-fir including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

SPU	SPU size, number of PAs, and percent protected			*In situ*		*Ex situ*	*Inter situ*
	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Fdi CT	1.06	0.01	1.02	0	4	25	1200 (1)
Fdi EK	1.22	0.08	6.39	≥3	19	45	1864 (2)
Fdi NE h	1.84	0.13	7.1	≥5	30	77	961 (2)
Fdi NE l	1.25	0.05	4.28	≥5	63	121	1024 (1)
Fdi PG	5.36	0.19	3.47	≥5	23	23	1440 (2)
Fdi QL	2.18	0.46	21.11	≥3	15	14	840 (2)
Total	12.91	0.92	7.13	≥21	154	305	8059 (12)

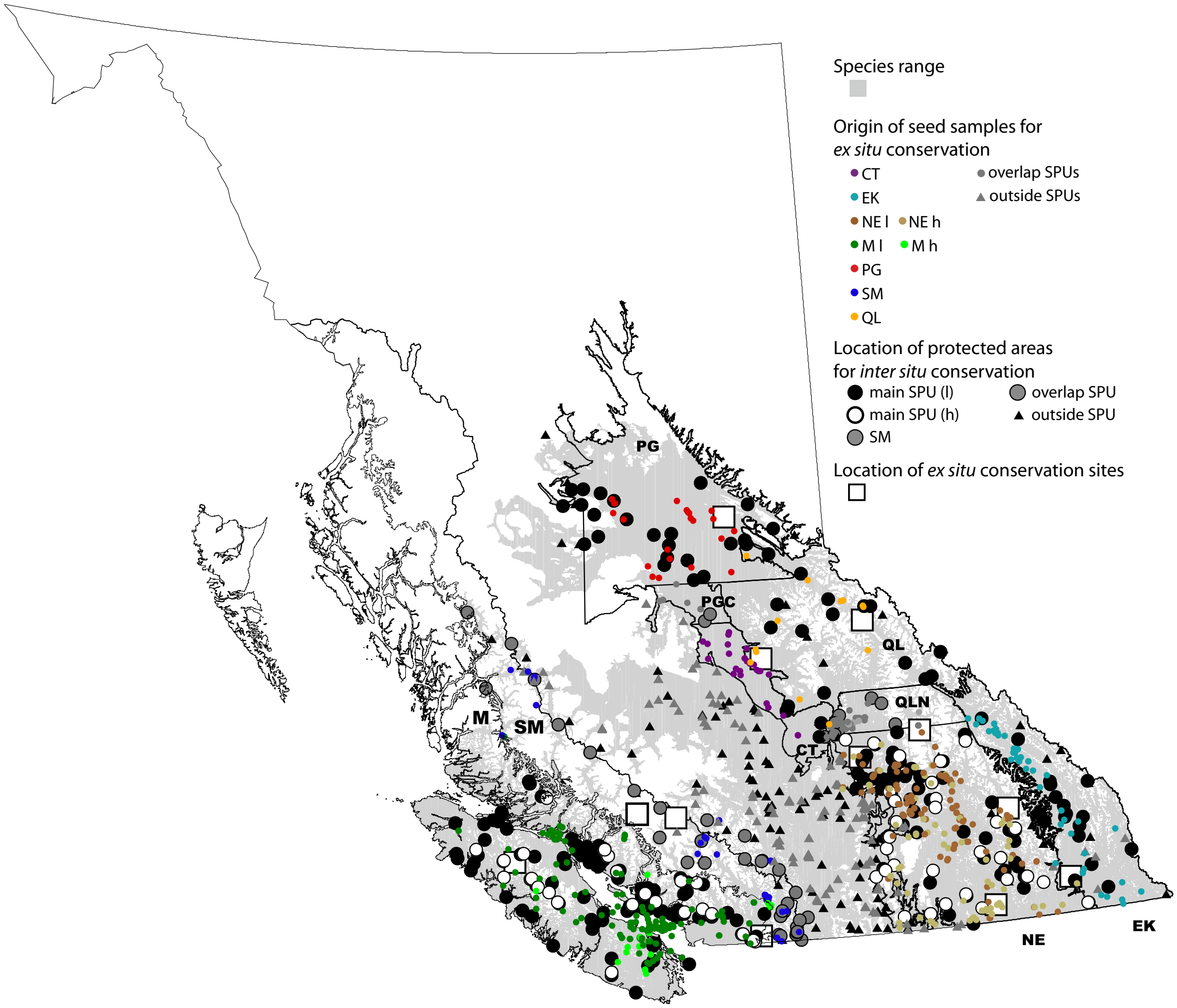

FIGURE 2 *Map of* in situ, inter situ, *and* ex situ *protection for Douglas-fir in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

7 Hw – WESTERN HEMLOCK (*TSUGA HETEROPHYLLA* (RAF.) SARG.)

7.1 Overview

Western hemlock grows in similar habitats and areas as western redcedar, including the Coast, Interior, and islands. This climatic climax species is extremely shade-tolerant, highly fecund, and regenerates abundantly under the canopy on organic substrates and moisture-receiving sites. This multi-layered canopy structure and precocious reproduction facilitates moderate levels of inbreeding. Seeds deteriorate in storage at rates similar to western redcedar. It frequently dominates stands, particularly in the coastal portion of its range, in terms of numbers, basal area, and standing volume. In higher-elevation sites, it grades into mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), but no hybridization has been confirmed between the two species. There are presently two SPUs for western hemlock, both on the Coast: Maritime high and Maritime low. There are no SPUs for the submaritime or interior portions of its range in British Columbia.

This shallow-rooted species can tolerate relatively moist sites, but is highly susceptible to windthrow and drought stress, and not tolerant of flooding, soil compaction, mechanical damage, or wildfire. Primary economic pests include mistletoe (*Arceuthobium tsugense* (Rosendahl) Jones, syn. *A. campylopodum*), hemlock looper (*Lambdina fiscellaria* ssp. *lugubrosa* (Hulst)), adelgids (*Adelgis cooleyi* Gill.), and heart rot (primarily *Echinodontium tinctorium* (Ellis & Everh.) and *Phellinus pini* (Thore:Fr.) Ames). Branch brooms caused by dwarf mistletoe infestation are frequently used in maritime to hypermaritime habitats as nesting platforms by Marbled Murrelet and other old forest-dependent species. Western hemlock exhibits considerable variability among populations for adaptive traits including cold hardiness, snow tolerance, and growth. Populations from approximately 1°S of planting sites consistently outperform local provenances for growth. The major traits selected for tree improvement are early height growth, volume at rotation, and stem form.

Western hemlock wood is of relatively low market value at present, and planting numbers range from 1 to 3 million annually as licensees rely on natural regeneration rather than absorb the cost of improved seed, seedling production, and planting costs. Hemlock wood is suitable for a wide range of uses from structural timber to pulp. This species comprises approximately 60% of the standing inventory in the Coast Forest Region. Its high harvest volume (6 to 10 million m^3 annually over the past 5 years) and relatively rapid growth on good, well-stocked sites makes it a good option for biomass production and carbon sequestration. Mature trees develop butt swell and tend to develop basal heart rot.

7.2 *In situ* protection levels

Both SPUs support good levels of *in situ* protection for this species by both total area and number of protected areas. Although the Maritime low SPU is 9.5% protected, there are 95 PAs that contain Ne ≥1000. The central Coast, particularly the Submaritime SPU, has recently had many newly designated protected areas, so an update of the inventory would likely reveal adequate protection. The extremely remote nature of this region and associated difficulties in access also provide a high degree of informal protection for populations. The interior portion of western hemlock habitat contains a good range of protected areas, except for the small disjunct population in the Cranbrook–Fernie area.

7.3 *Inter situ* protection levels

Installations designated as primary Maritime high *inter situ* trials have limited Ne (72), but many high-elevation genotypes are tested at a wide range of sites that were designed primarily to test lower-elevation genotypes, including sites within the Maritime high SPU. Primary Maritime low trials are replicated in two sites with Ne of 359 (Table 8), including material from Washington and Oregon, some of which is incorporated into the breeding populations for the Maritime low SPU. Many provenance and progeny trials contain additional western hemlock genotypes from across the species' range, and include a large number of families that are not considered primary *inter situ* trials. However, those trials could still have some important *inter situ* genetic conservation potential.

7.4 *Ex situ* protection levels

There are sufficient *ex situ* collections of western hemlock seed at the TSC, including representation from nearly all areas of the species' British Columbia range (Table 8). Gaps at the time of analysis include the series of islands and inlets along the north-central Coast from Portland Inlet to Rivers Inlet, the northernmost extent of the distribution in the Rocky Mountain Trench, and the isolated population in the Cranbrook–Fernie area (Figure 3); however, many of these sites have since been protected and would not require additional collections. Seed viability deteriorates approximately 1% per year, on average.

7.5 Conservation status summary

Western hemlock is well represented in all levels of protection with the exception of *inter situ* trials containing Maritime high SPU material. Additional protection and sampling from outlying and remote populations at the margin of the species' range would add more comprehensive representation to all aspects of hemlock genetic conservation. Periodic seed testing and replenishing *ex situ* reserves should be a component of this species' genetic conservation to mitigate the effects of seed deterioration.

TABLE 8 *Conservation status of western hemlock including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Hw M h	3.09	0.38	12.35	≥10	32	52	72 (2)
Hw M l	7.33	0.70	9.51	≥10	95	100	359 (2)
Total	10.42	1.08	10.36	≥20	127	152	431 (4)

