# COSEWIC
# Assessment and Status Report

on the

# Whitebark Pine
## *Pinus albicaulis*

**in Canada**

**ENDANGERED**
**2010**


**COSEWIC**
Committee on the Status
of Endangered Wildlife
in Canada

**COSEPAC**
Comité sur la situation
des espèces en péril
au Canada

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# COSEWIC
# Assessment Summary

**Assessment Summary – April 2010**

**Common name**
Whitebark Pine

**Scientific name**
*Pinus albicaulis*

**Status**
Endangered

**Reason for designation**
This long-lived, five-needled pine is restricted in Canada to high elevations in the mountains of British Columbia and Alberta. White Pine Blister Rust alone is projected to cause a decline of more than 50% over a 100 year time period. The effects of Mountain Pine Beetle, climate change, and fire exclusion will increase the decline rate further. Likely, none of the causes of decline can be reversed. The lack of potential for rescue effect, life history traits such as delayed age at maturity, low dispersal rate, and reliance on dispersal agents all contribute to placing this species at high risk of extirpation in Canada.

**Occurrence**
British Columbia, Alberta

**Status history**
Designated Endangered in April 2010.

**COSEWIC**
**Executive Summary**

**Whitebark Pine**
*Pinus albicaulis*

## Species information

Whitebark Pine (*Pinus albicaulis*) is a five-needled pine, typically 5-20 m tall with a rounded to irregular crown. Its egg-shaped seed cones (5-8 cm long by 4-6 cm wide) are dark brown to purple and remain on the tree unless removed by animals. The seeds are large for a pine at 7-11 mm long, chestnut brown and wingless.

## Distribution

Whitebark Pine occurs in high-elevation forests in the mountains of western Canada and the USA. In Canada, it extends from the Canada-USA border to about 200 km north of Ft. Saint James in the Coast Mountains and to about 150 km north of Jasper in the Rocky Mountains. The range of the species in Canada extends over an area estimated to be 190,067 sq km or about 56% of its global range.

## Habitat

Whitebark Pine occurs at or close to treeline, forming both open and closed forests, often in association with Engelmann Spruce and Subalpine Fir. Regeneration occurs primarily on sites disturbed by fire or avalanche, which provide the open habitat required by this shade-intolerant species. Habitat quality is declining across its range due to fire exclusion and competition from other trees. Nearly all Whitebark Pine forest occurs on public lands.

## Biology

Whitebark Pine is a long-lived species, often living to more than 500 years and sometimes more than 1000 years. Cones are typically first produced at 30-50 years but no sizable crop is produced until 60-80 years and cone production is irregular with some years of no or very low production. The generation time (average age of trees) is approximately 60 years. Whitebark Pine is obligately dependent on Clark's Nutcracker to disperse seeds for regeneration. Cones do not open to release the seed, rather seeds must be removed by the bird and cached in the ground. The seeds are a rich food source and are used by many birds and mammals, including Black and Grizzly bears.

## Population sizes and trends

The number of mature Whitebark Pine trees in Canada is estimated to be about 200 million. Populations in Canada and the USA are declining due to the combined effects of White Pine Blister Rust, Mountain Pine Beetle, fire exclusion, and climate change. The population in Waterton Lakes National Park has been declining at 3.5%/year, which translates into a 97% decline within 100 years. In the Rocky Mountains of Alberta and British Columbia, the decline rate is 1.5%/year, which over 100 years is 78%. The estimated population decline in all of Canada is more than 50% over the next 100 years. Rescue from populations in the USA is not a realistic possibility given the extent and severity of threats there.

## Limiting factors and threats

Whitebark Pine is imminently and severely threatened throughout its range by four human-influenced factors: White Pine Blister Rust (an introduced species), Mountain Pine Beetle, fire exclusion, and climate change. Although each of these factors alone pose significant threats to Whitebark Pine, they interact and reinforce each other to further increase the severity of the impacts.

## Special significance of the species

Whitebark Pine is keystone species at the centre of a high-elevation network of plants and animals, enabling increased biodiversity. It provides food and habitat for numerous birds and mammals. It facilitates the establishment and growth of other plants in the harsh, upper subalpine environment and helps regulate snowpack and runoff, providing watershed stability. The seeds were used as food by Aboriginal peoples.