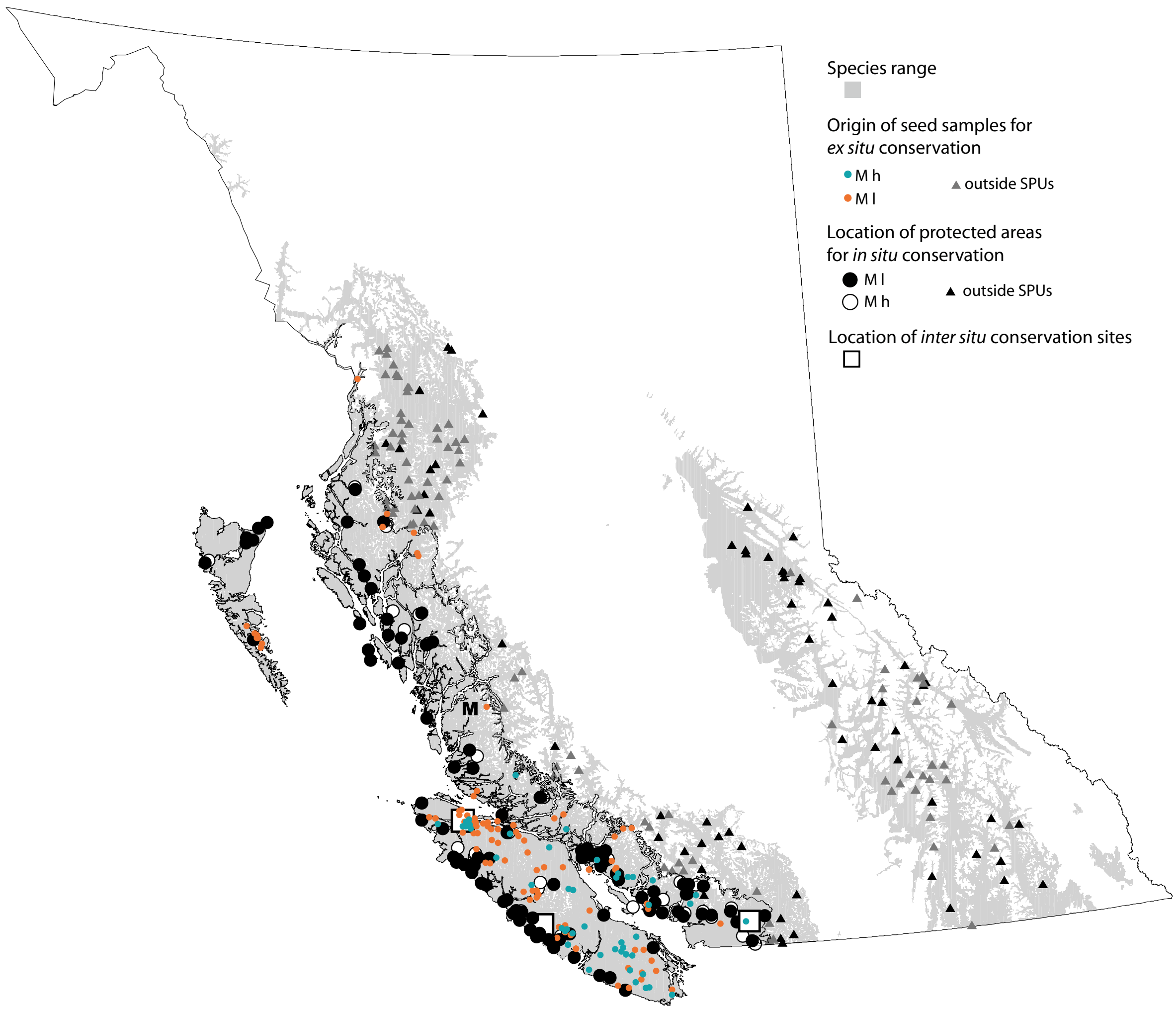

FIGURE 3 *Map of* in situ, inter situ, *and* ex situ *protection for western hemlock in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

8 Lw – WESTERN LARCH (*LARIX OCCIDENTALIS* NUTT.)

8.1 Overview

Western larch is the only commercially managed deciduous conifer in British Columbia. It currently has three SPUs: two low elevation and one high (as well as the NEK overlap area). Frequently associated with Douglas-fir, this montane species is most frequent in the IDF, ICH, and MS zones, occasionally extending to the adjacent ESSF zone in the Okanagan and Kootenays. Fire is typically the major disturbance agent in stands containing western larch; its thick bark provides considerable protection and it is well adapted to moderate to frequent fire regimes. It regenerates abundantly on mineral seedbeds with highly shade-intolerant seedlings. The deep taproot provides stability, supporting a cylindrical bole. Relatively thin, flexible branches confer tolerance to snow loading and wind shear. This species is typically early seral, maintained across the landscape by fire.

Dwarf mistletoe (*Arceuthobium laricis* (Piper) St. John) is a major pest of larch, weakening upper branches and causing infested branches to develop brooms and snap as the wood is weakened, but it only rarely kills trees. *Armillaria ostoyae* is a moderately frequent pathogen that kills trees, particularly younger larch; however, silvicultural and genetic research has been ongoing to mitigate the impacts of this disease (Morrison et al. 1992; Hagle 2006). In wetter climates, needle blight develops, hindering photosynthesis. Needle-boring insects, primarily Lepidopterae, also affect larch, but their impacts to date have not been significant. Climate change models predict that the climatic niche of western larch will cover a larger geographic area over the medium to longer term (Hamann and Wang 2006), and this species is a candidate for assisted migration for reforestation within British Columbia. Whether this would be associated with increasing incidence or severity of biotic or abiotic damage is unknown.

The wood of larch is extremely strong and durable, and is usually sound with irregular, tight knots. It is often harvested and sorted with Douglas-fir in a mix for structural lumber, but has many other uses in secondary manufacturing, especially producing furniture and veneer. Planting since 2002/03 has ranged from 4 to 7 million seedlings annually, with reported annual harvests of approximately 0.5 million m^3.

8.2 *In situ* protection levels

Throughout its managed range, western larch is generally underprotected, ranging from 5% (Nelson low) to 9% (Nelson high) within protected areas by SPU (Table 9). Although it occurs in the East Kootenay and Nelson high SPUs and the forest cover inventory has confirmed adequate representation, the botanical inventory estimated that no PAs contained Ne ≥1000. Estimates of this species based on photo interpretation may be unreliable since, depending on such factors as time of year, photo quality, and colour, larch may not be clearly visible on photos. Subalpine larch (*L. lyallii* Parl.) has also been mapped as western larch at higher elevations, overestimating the frequency of western larch in the NE high and NEK overlap SPUs. Western larch also has a patchy spatial distribution, requiring careful spatial stratification of cruise check plots or botanical inventory sample plots. Ground-truthing is recommended to improve accuracy and confirm the status of *in situ* protection of this species.

8.3 *Inter situ* protection levels

The Nelson low and East Kootenay SPUs have adequate protection in trials with adequate Ne and replication across the landscape (Table 9). Some populations adapted to the Nelson high SPU are contained in these trials, although this SPU does not have dedicated *inter situ* primary installations.

8.4 *Ex situ* protection levels

All SPUs have sufficient seed collections in storage from a representative sample of the species' British Columbia range (Table 9, Figure 4).

8.5 Conservation status summary

Western larch is a relatively minor commercial species, harvested and managed in conjunction with Douglas-fir, lodgepole pine, hybrid white spruce, and other associates. Recent tree improvement activities have resulted in good representation in two of the three SPUs in *inter situ* trials, and all SPUs are well represented in *ex situ* seed inventory. There are no major imminent threats to this species. The major conservation gaps are *in situ* protection and accurate identification of populations in forest inventory mapping. Confirmation of populations on the ground within protected areas is recommended due to difficulties in photo interpretation resulting from this species' spatial distribution.

TABLE 9 *Conservation status of western larch including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Lw EK	1.13	0.08	6.82	0	6	28	1147 (2)
Lw NE h	1.36	0.13	9.22	0	5	22	0
Lw NE l	1.79	0.09	4.99	≥3	13	78	1393 (6)
Total	4.28	0.30	7.01	≥3	24	128	2540 (8)

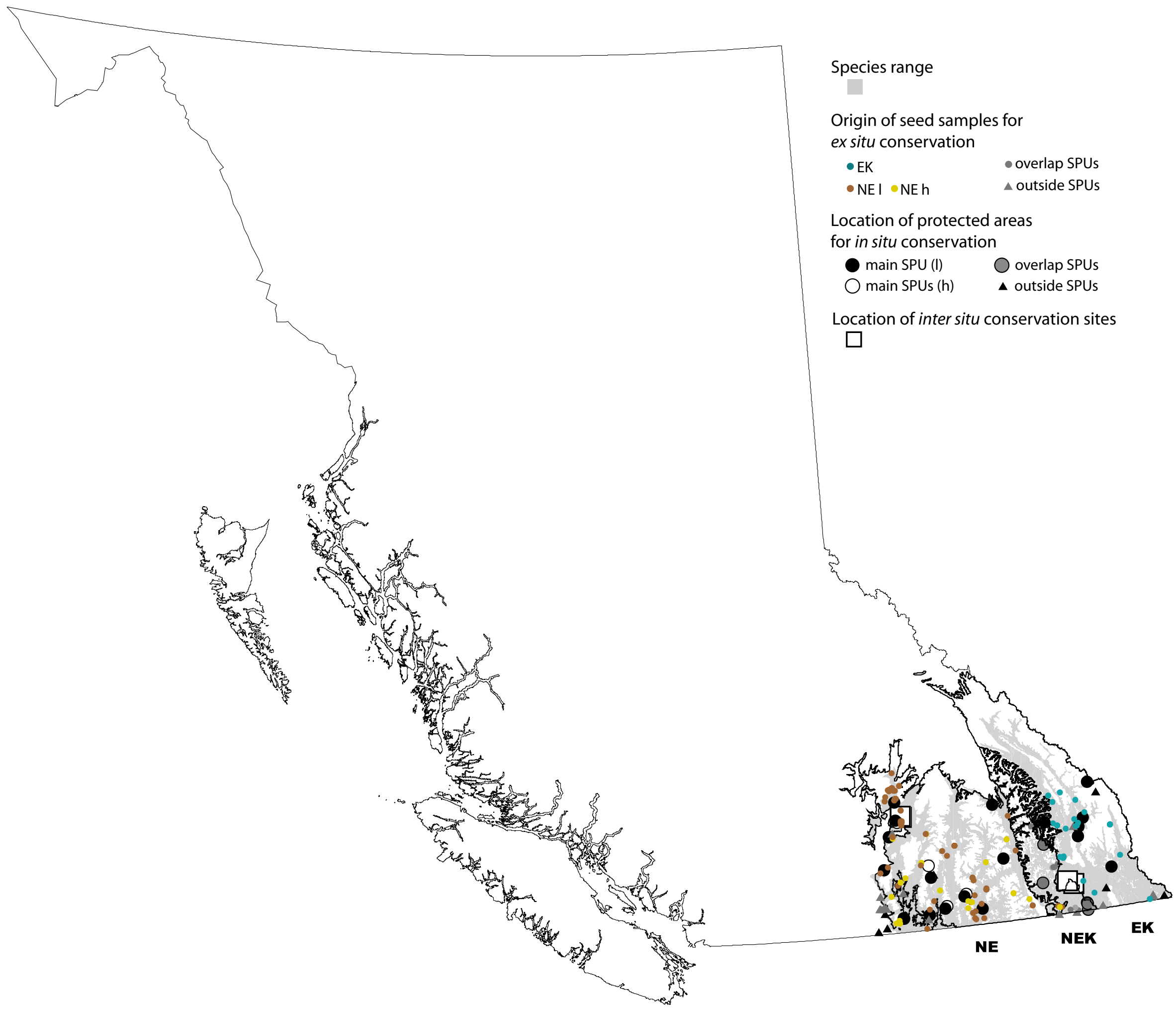

FIGURE 4 *Map of* in situ, inter situ, *and* ex situ *protection for western larch in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

9 Pli – LODGEPOLE PINE (*PINUS CONTORTA* SSP. *LATIFOLIA* ENGELM. EX S. WATS.)

9.1 Overview

Lodgepole pine is the most widely harvested and planted species in the province: over the past 5 years, harvesting has ranged from 27 to over 40 million m^3 annually, with 76 to 134 million seedlings planted. It is an ecological generalist with a wide edaphic amplitude across much of its range, occurring in habitats from alpine talus slopes to hypermaritime bogs throughout most of the province. It hybridizes with jack pine (*P. banksiana*) in the northeast corner of British Columbia where the two species are sympatric. In marginal habitats it is found on both wet and dry nutrient-poor sites. It is a highly prolific and precocious seed producer, with a durable seed bank within serotinous cones that maintain viable seed for decades. This species is a main component of the forest economy in the southern two-thirds of the province, generally from sub-boreal regions south to the U.S. border, and from the east slope of the Coast Mountains to Alberta. Sites supporting economically viable lodgepole pine stands include zonal to drier sites throughout the forested BGC zones of this area on a diverse range of parent materials and slope positions.

Losses of important lodgepole pine *inter situ* genetic resources as well as dozens of important B+ (select natural population) provenances and provenance trials have occurred due to the province-wide mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) epidemic, which has affected over 12.5 million hectares to date. Increasingly warm winters and droughty growing seasons have combined to physiologically stress host trees and provide ideal conditions for the indigenous beetle to shift from an endemic to epidemic pest, attacking younger trees and other species. The beetle–pine system is generally seen as an ecological driver that restores young seral pine stands across a landscape after beetle kill of old timber, followed by patchy medium to large fires of moderate intensity. The durable, prolific seed bank restores the original population after fires or other disturbances. Managing the current impacts and mitigating the ensuing effects over the medium term have resulted in a range of innovative policy directives and adaptive management initiatives. The MPB outbreak has emphasized how quickly, and to what extent, natural disturbances can affect *in situ*, *ex situ*, and *inter situ* genetic conservation vehicles, and the importance of incorporating risk management in genetic resource management strategies.

Lodgepole pine genetic resources are stratified into eight SPZs comprising 16 SPUs, where each zone is typically subdivided into a high- and a low-elevation unit. Transitional SPUs (overlap areas) are zones where material from adjacent SPUs can be planted because clinal genetic variation in these areas is gradual, permitting greater management flexibility. For example, sites in the Prince George–Nelson (PGN) overlap SPU can support merchantable growth of seed sources from either the Prince George or the Nelson SPU (Snetsinger 2004). The comprehensive series of provenance installations established by the British Columbia Forest Service has been an invaluable resource in assessing seed transfer and adaptive parameters for this species.

9.2 *In situ* protection levels

Lodgepole pine is very well protected throughout its central range (Figure 5). The only gap identified was the Nass–Skeena high-elevation SPU where there were no protected areas identified with Ne >1000 in this important Coast–Interior transitional area where lodgepole pine hybridizes with shore pine (*P. contorta* ssp. *contorta*) at lower elevations (Table 10). This could warrant some genetic conservation activities in this area, such as assigning a new protected area, making additional *ex situ* collections, or conservation plantings. This area is rugged and remote with relatively little development outside of the major transportation corridor, so if sufficiently large populations of lodgepole pine exist in the area, they are not likely subject to imminent harvesting or development. Nevertheless, threats due to climate change, wildfire, mountain pine beetle, or diseases cannot be ruled out. It is necessary to periodically update assessments of populations identified for *in situ* protection to account for these changes across the landscape. The proportion of each SPU represented in the protected areas network varies, generally with proximity to population centres and associated development activities. The least protected SPU was Peace River low, with only 1.5% in parks and reserves (also see Yanchuk and Lester 1996); most of the low-elevation SPUs were under-represented in parks compared to the provincial objective of 12% (with the exception of Bulkley Valley Low at 15%). Every SPU had far more protected areas with Ne ≥1000 calculated from the forest cover inventory than estimated using the botanical database (Table 10).

9.3 *Inter situ* protection levels

Inter situ collections of lodgepole pine have been seriously affected and many are still at risk due to MPB. The level of beetle attack at the trial, local, and regional levels was a major influence in prioritizing trials. One mitigating factor is the extreme selection pressure this epidemic is exerting: it is now possible to identify putatively resistant genotypes since the likelihood of escape is small with such high densities of beetle populations. Effective population sizes in *inter situ* installations range from ~600 to 1750, implying that as few as 20 copies of dominant rare alleles (with a frequency of ≤1%) may be protected in each primary trial (Yanchuk 2001). No major genes for resistance to MPB have yet been identified that segregate in these populations, although significant quantitative levels of resistance are present, albeit with relatively low heritabilities (Yanchuk et al. 2008).

Six of the eight low-elevation SPUs have primary *inter situ* tests in place, East Kootenay and Peace River being the only exceptions (Table 10). Other trials contain some families and genotypes for these SPUs, but have not been designated primary trials for reasons described above, or because SPU boundaries changed after trials were established with populations from former SPUs. Although there are no trials in most high-elevation SPUs, alleles and families from these SPUs are contained within low-elevation sites because these were established before the subdivision of SPZs into elevational bands. Higher pressure from intensive forest management and beetle attack also supports prioritization of *inter situ* efforts in these lower-elevation units, but for higher-elevation areas we will rely on the *in situ* and *ex situ* seed collection resources.

9.4 *Ex situ* protection levels

All lodgepole pine SPUs currently have adequate representation in *ex situ* collections (range: 15 to 174 seedlots with Ne ≥1000), except Nass–Skeena high, which has only two collections that likely include some hybrids with shore pine (Table 10). These collections comprise a valuable resource, since many of the forest stands they represent have largely been eliminated due to beetle outbreaks, wildfire, and harvesting, although there are likely viable seed banks stored in the serotinous cones. Demand for seed for reforestation is very high, however, and care must be taken to retain the full geographic range of *ex situ* samples for genetic conservation. In terms of ecological representation, samples from north of Peace River are under-represented, with only two samples in storage from the SWB zone containing ≥1000 viable seeds, although there is abundant *in situ* protection in the area (Figure 5). This area is relatively environmentally homogeneous, and does contain large natural populations of lodgepole pine. Although the area north of Peace River is not currently within an SPU, it may warrant one in the future, and representation in collections should be reconsidered at that time.

9.5 Conservation status summary

Lodgepole pine populations are represented in adequate numbers in most SPUs throughout its core British Columbia range except the Nass–Skeena high, which would benefit over the long term from a new protected area for this population. Populations inventoried in protected areas for this analysis may have since been killed by the current mountain pine beetle outbreak or fires. However, the durable native seed bank protected by long-lived serotinous cone storage is likely a sufficient long-term repository for the alleles of these parent populations. *Inter situ* trials of lodgepole pine contain Ne of ~600 to 1750 at the low-elevation SPUs throughout its range. These sites were prioritized based on beetle attack as a main consideration. *Ex situ* collections contain important collections of germplasm for populations that are now extirpated due to MPB-caused mortality across the landscape.

TABLE 10 *Conservation status of lodgepole pine including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Pl BV h	1.86	0.35	18.86	≥1	13	31	0
Pl BV l	3.44	0.52	14.99	≥3	28	174	1229 (1)
Pl CP h	4.06	0.34	8.42	≥3	21	21	0
Pl CP l	2.11	0.15	7.18	≥3	20	46	1131 (3)
Pl EK h	1.26	0.18	14.56	≥1	11	50	0
Pl EK l	1.03	0.06	5.63	≥1	16	72	0
Pl NE h	1.94	0.26	13.29	≥3	17	55	0
Pl NE l	2.05	0.13	6.43	≥10	27	133	1190 (3)
Pl NS h	0.33	0.02	6.45	0	0	2	0
Pl NS l	1.25	0.06	4.85	≥1	8	76	585 (2)
Pl PG h	3.77	0.74	19.56	≥5	22	81	1053 (2)
Pl PG l	2.69	0.23	8.65	≥5	24	127	1248 (2)
Pl PR h	1.41	0.09	6.29	≥1	9	15	0
Pl PR l	3.77	0.06	1.54	≥3	14	32	0
Pl TO h	1.08	0.11	10.19	≥3	26	125	0
Pl TO l	1.31	0.12	9.42	≥10	26	158	1755 (3)
Total	33.36	3.42	10.25	≥53	282	1179	8191 (16)

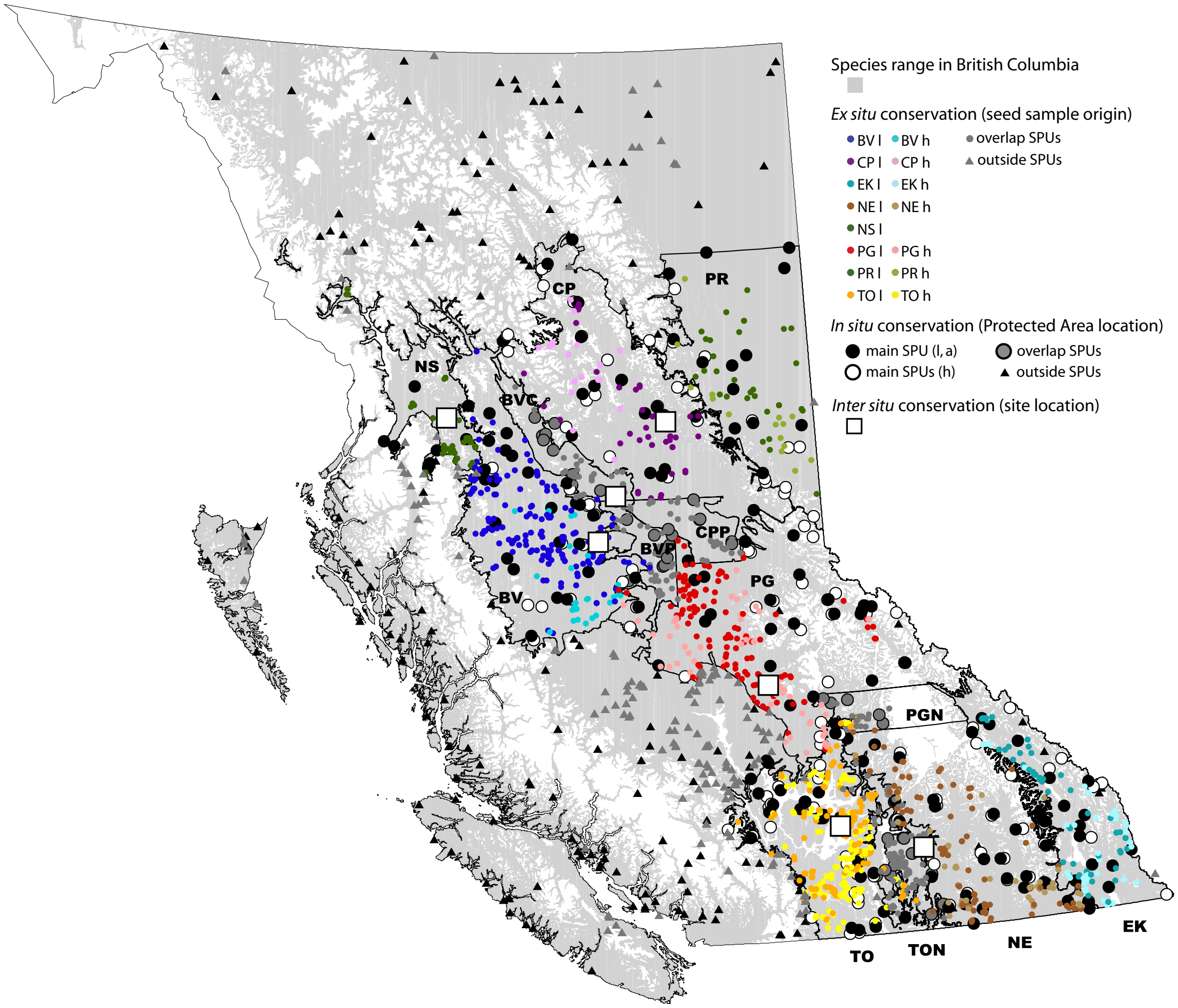

FIGURE 5 *Map of* in situ, inter situ, *and* ex situ *protection for lodgepole pine in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