**Existing protection**

Whitebark Pine is globally assessed overall as *Vulnerable* (high risk of extinction in the wild in the medium-term future) by IUCN.

In Alberta, it has been assessed as *Endangered* and has been listed by the Minister of Sustainable Resource Development as *Endangered* under the Alberta Wildlife Act. This currently provides no legal protection but measures have been taken to ensure that, outside of protected areas, it is not inadvertantly harvested and that planning for harvesting, fire management, and Mountain Pine Beetle management takes it into account.

In British Columbia, it is ranked as S3? (Special Concern/Vulnerable) and is blue-listed. This provides no legal protection and Whitebark Pine has been harvested in some areas, although the extent is not clear. However, British Columbia government agencies have suggested voluntary conservation measures. About 26% of Whitebark Pine range in British Columbia occurs in protected areas.

In the USA, the Natural Resources Defense Council petitioned the US Fish and Wildlife Service in December 2008 to list Whitebark Pine as *Endangered* under the US *Endangered Species Act*.

# TECHNICAL SUMMARY

*Genus species: Pinus albicaulis*
Whitebark Pine — pin à écorce blanche
Range of occurrence in Canada: AB, BC

**Demographic Information**

| | |
|---|---|
| Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the used “plants with seedbanks” IUCN guideline IUCN guidelines(2008), age of 1st reproduction + median time to germination is being used) | 60 yrs |
| Is there an [observed, inferred, or projected] continuing decline in number of mature individuals? | Yes |
| Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]<br>Actual decline data are only available over the last approximately 10 years and varies across the range of the species with highest known Canadian declines from Waterton National Park (~70%). | Variable across range between 20 and 70% |
| [Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations]. | Unknown |
| [Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations]. | Likely >57% reduction |
| [Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future. (Calculated decline for a maximum of 100 years for Canadian population due to White Pine Blister Rust only.) | 57% based on White Pine Blister Rust + additional additive impacts of beetles and climate change on declines |
| Are the causes of the decline clearly reversible and understood and ceased? | No |
| Are there extreme fluctuations in number of mature individuals? | No |

**Extent and Occupancy Information**

| | |
|---|---|
| Estimated extent of occurrence | 190,067 km² |
| Index of area of occupancy (IAO) | 47,972 km² |
| Is the total population severely fragmented? | No |
| Number of “locations” (as per definition, in relation to threat)<br>(The current Mountain Pine Beetle epidemic can be considered a single threatening event that potentially affects all individuals. White Pine Blister Rust also can be considered this way. However, due to the widespread nature of the species’ range and the difficulty in even determining the number of populations, it is not possible to readily determine location based on IUCN guidelines.) | Unknown |
| Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?<br>Inferred and projected based on impact of White Pine Blister Rust. | Yes |
| Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy? | Yes |

| | |
|---|---|
| Is there an [observed, inferred, or projected] continuing decline in number of populations?<br><br>Although the number of populations has not been determined, clearly the numbers would decline considering the extensive and dramatic impact of White Pine Blister Rust that has been documented to date. | Yes |
| Is there an [observed, inferred, or projected] continuing decline in number of locations? | Unknown but probably |
| Is there an [observed, inferred, or projected] continuing decline in [area, extent and/or quality] of habitat? | Yes |
| Are there extreme fluctuations in number of populations? | No |
| Are there extreme fluctuations in number of locations (as per definition, in terms of threat)? | No |
| Are there extreme fluctuations in extent of occurrence? | No |
| Are there extreme fluctuations in index of area of occupancy? | No |

**Number of Mature Individuals (in each population)**

| **Population** | **N Mature Individuals** |
|---|---|
| Widespread populations | |
| Total estimated for Canada | ~200 million |

**Quantitative Analysis**

| | |
|---|---|
| Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years]. | None available |

**Threats (actual or imminent, to populations or habitats)**

| |
|---|
| White Pine Blister Rust, Mountain Pine Beetle, fire exclusion, climate change |

**Rescue Effect (immigration from an outside source)**

| | |
|---|---|
| Status of outside population(s)?<br>USA: declining | |
| Is immigration known or possible? | Unlikely |
| Would immigrants be adapted to survive in Canada? | Likely |
| Is there sufficient habitat for immigrants in Canada? | Unlikely within the existing range of the species |
| Is rescue from outside populations likely? | No |

**Current Status**

| |
|---|
| COSEWIC: Endangered (April 2010) |

**Status and Reasons for Designation**

| **Status:**<br>Endangered | **Alpha-numeric code:**<br>A3ce+4ace |
|---|---|
| **Reasons for designation:**<br>This long-lived, five-needled pine is restricted in Canada to high elevations in the mountains of British Columbia and Alberta. White Pine Blister Rust alone is projected to cause a decline of more than 50% over a 100 year time period. The effects of Mountain Pine Beetle, climate change, and fire exclusion will increase the decline rate further. Likely, none of the causes of decline can be reversed. The lack of potential for rescue effect, life history traits such as delayed age at maturity, low dispersal rate, and reliance on dispersal agents all contribute to placing this species at high risk of extirpation in Canada. | |

**Applicability of Criteria**

| |
|---|
| **Criterion A** (Decline in Total Number of Mature Individuals): Meets Endangered A3ce+4ace. Meets A3ce due to the projected decline of mature individuals of more than 50% over the next 100 years due to a decline in IAO and EO resulting from an introduced pathogen. Meets A4ace based on a past and projected decline of more than 50% in mature individuals where the observed impact of the introduced pathogen results in a decline in IAO and EO where the reduction and its causes have not ceased and are not reversible. |
| **Criterion B** (Small Distribution Range and Decline or Fluctuation): Not applicable. EO and IAO above thresholds. |
| **Criterion C** (Small and Declining Number of Mature Individuals): Not applicable. Population size of mature individuals exceeds thresholds. |
| **Criterion D** (Very Small or Restricted Total Population): Not applicable. Both population size of mature individuals and IAO above thresholds. |
| **Criterion E** (Quantitative Analysis): None available. |

**COSEWIC HISTORY**

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

**COSEWIC MANDATE**

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

**COSEWIC MEMBERSHIP**

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

**DEFINITIONS**
**(2010)**

| | |
|---|---|
| Wildlife Species | A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years. |
| Extinct (X) | A wildlife species that no longer exists. |
| Extirpated (XT) | A wildlife species no longer existing in the wild in Canada, but occurring elsewhere. |
| Endangered (E) | A wildlife species facing imminent extirpation or extinction. |
| Threatened (T) | A wildlife species likely to become endangered if limiting factors are not reversed. |
| Special Concern (SC)* | A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats. |
| Not at Risk (NAR)** | A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances. |
| Data Deficient (DD)*** | A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction. |

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada — Environnement Canada
Canadian Wildlife Service — Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

# COSEWIC Status Report

on the

# Whitebark Pine
*Pinus albicaulis*

**in Canada**

2010

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## SPECIES INFORMATION

### Name and classification

| | |
|---|---|
| Scientific name: | *Pinus albicaulis* Engelm. |
| Synonyms: | *Apinus albicaulis* (Engelm.) Rydb. |
| Common name: | Whitebark Pine, Scrub Pine, pin à blanche écorce |
| Family: | Pinaceae (pine family) |
| Major plant group: | Gymnosperms (conifers) |

Whitebark Pine is the only native North American stone pine (Lanner 1996). Within *Pinus* (family Pinaceae), Whitebark Pine is placed in the subgenus *Strobus*, which also contains other five-needled, white pines. Traditional taxonomic treatments (e.g., Little and Critchfield 1969, Price *et al*. 1998, Lanner 1990) placed Whitebark Pine in the subsection *Cembrae* with four Eurasian stone pines, separated from about 25 other white pine species of the subsection *Strobi*.

However, recent phylogenetic, DNA-based studies (Liston *et al*. 1999, 2007; Gernandt *et al*. 2005; Eckert and Hall 2006; Syring *et al*. 2005, 2007) show no evidence for monophyly in subsections *Cembrae* and *Strobi* and thus, merge the two into a new subsection *Strobus*. Whitebark Pine forms a clade with the 12 Eurasian species in *Strobus* plus Sugar Pine (*P. lambertiana*), another North American species. All other North American species in *Strobus* are more distantly related and not part of the clade containing Whitebark Pine (Syring *et al*. 2007). The stone pines, including Whitebark Pine, appear to have originated in Eurasia and to be a subset of *Strobus* species that have evolved specializations for seed dispersal by nutcrackers.