10 Pw – WESTERN WHITE PINE (*PINUS MONTICOLA* DOUGL. EX D. DON)

10.1 Overview

Western white pine is found at very low densities over its historic range, since populations have declined sharply over the last century (Maloy 1997). Although this species is fairly widespread along the Coast and in the Interior up to approximately 52°N, mortality due to the introduced pathogen *Cronartium ribicola* J.C. Fisch. ex Rabenh., which causes white pine blister rust, has decimated trees and regeneration in areas that historically harboured mature stands throughout much of the Interior. These white pine forests have converted to stands of alternative species with relatively sparse distribution of individual white pine trees. Remaining individuals may have been subject to high selection pressure for blister rust resistance, and many either appear to be tolerant, to be resistant, or to suffer mortality as the pathogen occupies a site (Sniezko et al. 2004). Blister rust resistance has been the focus of intensive selection, breeding, and testing programs throughout the U.S. Inland Empire and Intermountain Regions by the USDA Forest Service (McDonald et al. 2004) and throughout its British Columbia range by the British Columbia Forest Service and the Canadian Forest Service over the past 60 years, with considerable gains emerging in the form of durable, highly resistant planting stock that can be used for reforestation (Hunt 2004a). Material in the British Columbia improvement program includes selections from Idaho that have shown extremely robust resistance via a variety of putative single-gene and polygenic mechanisms (Hunt 2004b).

As a result of blister rust and limited availability of rust-resistant planting stock, western white pine is not widely planted in British Columbia. Annually, seedlings planted vary from 0.8 to 1.3 million, typically as an alternative to more root rot-susceptible species in disease centres (e.g., *Armillaria* spp.) or where plantations have failed due to deer browse. There are two disjunct ranges of western white pine in British Columbia: coastal and interior, each represented by one SPU. Populations from both are highly plastic in terms of phenotypic and adaptive traits, and relatively genetically homogeneous within these zones (more zones have been identified in the U.S.). Seed transfer can thus occur safely across wide geographic and elevational distances without maladaptation affecting growth and health; however, adaptation to environmental stress appears to be robust only for trees transferred from the Interior to the Coast and not in the opposite direction (Meagher and Hunt 1999). Trees typically mature around age 10 to 15, producing large winged seed that provides valuable food for birds and rodents. This attractive tree can grow extremely rapidly on good sites, and often outperforms cohorts of other species at higher elevations due to its snow-shedding flexible branches, good freezing tolerance, and high photosynthetic leaf area. The taproot system also increases its capacity to withstand adverse environmental conditions, but optimal habitats are typically mesic to moister and mesotrophic to richer.

This species produces valuable strong, relatively light and durable white wood that can be used in a wide range of products from lumber to veneer to furniture, panelling, and pulp. Limited supply, however, has constrained economic opportunities to niche markets and small mill runs, so logs in storage must be submerged or treated to prevent staining and checking to capture the full value. Harvest is limited and often full value is not recovered from these logs due to their scattered distribution in stands, where they are treated as whitewood in SPF (spruce–pine–fir) mixtures. Reported harvest volumes over the past 5 years range from a high of 132,000 m^3 in 2002/03, declining to 62,000 m^3 in 2006/07.

10.2 *In situ* protection levels

Both the coastal and interior SPUs of western white pine are somewhat under-represented in the PA network, hovering around 9%, below the provincial target of 12% (Table 11). Estimates of PAs containing Ne >1000 also identified gaps for this species in the Maritime SPU. The botanical inventory estimated a minimum of three PAs with sufficient population size, but the forest inventory only could confirm two. Conversely, for the interior (Kootenay–Quesnel) SPU, the botanical inventory identified only one candidate PA, but the Forest Cover inventory identified 23 (Table 11). Ground-truthing is required to substantiate protection levels for both areas, given the wide discrepancy between the estimates and difficulty of identifying this species in inventory data. Many outlying populations identified by Yanchuk and Lester (1996) have since been incorporated into new protected areas. Several populations were identified within PAs that lie outside the Maritime SPU, bordering on what corresponds to the Submaritime SPU for other coastal species, ranging from the Skagit Valley to northwest of Pemberton (Figure 6). The drier interior populations, as well as those in the CDF zone, also appear to be under-represented within the SPU. This may reflect the relatively poor growth of western white pine in these areas due to environmental limitations (e.g., drought), leading to sparse populations; in the CDF this also is likely due to habitat fragmentation and small PAs.

The scattered distribution and limitations associated with the typical scale of photo interpretation (1:20,000 or smaller) for forest cover is likely the cause of these discrepancies. On air photos with scales of 1:5,000 or 1:10,000, experienced mappers could identify white pine canopies, but these would likely be missed unless detailed field plot data were available to confirm the presence of this species. Cruise check plots might overestimate or underestimate cover of western white pine in different ecosystem types, depending on local abundance.

10.3 *Inter situ* protection levels

As a result of the ongoing breeding program for blister rust resistance, *inter situ* trials have been designed to represent aggregates of large collections of provenances from throughout the species' range, emphasizing selected rust-resistant or rust-tolerant individuals and their progeny. Although this information is available, the plasticity and genecological patterns of this species do not warrant population-based management, as with most other species. Many individuals within the British Columbia *inter situ* installations are of U.S. origin, particularly Idaho, and contain many durable rust-resistant or rust-tolerant individuals and families from the long-standing tree improvement program of the USDA Forest Service. Many of the original 318 coastal and 150 interior selected plus trees for this program from British Columbia and locations throughout the U.S. have succumbed to the disease in controlled screenings, revealing their initial canker-free status to be due to escape rather than genetic resistance. Testing is ongoing to isolate inheritance mechanisms for the various phenotypes of rust resistance and rust tolerance.

10.4 *Ex situ* protection levels

A wide variety of provenances are represented in *ex situ* seed collections with over 1000 viable seeds, but these are largely comprised of the core populations from the coastal and interior regions, with peripheral populations under-represented (e.g., the MS, IDF, and CDF zones, and the entire western British Columbia Rocky Mountain valleys from McBride to Akamina-Kishinena Provincial Park) (Figure 6). The Maritime SPU is particularly poorly represented geographically. However, given the inherent plasticity and distribution of genetic variation in the species, the specific locations of collections may not be a concern. Any future seed collections should focus on putatively resistant and tolerant genotypes, particularly resistant families obtained from the U.S. breeding programs under germplasm-sharing agreements, and should be conducted by personnel trained in blister rust identification who can discern host reactions.

10.5 Conservation status summary

In situ conservation of western white pine requires ground-truthing due to the difficulty in mapping this sporadically distributed species and likelihood of mortality due to blister rust in the interval between inventories. The Maritime SPU, in particular, has insufficient PAs encompassing an adequate number of individuals. Representation of indigenous populations in *inter situ* trials also must be revisited: many individuals originally selected for inclusion in the British Columbia tree improvement program have died and census and effective population sizes have been reduced due to mortality. Although there is adequate seed available for *ex situ* conservation, the range of populations in those collections is narrow, mostly comprising the core populations within each SPU. Since western white pine is an adaptive generalist with no apparent clines or genotype–environment interaction within these SPUs, this may not pose an immediate problem, but the likelihood of capturing rare alleles that may confer blister rust resistance or tolerance is higher over a wider sampling area, including the U.S.

TABLE 11 *Conservation status of western white pine including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Pw KQ	4.57	0.41	9.00	≥1	23	55	300 (6)
Pw M	6.54	0.61	9.32	≥3	2	30	936 (2)
Total	11.11	1.02	9.18	≥4	25	85	1236 (8)