No subspecific taxa have been described for Whitebark Pine.

### Morphological description

In Canada, mature trees are typically 5-20 m tall, with a rounded to irregularly spreading crown and upswept branches, and may reach over 1 m in diameter at the base (Hosie 1979, Douglas *et al*. 1998). In many cases, genetically distinct individuals, which have arisen from a seed cache, give the appearance of multiple stems joined at or below the soil surface. The bark on younger trees is smooth light grey to white.

The needles are in bundles of five and are 4-7 cm long (Douglas *et al*. 1998). Seed cones (Figure 1a) are ovoid, 5-8 cm long and 4-6 cm wide, and dark brown to purple (Kral 1993). Seeds are 7-11 mm long, chestnut brown and wingless. The cones are at the outer ends of upper branches, remain closed at maturity and remain on the tree unless removed by animals. Pollen cones are ca. 10-15 mm long, typically scarlet coloured, and on new growth throughout the canopy (Kral 1993, McCaughey and Tomback 2001) (Figure 1b).

A

B

Figure 1. Whitebark Pine cones: seed cone (a) and cluster of pollen cones (b). Photos by G. J. Stuart-Smith.

Whitebark Pine can be confused with Limber Pine (*P. flexilis)* where the ranges of two species overlap in southwestern Alberta and southeastern British Columbia. Both species have five needles, often grow on rocky, exposed sites, and can have a similar canopy shape. Seed cones of Limber Pine are typically longer (7-15 cm vs. 5-8 cm for Whitebark Pine), are tan coloured vs. brown to purple, open to release the seeds and then drop from the tree vs. closed cones that remain on the tree unless removed by animals. The presence of cones on the ground beneath a tree is often the clearest evidence of Limber Pine. The pollen cones of Limber Pine are typically yellowish vs. scarlet for Whitebark Pine.

## Population spatial structure and variability

Genetic variation in Whitebark Pine has been assessed with allozymes and DNA analysis (Breuderle *et al*. 1998, Jorgensen and Hamrick 1997, Stuart-Smith 1998, Krakowski *et al*. 2003, Bower and Aitken 2008). Whitebark Pine generally shows a low level of variation at both the local population level and the species level (across populations), with a mean Fst of 0.058 (Breuderle *et al*. 2001, Bower and Aitken 2008). Local populations typically contain at least 90% of the species level diversity (Jorgensen and Hamrick 1997) and the majority of genetic diversity is due to differences among individuals within a local population (Breuderle *et al*. 2001).

There is some evidence of weak geographic differentiation in genetic markers among the Rocky Mountain, Coast-Cascade and Sierra Nevada portions of the species range (Breuderle *et al*. 2001, Richardson *et al*. 2002) but this constitutes a small portion of the total genetic diversity. However, significant differences in quantitative phenotypic traits, such as height growth, cold hardiness and needle flush, do exist among geographic regions (Bower and Aitken 2006, 2008). Trait variation is largely clinal and indicates local adaptation.

Despite the naturally fragmented distribution due to habitat discontinuity, gene flow is estimated to be sufficient to overcome genetic drift (Jorgensen and Hamrick 1997, Stuart-Smith 1998, Breuderle *et al*. 1998). Seed dispersal by birds appears to be the main determinant of genetic structure, although postglacial migration from separate Pleistocene refugia may account for some differences (Richardson *et al*. 2002 ).

## Designatable units

There are no taxonomic subspecies or varieties recognized for this species. There is little genetic variation among populations across the species' range; most genetic diversity is within a local population and local populations typically contain at least 90% of the species level diversity (see *Genetic description* above). Although the distribution is naturally fragmented, gene flow appears to be sufficient to overcome genetic drift. While Whitebark Pine occurs in both the Southern Mountain and Pacific Ecological Areas (COSEWIC 2008), the boundary between the ecological areas does not correspond with any significant characteristic (e.g., morphology, genetic structure, white pine blister rust infection rate). All portions of the population in Canada are facing similar threats and no splitting of the species is required to reflect the probability of extirpation in Canada. Thus, only one designatable unit is recognized.