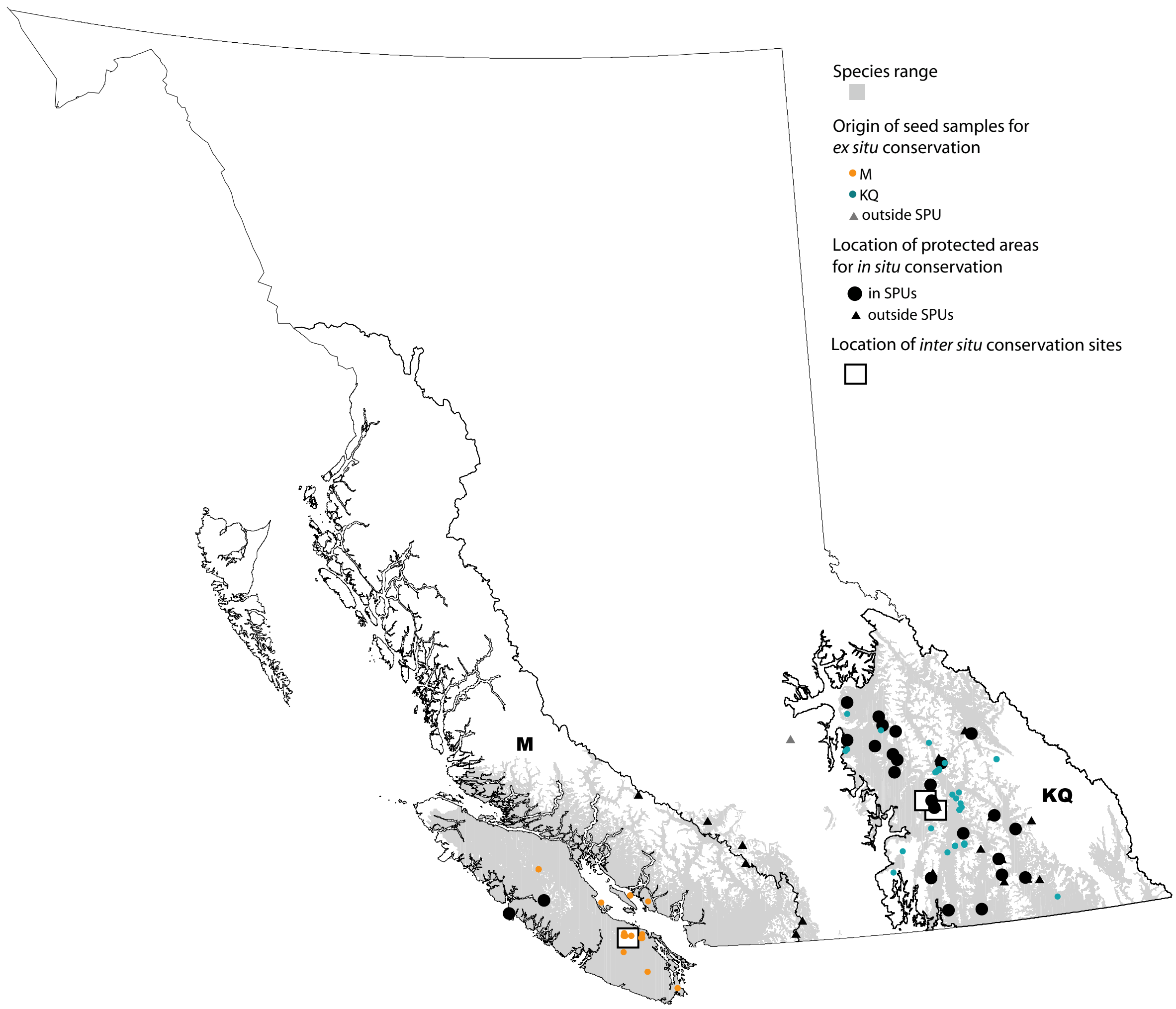

FIGURE 6 *Map of* in situ, inter situ, *and* ex situ *protection for western white pine in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

11 Ss – SITKA SPRUCE (*PICEA SITCHENSIS* (BONG.) CARR.)

11.1 Overview

Sitka spruce is restricted to lower-elevation coastal habitats below 700 m, including all coastal islands and Haida Gwaii. This species prefers well-drained floodplains with gravelly, sandy soils, but also occurs in coastal forested swamps and sites with fluctuating water tables that retain fresh to moist soil moisture status during the growing season. On productive sites, Sitka spruce can grow to over 90 m tall and several metres in diameter. It requires a mineral seedbed for regeneration, typically exposed as a result of windthrow and streambank erosion or deposition. The species hybridizes with hybrid white spruce in the Nass–Skeena transition zone to montane elevations, and this region is managed as two SPUs. These trees are intermediate in character between interior and Sitka spruce with respect to cold tolerance, growth, phenology, productivity, and ecological niche.

All low-elevation coastal Sitka spruce habitat is managed as a single Maritime SPU. Haida Gwaii does not currently have the white pine shoot tip weevil (*Pissodes strobi* Peck), and also has relatively high levels of genetic diversity compared to other populations of spruce (Gapare et al. 2005; Mimura and Aitken 2007). This weevil kills the current leader, whereupon a lateral takes over, causing excessive branching and poor stem form, affecting height growth. The weevil generally attacks trees between 3 and 15 m tall, which offer a balance between leader nutrition and height for the weevil to ascend after overwintering in the forest floor. Sitka spruce is also susceptible to windthrow as a result of its shallow root system, and is highly susceptible to stem damage from snow. It has relatively low resistance to freezing in its maritime habitat, and the thin bark also provides little protection from fire, which is infrequent in Sitka spruce habitat. Sitka spruce has a pronounced clinal trend in most adaptive traits, restricting seed transfer by latitude and elevation (Xu et al. 2000; Mimura and Aitken 2007).

As a result of weevil damage, Sitka spruce has been eliminated from most artificial regeneration programs despite its desirability for harvesting, since trees attacked by weevil often fail to meet free-growing criteria. This is causing a shift in the species composition across coastal landscapes as cutblocks are being converted to a different species mixture than that harvested (Forest Practices Board 2008). Harvest volume records often do not distinguish between Sitka and Sitka–hybrid spruce, except by geographic area, reflecting a steep decline over the past 5 years from 2.5 million m^3 to 0.4 million m^3 annually with planting declining from 1.3 million to 0.5 million seedlings. The British Columbia Forest Service has been intensively testing and breeding naturally weevil-resistant populations of Sitka spruce (King et al. 2004). Two main populations have been found to contain resistant individuals, with the resistance highly localized to the Qualicum River watershed of eastern Vancouver Island and the Maple Ridge area of the Lower Mainland, and not found elsewhere despite extensive searching. Resistance appears to be largely a function of resin canals that pitch out weevil attacks either as a result of naturally high levels of resin canals or an induced mechanism that causes the trees to produce resin under stress; biochemical mechanisms are under investigation. Sitka-hybrid white spruce in the Nass and Skeena Valleys show higher natural resistance levels than pure Sitka spruce, and this may be attributed largely to sclereid cells (in combination with resin canals), which have harder cell walls and physically resist weevil attack (King and Alfaro 2009). Weevil-resistant seed is available for reforestation, but must be deployed on appropriate sites and in mixtures with susceptible genotypes to provide durable resistance.

Sitka spruce has wood that is light and strong, commanding high prices. It is suitable not only for structural timber, but also for woodworking and high-value applications such as sounding boards for pianos and guitar components. Spruce is typically logged and sorted with pine and fir in an SPF grade mix, but valuable old growth is generally sold at auction for value-added products. The shallow roots create butt swell, and branches are often retained relatively low on the bole in more open-grown stands.

11.2 *In situ* protection levels

Less than 10% of the Maritime SPU is protected. There are, however, many protected areas with Ne ≥1000, and more protected areas were added recently under the North and Central Coast Land Use Planning process (not quantified here). Protected areas also occur in areas with the resistant populations; even if Ne in these areas is <1000, they are valuable areas for long-term genetic conservation. Locally, protection of sufficiently large populations in the Georgia Lowlands region is deficient (also see Yanchuk and Lester 1996), and the prevalence of private lands and the highly disturbed nature of the ecosystems in the area make it unlikely that adequate conservation of those populations could occur *in situ*. Only 7% of the Nass–Skeena SPU is within protected areas, but the Submaritime SPU has 13% of the area in protected areas (Table 12). Both of these SPUs have adequate protection based on number of populations with Ne ≥1000, but the botanical inventory estimated only two areas in the Nass–Skeena as likely candidates. This discrepancy warrants field confirmation. Although there has been a substantial amount of logging in these areas, much of the terrain is remote and steep, making operations economically marginal at this time. Consequently, although there are neither many nor large protected areas, natural populations may remain intact over much of the Sitka–hybrid white spruce SPUs.

11.3 *Inter situ* protection levels

Primary *inter situ* trials contain material from sources adapted to each SPU, and incorporate a fairly wide range of provenances permitted under current seed transfer guidelines (Snetsinger 2004). Several trials include F1 progeny, as well as genotypes and sites on Haida Gwaii where selection pressures differ because there are no weevils present, and programs focus on growth potential. The British Columbia program has focussed on selecting and breeding genotypes resistant to the shoot tip weevil, and crosses were designed primarily to capture variation and durability in resistance mechanisms. No trials were designated as primary *inter situ* Sitka–hybrid white spruce trials, although many other trials contain a range of provenances from these areas. The extremely sharp clines in the Nass–Skeena and Submaritime SPUs likely do not support establishing such trials at this time, as forest managers use local seed and may also use superior (non-local) provenances within permitted areas.

11.4 *Ex situ* protection levels

There is adequate *ex situ* conservation for seed from the various SPUs for both Sitka and Sitka–hybrid white spruce (Table 12), but higher-elevation (i.e., MH zone) Sitka spruce is not well represented and additional seed collection is required from the ESSF, MH, and MS zones. Documentation of Sitka–hybrid white spruce seedlots is frequently limited by earlier collections frequently labelling material as interior or white spruce. The core of the range of Sitka spruce (and its hybrids) is well represented in collections, but the periphery less so (Figure 7).

11.5 Conservation status summary

Sitka spruce is adequately conserved throughout its native range, and at lower elevations in *ex situ* collections. Sitka–hybrid white spruce appears adequately protected. Additional collections should be made for higher-elevation and peripheral populations of Sitka and Sitka–hybrid white spruce. Field confirmation of Sitka–hybrid white spruce *in situ* populations should also be undertaken to resolve the considerable differences in status between the shortfall in conservation indicated by the botanical inventory and the adequacy of conservation indicated from the forest cover analysis. There is adequate representation of both Sitka and Sitka–hybrid white spruce in protected areas, but *inter situ* trials have not been established for the Submaritime and Nass–Skeena SPUs.

TABLE 12 *Conservation status of Sitka spruce including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			*In situ*		*Ex situ*	*Inter situ*
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Ss M	8.42	0.80	9.55	≥10	63	52	1326 (13)
Sxs NS	0.99	0.07	7.11	≥2	7	27	0
Sxs SM	4.05	0.53	13.00	≥5	21	85	0
Total	13.46	1.40	10.40	≥17	91	164	1326 (13)