## DISTRIBUTION

### Global range

Whitebark Pine occurs in high elevation forests of the mountains of western North America in two geographical areas (Figure 2). The first extends through the Coast and Cascade Mountains in British Columbia, Washington, and Oregon, to the Sierra Nevada of central California. The second includes the major ranges of the Rocky Mountains from approximately 54°N in British Columbia, to 41°N in the Wind River Range in western Wyoming. Isolated occurrences in southern British Columbia likely narrow the gap between the two areas to <100 km.

Estimates of the extent of occurrence (EO), based on estimates of jurisdictional EOs, vary depending on map scale, information available, and other procedures used to make the estimate (Table 1).

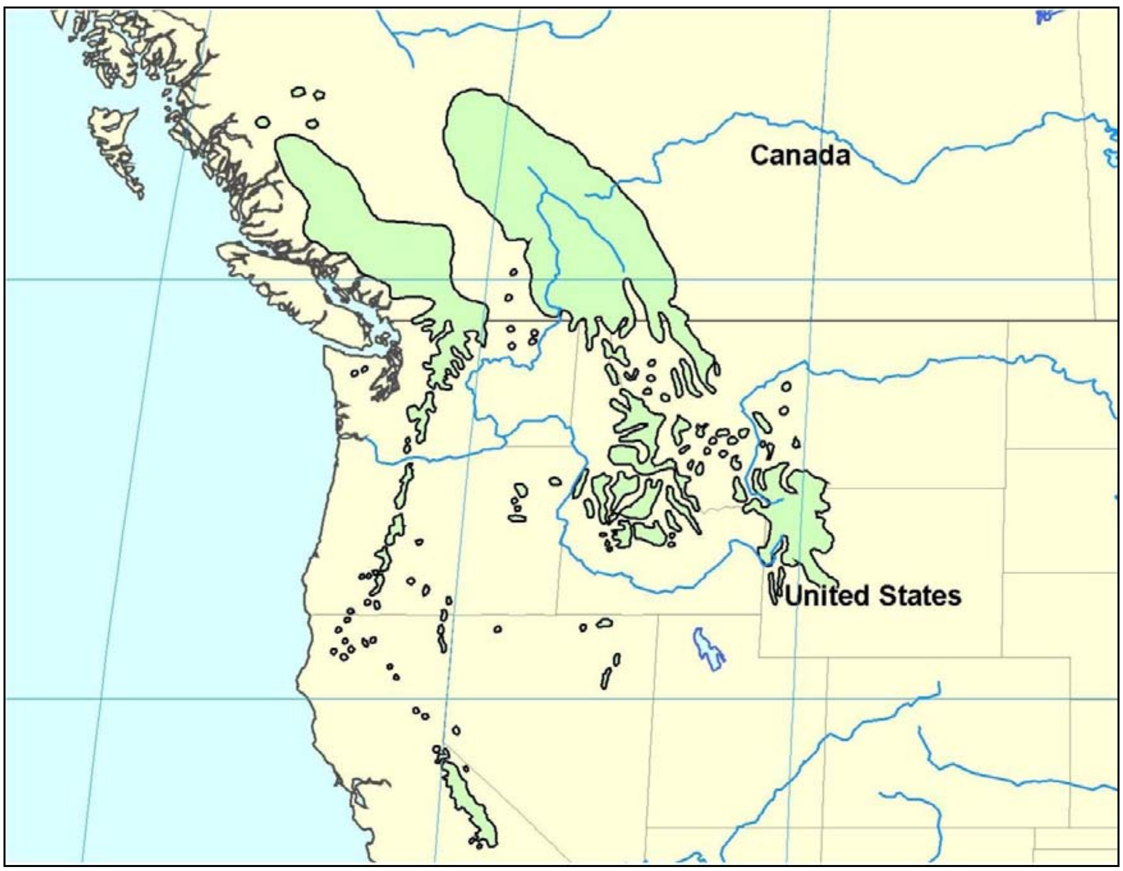


Figure 2. Global range of Whitebark Pine.

**Table 1. Estimates of extent of occurrence. (The methods used for the estimates were evaluated and the estimates in bold type were selected as the best current estimate.)**

| Jurisdiction (source) | Sq km |
|---|---|
| AB (Wilson 2007) | 29,786 |
| **AB (Stuart-Smith 2008)** | **45, 067** |
| | |
| BC (Wilson 2007) | 217,369 |
| **BC (BC-CDC 2007)** | **145,000** |
| BC (Stuart-Smith 2008) | 135,928 |
| BC (CFCG 2008) | 78,498 |
| | |
| CN (Wilson 2005) | 250,800 |
| CN (Wilson 2007) | 247,155 |
| CN (Stuart-Smith 2008) | 180,998 |
| **CN composite[1]** | **190,067** |
| | |
| USA (Wilson 2005) | 147,665 |
| USA (Wilson 2007) | 146,396 |
| **USA (mean of Wilson 2005, 2007)** | **147,000** |
| | |
| Global (Wilson 2005) | 398,465 |
| Global (Wilson 2007) | 393,551 |
| **Global composite[2]** | **337,067** |

[1] sum of AB (Stuart-Smith 2008) + BC (BC-CDC 2007)
[2] sum of CN composite + USA (mean Wilson 2005, 2007)

## Canadian range

Whitebark Pine has been a member of North American subalpine ecosystems for at least 100,000 years (Baker 1990). About 10,000 to 15,000 years ago, the species was more widespread during cooler, post-glaciation conditions. During the warm, dry Hypsithermal period (8350 to 3000 BP), it retreated to higher elevations with reduced abundance (Reasoner and Hickman 1989, McCaughey and Schmidt 2001). A general cooling trend until recent times has resulted in the present distribution of Whitebark Pine in the mountains of western Canada (Figure 3).