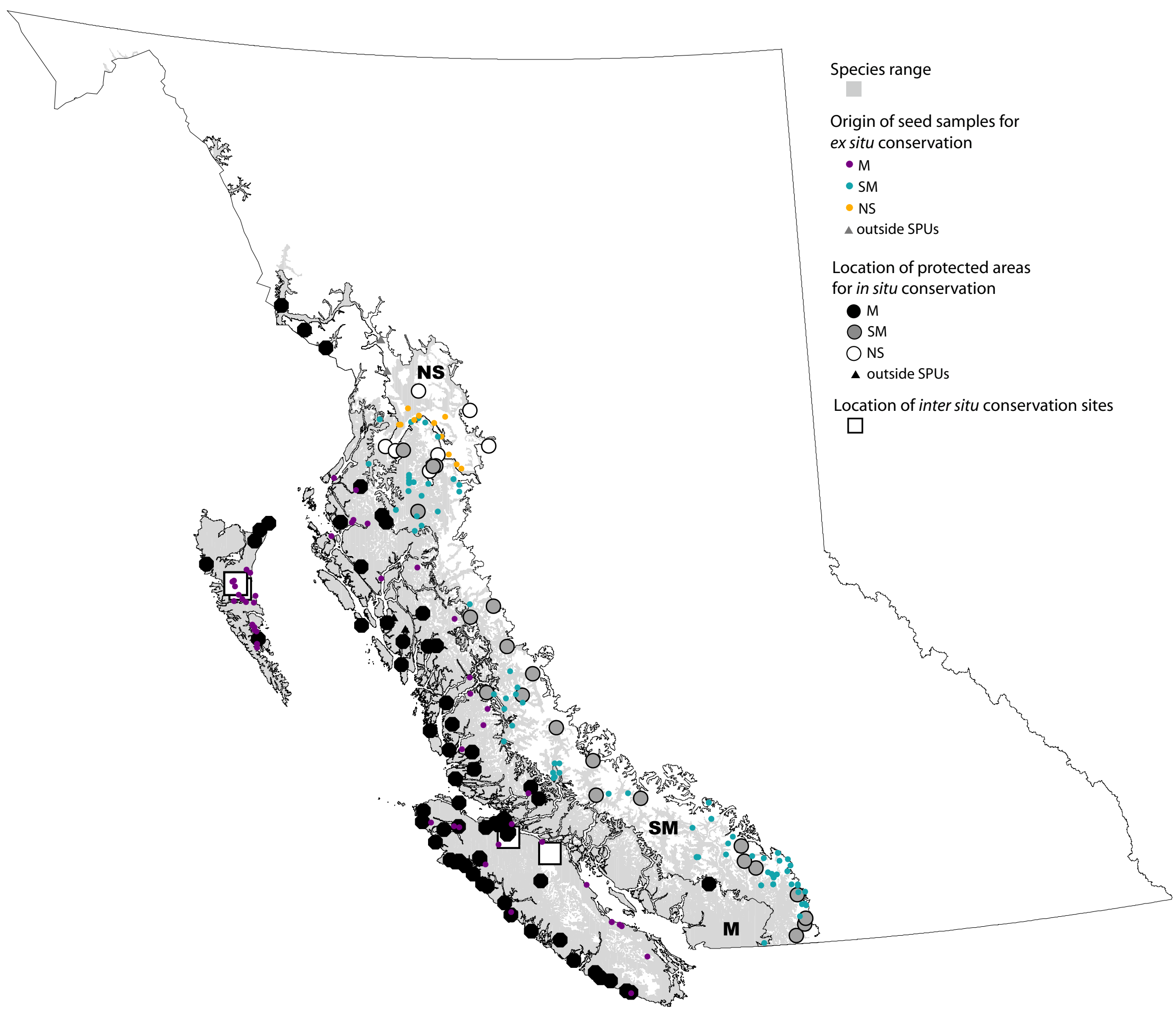

FIGURE 7 *Map of* in situ, inter situ, *and* ex situ *protection for Sitka and Sitka–hybrid white spruce in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

12 Sx – HYBRID WHITE SPRUCE (*PICEA GLAUCA* (MOENCH) VOSS, *P. ENGELMANNII* PARRY EX ENGELM.), AND HYBRIDS

12.1 Overview

Hybrid white spruce, comprising white spruce, Engelmann spruce, and their hybrids, is a major commercial species complex that is managed as a single "species" throughout much of British Columbia. It occurs across a diverse group of biogeoclimatic zones, and is intermediate in quantitative traits and ecological tolerances between the component species, depending on the proportion of each species' genes within a population. Typically a later seral species, it thrives under a pioneer canopy of aspen (*Populus tremuloides* Michx.) or lodgepole pine, eventually forming a significant component of climax stands throughout a wide range of ecosystems. In old forests, abundant lichen accumulating on branches and bark provides key winter forage for ungulates. Hybrid white spruce is adapted to habitats ranging from montane forests up to timberline to poorly drained lowlands. In its boreal forest habitat, this species is subject to large, moderately infrequent, stand-replacing patchy wildfires that most often convert the landscape to lodgepole pine, with aspen in riparian areas and grassland ecotones.

Major threats to this species in British Columbia include the spruce beetle (*Dendroctonus rufipennis* Kirby), a bark beetle with similarities to the mountain pine beetle that attacks mature stands. Adelgid species cause dieback and defoliation. Hybrid white spruce is susceptible to the white pine shoot tip weevil that damages the leader and affects free-growing status and merchantability. *Armillaria* also attacks this species, as do a range of other pathogens. Spruce has thin bark, which makes it susceptible to damage by fire and mechanical injury. The shallow root system is susceptible to windthrow, root rot, and soil compaction.

Hybrid white spruce represents the second largest planting program in British Columbia (after lodgepole pine): 55 to 64 million seedlings are planted, and 10 to 13 million m^3 is harvested annually. The major trait for tree improvement for hybrid white spruce is growth and yield, with weevil resistance an important secondary trait. Wood quality and stem form are also considered in the selection process. The wood is strong and durable, and typically has small but fairly abundant tight and loose knots, depending on stand density. It is light in colour and marketed with SPF white wood for dimensional and structural lumber, oriented strandboard, and veneer, and occasionally for pulp. Hybrid white spruce has not been subject to the same specialty product development as Sitka spruce.

12.2 *In situ* protection levels

For the most part, hybrid white spruce is well protected across its range. There are many SPUs with sufficient coverage, but protection levels vary considerably. Two SPUs were identified based on the botanical inventory as having fewer than three protected areas with Ne >1000, but when analyzed using the forest inventory, one had 16 and one had three; additional sampling to ascertain frequency or abundance was also recommended by Yanchuk and Lester (1996). These populations should be ground-truthed for verification. In terms of the proportion of each SPU falling within protected areas, eight of the 10 SPUs were below 12% (Table 13). The lowest, Peace River low, had only 2% of its area protected; Prince George low (3%), Thompson–Okanagan low (5%), and Nelson low (6%) were also markedly underprotected. In the

Thompson–Okanagan low SPU, the Birch Islands populations have been identified as ecologically and commercially significant populations in high-productivity habitat that is not currently protected in an area dominated by private land ownership. Nevertheless, all of these SPUs had sufficient population sizes within protected areas to be sustained over the long term.

12.3 *Inter situ* protection levels

All SPUs for hybrid white spruce have adequate *inter situ* installations, except the Thompson–Okanagan SPUs, which will be established when second-generation material is available (within the next several years); the Nelson SPUs, in addition to the primary trials, have locally adapted material in adjacent trials that were established prior to changing SPU boundaries (Table 13). Transitional SPUs that allow seed from adjacent areas to be deployed in climatically suitable habitats are widespread in the hybrid white spruce program. Extensive orchards for seed production contain large collections of individuals and their progeny from the core areas of selected SPUs.

12.4 *Ex situ* protection levels

Hybrid white spruce grows across a broad area and wide range of habitats, and is used extensively in reforestation. There are few *ex situ* collections from many of the boreal (SBS, SBPS, and SWB) BGC zones that lie mostly within the Peace River high and low SPUs, or from areas outside of current SPUs that support major populations of this species complex (Figure 8). Intensive forest management has recently expanded northward with accelerated resource development in the area, coupled with projections from climate change, leading to the potential to create additional SPUs in these boreal zones. The Peace River high SPU has only two operational seedlots with >1000 viable seeds in storage (Table 13). Although outside the jurisdiction of British Columbia, Alberta has genetic resource programs that contain seed adapted to these areas that may be available if needed. It is not recommended that additional *ex situ* collections be made at this time, but the status should be re-evaluated periodically given the factors discussed above.

12.5 Conservation status summary

Hybrid white spruce is moderately well protected in the various SPUs, but in areas that are the focus of intensive forest harvesting and various land-intensive developments (e.g., Prince George high, Thompson–Okanagan low), the species is under-represented in the proportion of area protected. The only SPU identified as deficient in protection based on the forest inventory was Peace River high, which was also under-represented in *ex situ* collections at the TSC. Central British Columbia populations have the highest numbers of genotypes represented in *inter situ* trials, with most at only one primary and one backup site. This widespread species is affected by bark beetles, wildfire, and site moisture regime, and is expected to experience major shifts in its range as a result of climate change (Hamann and Wang 2006). Maintaining a full suite of genetic resources for this species is very important to retain the full potential for managing its genetic resources over the medium to long term.

TABLE 13 *Conservation status of hybrid white spruce including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Sx BV h	1.86	0.35	18.86	≥1	1	2	0
Sx BV l	2.26	0.36	15.82	≥1	16	74	679 (1)
Sx EK	1.61	0.13	8.07	≥3	14	59	421 (1)
Sx NE h	1.40	0.13	9.64	≥5	21	58	660 (1)
Sx NE l	2.11	0.12	5.65	≥10	32	125	304 (1)
Sx PG h	2.38	0.26	11.04	≥5	23	35	1237 (2)
Sx PG l	6.97	0.22	3.22	≥10	45	169	2500 (4)
Sx PR h	0.59	0.05	8.80	0	3	2	874 (5)
Sx PR l	11.65	0.26	2.20	≥10	29	48	555 (1)
Sx TO h	2.98	0.38	12.79	≥10	33	66	0
Sx TO l	4.96	0.25	4.97	≥10	25	48	0
Total	36.91	2.16	5.85	≥64	241	684	7230 (16)