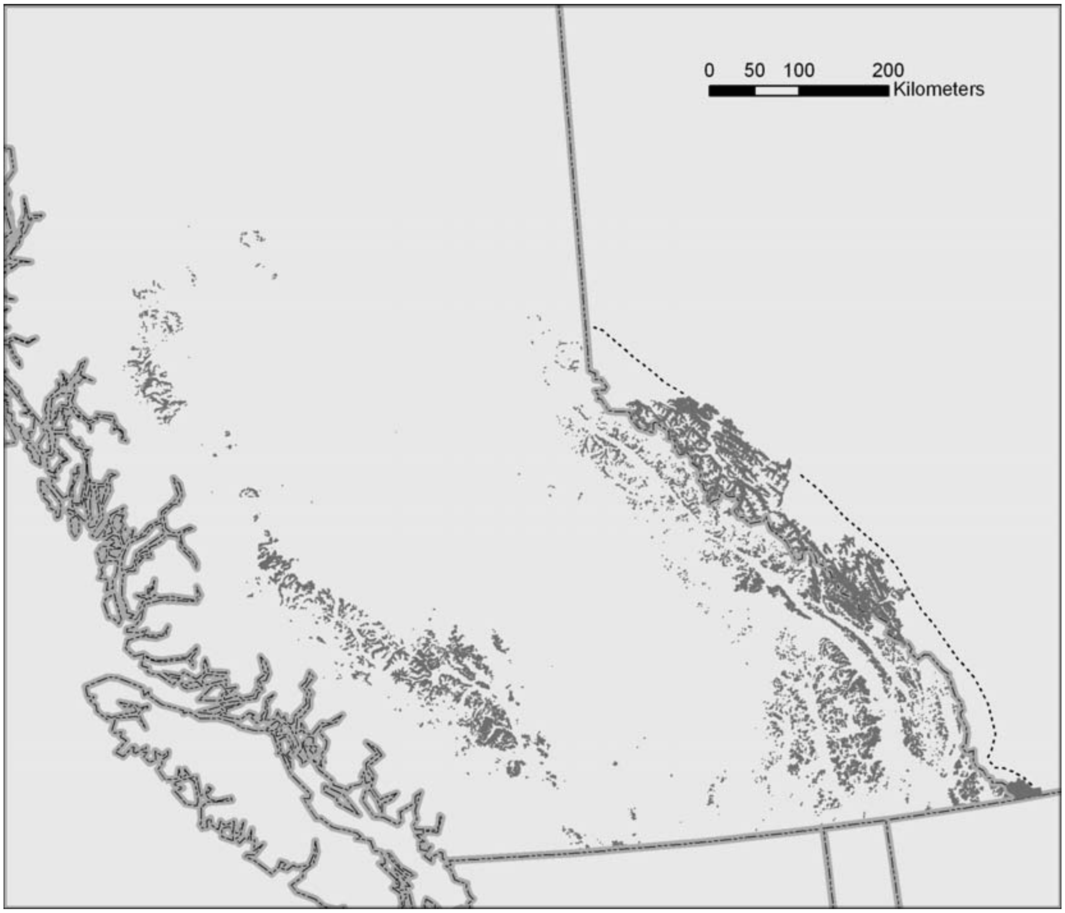


Figure 3. Canadian range of Whitebark Pine. Dotted line in Alberta indicates eastern edge of range.

In western British Columbia, Whitebark Pine reaches its northernmost extent at about 55°N in the Coast Mountains, approximately 200 km northwest of Fort St. James (Zeglen 2002). In the Rocky Mountains, the northern limit is about 150 km north of Jasper on the British Columbia and Alberta border at about 54°N (Ogilvie 1990).

The extent of occurrence in Canada is estimated as 190,067 sq km or 56% of the global range (Table 1). Alberta is estimated to contain 24% of the Canadian range and British Columbia 76%.

The index of area of occupancy (IAO) was estimated using a 2 km x 2 km grid in accordance with COSEWIC guidelines. The IAO is estimated for Alberta at 7148 sq km (Wilson 2007) and for British Columbia at 40,824 sq km based on a current distribution map for British Columbia (Campbell pers. comm. 2008). The IAO for Canada is estimated as 47,972 sq km.

The Area of Occupancy (AO) based on the area of mapped polygons is estimated for Alberta as 1099 sq km (Wilson 2007) and for British Columbia as 5610 sq km (BC-CDC 2007), for a Canadian total of 6709 sq km. These AO numbers are underestimates since the detailed, stand-level distribution of Whitebark Pine is not known.

Although many populations have declined in abundance, no population extirpations are known and thus, no decrease in range, EO or AO is known. However, as population declines continue, extirpations are expected, as have occurred in the USA (Schwandt 2006).

Whitebark Pine exhibits varying degrees of natural disjunction or fragmentation throughout its range in Canada. The greatest disjunction is between the Coast-Cascade Mountains and the Rocky Mountains, although there is possibly some connection via populations in southern British Columbia.

Whitebark Pine is obligately dependent on Clark's Nutcracker (*Nucifraga columbiana*) for seed dispersal (Tomback 1982a, 1982b). The range of Clark's Nutcracker includes the entire range of Whitebark Pine in Canada (Tomback 1998). However, the range of the bird extends well beyond that of Whitebark Pine in the western USA.

## HABITAT

### Habitat requirements

Whitebark Pine occurs typically in high elevation, upper subalpine habitats ranging from timberline, where it may occur as stunted krummholz, down to closed subalpine forest. The elevational limits vary latitudinally in Canada from ca. 1950 m to ca. 2250 m at the Canada-USA border (Achuff *et al*. 2002) and from as low as ca. 1000 m to ca. 1600 m in northcentral British Columbia (Ogilvie 1990).

In moist portions of its range, Whitebark Pine is most prevalent on dry, southerly aspects, often on ridgetops or exposed upper slopes, whereas in drier areas, it becomes more common on cool, moist sites (Arno and Hoff 1989). The soils that support Whitebark Pine are chiefly Orthic Regosols, Orthic Eutric Brunisols, Orthic Dystric Brunisols, and Orthic Humo-Ferric Podzols (Ogilvie 1990). The soils are typically coarse, rocky, and shallow over bedrock, and well to rapidly drained. Soils in the Rocky Mountains front ranges tend to be calcareous and basic to circumneutral, while those in the Coast Mountains and Rocky Mountains main ranges are usually more acidic (Holland and Coen 1982, Krajina *et al*. 1982, Achuff *et al*. 1984a, 1984b, 1993, 2002, Lea 1984, Meidinger and Pojar 1991, Gould 2009). In the northern end of its range in the Rocky Mountains of Alberta, the tree appears to be restricted to non-calcareous materials (Gould 2009). Parent materials include glacial till, colluvium, and weathered bedrock derived from sedimentary (limestone, sandstone, shale), metamorphic (quartzite, gneiss, schist), and a variety of igneous bedrock types (Ogilvie 1990).