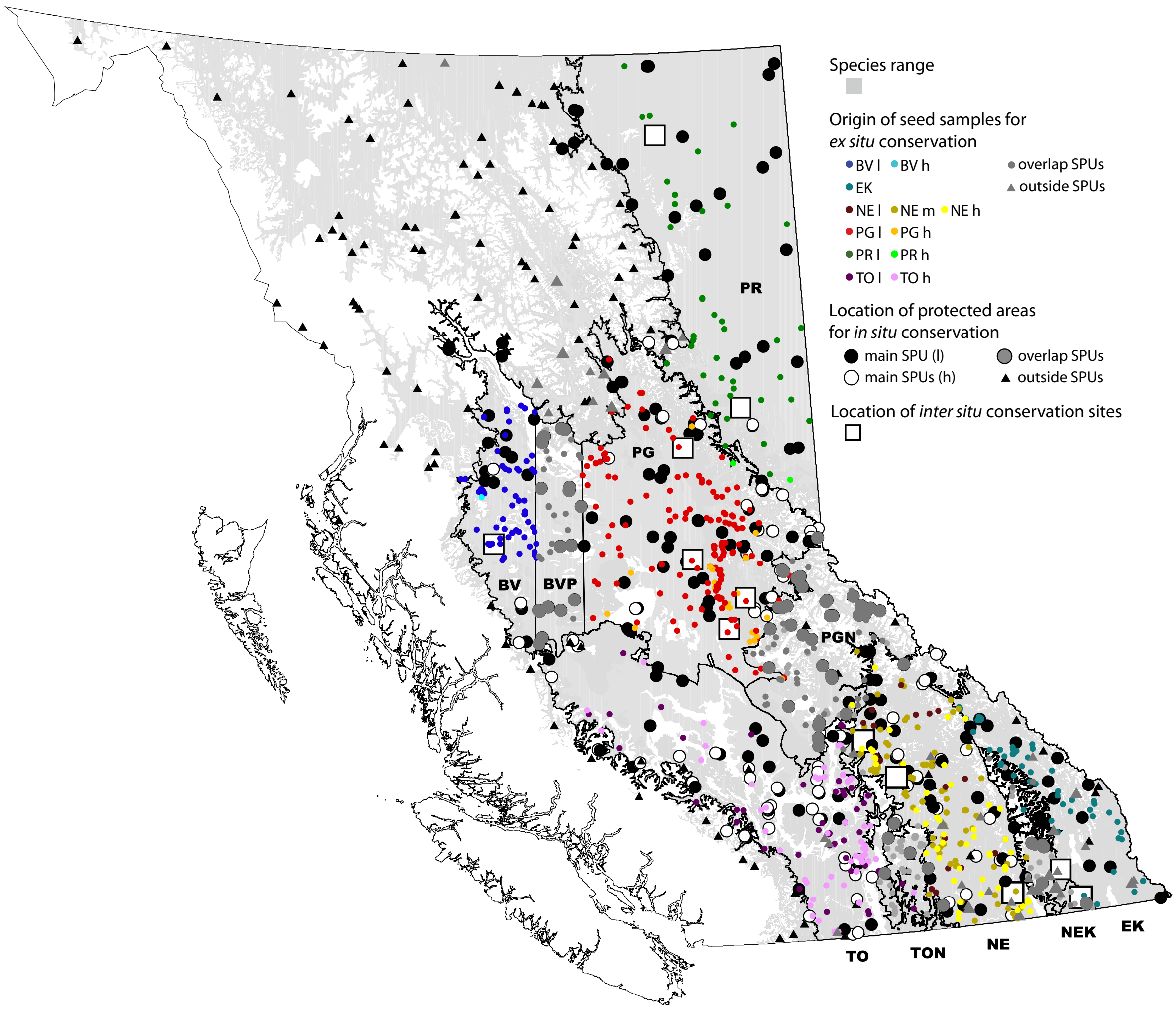

FIGURE 8 *Map of* in situ, inter situ, *and* ex situ *protection for hybrid white spruce in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

13 Yc – YELLOW-CEDAR (*CHAMAECYPARIS NOOTKATENSIS* (D. DON) SPACH)

13.1 Overview

Yellow-cedar occupies montane sites in southern British Columbia, decreasing in elevation to sea level on the north Coast, where it is most common in hypermaritime blanket bogs. Its habitat often has high snowpacks, to which its flexible, drooping branch habit is well adapted. Its distribution encompasses the Coast, including Haida Gwaii, with a disjunct, genetically depauperate population in the southern Kootenays. This species requires cool, moist conditions for successful reproduction in the wild, and does not reach reproductive maturity in typical conditions until approximately age 20 to 25. The likelihood of suitable conditions occurring throughout the reproductive window for successive years is low, and seed set and viability are very low. It can reproduce asexually by layering. Currently the species is propagated for reforestation using rooted cuttings and wild-stand seed collections, but seed orchards are being established for operational use. Optimal orchard management and induction techniques are being developed. There is only one SPU, the Maritime, that follows the boundaries described for other coastal species.

This species has few natural pests that cause serious economic damage. It is, however, susceptible to abiotic damage from drought, winter desiccation, sunscald, and flooding. Its relatively thin bark provides little protection from fire, but fire return intervals are infrequent in the CWH and MH zones that comprise the majority of yellow-cedar habitat. Trees growing on flooded sites often develop a characteristic multi-stemmed candelabra form, rendering them unmerchantable. Stands are also frequently disturbed by mass wasting on unstable slopes. At the northern edge of its range in coastal Alaska, yellow-cedar is suffering from widespread decline, signified by poor vigour and high mortality. Many studies over the past several decades have investigated a range of potential causes. In these peripheral populations the species appears maladapted to the climatic and environmental extremes due to adaptational lag associated with postglacial colonization and migration, with pronounced decline at the lower limit of seasonal snowpack (D'Amore and Hennon 2005; Hennon et al. 2005, 2006).

The wood of yellow-cedar has very high value for woodworking, structural timbers, veneer, finishing, cabinetry, and artisan woodworking. It is light yellow, with relatively small knots, little to no decay, and high workability. Drawbacks include spiral grain, taper and butt swell, and tendency of large (old-growth) boles to shatter when felled. Helicopter logging is currently common in valuable stands. Five-year data reveal provincial annual harvest levels of from 0.6 to 1 million m^3, and replanting at 0.9 to 1.6 million seedlings, reflecting its limited distribution and niche market. Reforestation of this species is limited by stock availability and relatively slow growth compared to other preferred species, where licensees would often prefer an alternative species that would reach free-growing more quickly.

13.2 *In situ* protection levels

Yellow-cedar in the Maritime SPU is well represented *in situ* with 12% of the SPU protected, including populations with Ne >1000 throughout (Table 14). Recent additions to the north and central Coast have increased protection in areas identified by Yanchuk and Lester (1996). The interior population, however, is not well protected. While there is a key ecological reserve (Evans Lake Ecological Reserve) in the area containing stands of mature yellow-cedar (Figure 9), Ne is estimated to be below 1000. Preliminary studies have indicated little population genetic differentiation in this isolated site, however, so it may not be possible to achieve Ne of 1000 or a census population of 5000 (J. Russell, B.C. Min. For., Res. Br., unpublished data). A microsatellite study found average genetic diversity and a range of outcrossing rates at a nearby population which was being harvested (Ritland et al. 2001). Ground-truthing is required for protected areas in the interior portion of the range of yellow-cedar.

13.3 *Inter situ* protection levels

Yellow-cedar is adequately represented in *inter situ* trials, with Ne >150 in replicated sites (Table 14). Considering the limited scope of deployment at this time, adding further individuals or families is not a current priority.

13.4 *Ex situ* protection levels

Populations within the Maritime SPU are not adequately represented in *ex situ* seed collections. Although there are 23 samples of >1000 viable seeds at the TSC, all samples originate from south of 50°N, the vast majority of which are from Vancouver Island (Figure 9). Additional samples are needed from the remainder of the range all along the Coast, including Haida Gwaii, and especially from disjunct interior populations. An estimate of Ne captured in *ex situ* archives through clone banks, progeny tests, and research seed collections is <1000, including hedge orchards for steckling production at coastal and interior sites.

13.5 Conservation status summary

Yellow-cedar is likely adequately protected throughout its range *in situ*; however, ground-truthing of interior PAs is required to estimate the protection level in this disjunct population. *Inter situ* installations are also adequate at present. Although there are some collections from interior populations, additional sampling is required for *ex situ* collections all along the central and north Coast and on Haida Gwaii, and comprehensive documentation of the interior populations is necessary.

TABLE 14 *Conservation status of yellow-cedar including: 1) the estimated number of protected areas (PAs) expected to contain an effective population size (Ne) of 1000 breeding individuals based on botanical inventory (BI) and using forest inventory (FI) data; 2) the number of stored seed samples with at least 1000 viable seeds each; and 3) effective population size of individuals at primary* inter situ *test sites with number of sites in parentheses.*

	SPU size, number of PAs, and percent protected			***In situ***		***Ex situ***	***Inter situ***
SPU	Area (ha × 10^6)	PA area (ha × 10^6)	Percent in PA	Estimated (BI) # PAs with Ne >1000	Confirmed (FI) # PAs with Ne >1000	# samples with ≥1000 viable seeds	Estimated Ne at primary sites (# sites)
Yc M	5.01	0.60	11.95	≥5	40	23	156 (4)
Total	5.01	0.60	11.95	≥5	40	23	156 (4)

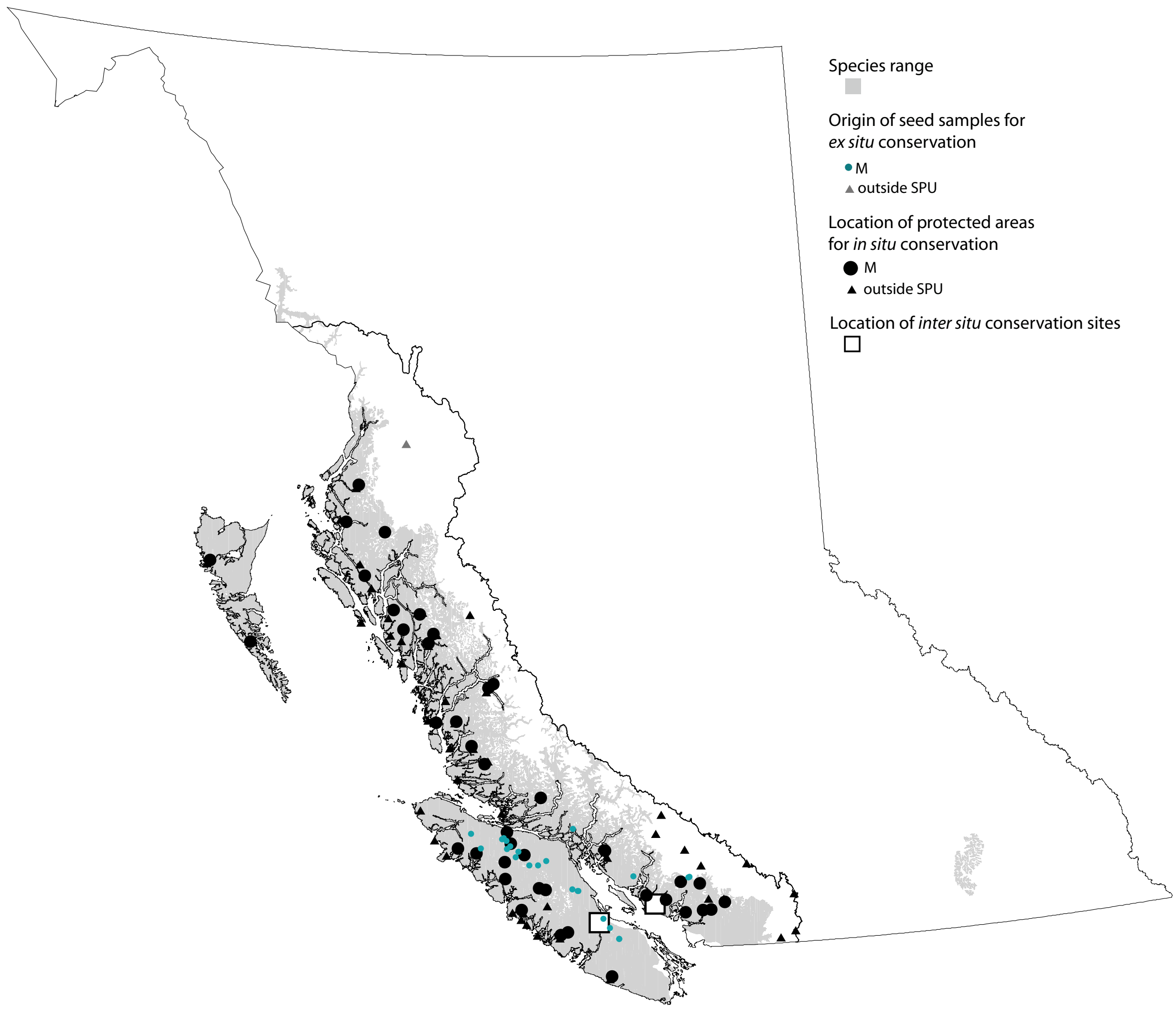

FIGURE 9 *Map of* in situ, inter situ, *and* ex situ *protection for yellow-cedar in British Columbia. Data are plotted if protected area populations are estimated to contain an effective population size (Ne) of ≥1000;* ex situ *collections contain ≥1000 viable seeds.*

B.C. Ministry of Forests (BCMOF). 2003. 2002/03 Annual service plan report. Victoria, B.C.

________. 2004. 2003/04 Annual service plan report. Victoria, B.C.

________.2005. 2004/05 Annual service plan report. Victoria, B.C.

B.C. Ministry of Forests and Range (BCMFR) and Minister Responsible for Housing. 2006. 2005/06 Annual service plan report. Victoria, B.C.

________. 2007. 2006/07 Annual service plan report. Victoria, B.C.

Blixt, S. 1994. Conservation methods and potential utilization of plant genetic resources in nature conservation. In: Integration of conservation strategies of plant genetic resources in Europe. Int. Symp. Plant Genetic Resources in Europe. F. Begemann and K. Hammer (editors). Dec. 6-8, 1993, Gatersleben, Germany, Inst. Plant Genet. Crop Plan Res. (IPK), Inf. Cent. Gen. Resour. (IGR), and Cent. Agric. Documentation Inf. (ZADI), pp. 82-87.

Chourmouzis, C., A. D. Yanchuk, A. Hamann, P. Smets, and S. N. Aitken. 2009. Forest tree genetic conservation status report 1: *In situ* conservation status of all indigenous British Columbia species. Centre for Forest Conservation Genetics, Forest Genetics Council of B.C., and B.C. Min. For. Range, For. Sci. Prog. Victoria, B.C. Tech. Rep. 053. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr053.htm

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2006. COSEWIC's assessment process and criteria. COSEWIC, Ottawa, Ont. www.cosewic.gc.ca/pdf/assessment_process_e.pdf

D'Amore, D.V. and P.E. Hennon. 2005. Evaluation of soil saturation, soil chemistry, and early spring soil and air temperatures as risk factors in yellow-cedar decline. Global Change Biology 12:524–545.

deGrammont, P.C. and A.D. Cuarón. 2006. An evaluation of threatened species categorization systems used on the American continent. Conserv. Biol. 20:14–27.

Food and Agriculture Organization of the United Nations (FAO), Forest & Landscape Denmark (FLD), and International Plant Genetics Resources Institute (IPGRI). 2004. Forest genetic resources conservation and management. Vol. 1: Overview, concepts and some systematic approaches. ipgri, Rome, Italy.

Forest Practices Board. 2008. High retention harvesting and timber sustainability on the British Columbia coast. Spec. Investig. Rep. FPB-SIR-20. Victoria, B.C.

Gapare, W.J., S.N. Aitken, and C. Ritland. 2005. Genetic diversity of core and peripheral Sitka spruce (*Picea sitchensis* (Bong.) Carr) populations: implications for conservation of widespread species. Biol. Conserv. 123:113–123.

Hagle, S.K. 2006. *Armillaria* root disease: ecology and management. In: Forest insect and disease identification and management guide of northern and central Rocky Mountain conifer and hardwood. Forest Health Protection and State Forestry Organizations, U.S. Dept. Agric. North. Reg., State and Private Forestry, Missoula, Mont. Guide 11.1.

Hamann, A., S.N. Aitken, and A.D. Yanchuk. 2004. Cataloguing *in situ* protection of genetic resources for major commercial forest trees in British Columbia. For. Ecol. Manage. 197:295–305.

Hamann, A., P. Smets, A.D. Yanchuck, and S.N. Aitken. 2005. An ecogeographic framework for *in situ* conservation of forest trees in British Columbia. Can. J. For. Res. 35:2553–2561.

Hamann, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology 87:2773–2786.

Hennon, P., D. D'Amore, D. Wittwer, A. Johnson, P. Schaberg, G. Hawley, C. Beier, S. Sink, and G. Juday. 2006. Climate warming, reduced snow, and freezing injury could explain the demise of yellow-cedar in southeast Alaska, USA. World Resource Rev. 18:427–450.

Hennon, P. D. D'Amore, S. Zeglen, and M. Grainger. 2005. Yellow-cedar decline in the North Coast Forest District of British Columbia. U.S. Dept. Agric. For. Serv., Pac. N.W. Res. Stn., Portland, Ore. Res. Note PNW-RN-549. Portland, Oreg.

Hunt, R.S. 2004a. Blister-rust-resistant western white pines for British Columbia. Nat. Resourc. Can., Can. For. Serv. Info. Rep. BC-X-397.

Hunt, R.S. 2004b. Environmental and inoculum source effects on resistance of Idaho F2 western white pine in British Columbia. Can. J. Plant Pathol. 26:351–357.

International Union for Conservation of Nature and Natural Resources (iucn). 2001. IUCN red list categories and criteria, version 3.1. IUCN Species Survival Commission, Cambridge, U.K.

________. 2003. Guidelines for application of IUCN Red List criteria at regional levels, version 3.0. IUCN Species Survival Commission, Gland, Switzerland and Cambridge, U.K.

Jaquish, B., V. Ashley, G. Phillips, and B. Hooge. 2007. Interior Douglas-fir tree breeding program. In: 2006/2007 Forest Genetics Council of BC Tree Improvement Program project report. Beacon Hill Communications Group Inc. and K. Thomas (co-ordinators and compilers). B.C. Min. For. Range, Tree Improvement Branch. pp. 13–14.

King, J.N. and R.I. Alfaro. 2009. Developing Sitka spruce populations for resistance to the white pine weevil: summary of research and breeding program. B.C. Min. For. Range, Victoria, B.C. Tech. Rep. 50. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr050.htm

King J.N., R.I. Alfaro, and C. Cartwright. 2004. Genetic resistance of Sitka spruce (*Picea sitchensis*) populations to the white pine weevil (*Pissodes strobi*): distribution of resistance. Forestry 77:269–278.

Lande, R. and G.F. Barrowclough. 1987. Effective population size, genetic variation, and their use in population management. In: Viable populations for conservation. M.E. Soulé (editor). Cambridge Univ. Press, Cambridge, Mass.

Lipow, S.R. R.G. Johnson, J.B. St. Clair, and K.J. Jayawickrama. 2003. The role of tree improvement programs for *ex situ* gene conservation of coastal Douglas-fir in the Pacific Northwest. For. Genetics 10(2):111–120.

Maloy, O.C. 1997. White pine blister rust control in North America: a case history. Ann. Rev. Phytopathol. 35:87–109.

McDonald G.I., P. Zambino, and R. Sniezko. 2004. Breeding rust-resistant five-needle pines in the western United States: lessons from the past and a look to the future. IUFRO Working Party 2.02.15 Int. Conf. R.A. Sniezko, S. Samman, S.E. Schlarbaum, and H.B. Kriebel (editors). July 23-27, 2001, Medford, Ore. U.S. Dept. Agric. For. Serv., Rocky Mountain Res. Stn., Fort Collins. Colo. Proc. RMRS-P-32, pp. 28-49.

Meagher, M.D. and R.S. Hunt. 1999. The transferability of western white pine to and within British Columbia based on early survival, environmental damage, and juvenile height. West. J. Appl. For. 14:41–47.

Mimura, M. and S.N. Aitken. 2007. Adaptive gradients and isolation-by-distance with postglacial migration in *Picea sitchensis.* Heredity 99:224–232.

Morrison, D.J., M. Merler, and D. Norris. 1992. Detection, recognition, and management of *Armillaria* and *Phellinus* root diseases in the southern interior of British Columbia. Can. For. Serv. and B.C. Min. For., Victoria, B.C. FRDA Rep. 179.

NatureServe. 2008. NatureServe conservation status. www.natureserve.org/explorer/ranking.htm (Accessed August 4, 2008).

O'Connell, L.M., F. Viard, J. Russell, and K. Ritland. 2001. The mating system in natural populations of western redcedar (*Thuja plicata*). Can. J. Botany. 79(6):753–756.

Ritland, C., T. Pape, and K. Ritland. 2001. Genetic structure of yellow-cedar (*Chamaecyparis nootkatensis*). Can. J. Botany. 79:822–828.

Russell, J.H. and C.F. Ferguson. 2008. Preliminary results from five generations of a western redcedar (*Thuja plicata*) selection study with self mating. Tree Genetics and Genomes. Tree Genetics & Genomes 4:509–518.

Snetsinger, J. 2004 [with amendments to 2009]. Chief Forester's standards for seed use. B.C. Min. For., Victoria, B.C.

Sniezko R.A., A. Bower, and A. Kegley 2004. Variation in *Cronartium ribicola* field resistance among *Pinus monticola* and 12 *P. lambertiana* families: early results from Happy Camp. In: Breeding and genetic resources of five-needle pines: growth, adaptability, and pest resistance. IUFRO Working Party 2.02.15 Int. Conf. R.A. Sniezko, S. Samman, S.E. Schlarbaum, and H.B. Kriebel (editors). July 23-27, 2001, Medford, Ore. U.S. Dept. Agric. For. Serv., Rocky Mountain Res. Stn., Fort Collins. Colo. Proc. RMRS-P-32, pp. 28-49.

Spittlehouse, D.L. 2008. Climate change, impacts, and adaptation scenarios: climate change and forest and range management in British Columbia. B.C. Min. For. Range, Res. Br., Victoria, B.C. Tech. Rep. 045. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr045.htm

Xu, P., C.C. Ying, and Y.A. El-Kassaby. 2000. Multivariate analyses of causal correlation between growth and climate in Sitka spruce. Silvae Genet. 49:257–263.

Yanchuk, A.D. 2001. A quantitative framework for breeding and conservation of forest tree genetic resources in British Columbia. Can. J. For. Res. 31:566–576.

Yanchuk, A.D. and D.T. Lester. 1996. Setting priorities for conservation of the conifer genetic resources of British Columbia. For. Chron. 72:406–415.

Yanchuk, A.D., J.C. Murphy, and K.F. Wallin. 2008. Evaluation of genetic variation of attack and resistance in lodgepole pine in the early stages of a mountain pine beetle outbreak. Tree Genetics & Genomes 4:171–180.

Ying, C.C. and A.D. Yanchuk. 2006. The development of British Columbia's tree seed transfer guidelines: purpose, concept, methodology, and implementation. For. Ecol. Manage. 227:1–13.