These habitats are typically patchy in the mountains and Whitebark Pine populations are naturally fragmented, especially between mountain ranges.

Whitebark Pine is shade intolerant and considered as a seral species in mixed species stands at the lower elevational end of its range where it will apparently be replaced successionally by other conifers, including Engelmann Spruce (*Picea engelmannii*), Subalpine Fir (*Abies lasiocarpa*), or Mountain Hemlock (*Tsuga mertensiana*). Regeneration most often occurs in early seral environments created by avalanche, glacial retreat or, most importantly, fire. However, at higher elevations where climatic conditions are more severe and fuels less continuous, Whitebark Pine forms stable communities and may persist for over a millennium (Arno and Hoff 1989, Perkins and Swetnam 1996, Luckman and Youngblut 1999).

Whitebark Pine is obligately dependent on Clark's Nutcracker for seed dispersal and subsequent regeneration (Tomback 1982a, 1982b, Lanner 1996). However, while Whitebark Pine is important to Clark's Nutcracker, especially in the pine's Canadian range, the bird is not obligately dependent on Whitebark Pine and also uses other tree seeds. See the *Dispersal/Migration* section below.

Although Whitebark Pine occasionally occurs in pure or nearly pure stands at high elevation, it more typically occurs in mixed species stands in a wide variety of forest community types (Arno and Hoff 1989, Arno and Weaver 1990, Ogilvie 1990, Arno 2001). In the northwestern part its range, Whitebark Pine is frequently associated with Engelmann Spruce, Subalpine Fir, and Mountain Hemlock. At lower elevations, Lodgepole Pine (*Pinus contorta*) and Douglas-fir (*Pseudotsuga menziesii*) occur with Whitebark Pine (Ogilvie 1990, Campbell 1998). East of the Cascades, Whitebark Pine is also associated with Engelmann Spruce and Subalpine Fir in higher areas as well as with Subalpine Larch (*Larix lyallii*). Lower elevation habitat in these areas is also occupied by Lodgepole Pine and occasionally Douglas-fir or Limber Pine (Corns and Achuff 1982, Wilson 2001, Achuff *et al*. 2002).

### Habitat trends

Although there has been no significant loss of habitat area, habitat has declined over the past century due to fire exclusion (prevention and suppression). Lack of historic fire regimes has affected regeneration habitat, resulted in greater competition and more rapid successional replacement, and increased the severity of both fire and insect and disease effects (Agee 1990, Arno 2001, Kendall and Keane 2001, Keane *et al*. 2002). See the *Limiting Factors and Threats* section below.

Habitat quality decline has occurred throughout the range of Whitebark Pine, both in Canada and the USA, since similar fire management policies have been followed (Keane *et al*. 2002). Recently, resource managers have begun to restore historic fire regimes but most Whitebark Pine habitat remains affected by past practices.

### Habitat protection/ownership

Whitebark Pine occurs essentially entirely on federal or provincial Crown lands. It occurs in national parks in both Alberta and British Columbia (Banff, Jasper, Kootenay, Mt Revelstoke-Glacier, Waterton Lakes, Yoho). Habitat is protected in national parks by the Canada *National Parks Act*, and by management plans and processes pursuant to maintaining or restoring ecological integrity. Managers of national parks in Alberta and BC are aware of the need and have taken measures to protect Whitebark Pine habitat in park management. No other occurrences on federal Crown land are known.

In Alberta, Whitebark Pine occurs in a variety of protected areas administered by Alberta Parks including provincial parks, wildland parks, wilderness areas, natural areas, ecological reserves and the Willmore Wilderness Park. Alberta Parks is currently assessing the health and status of Whitebark Pine in protected areas and considering its conservation in management planning (Gould pers. comm. 2008).

Whitebark Pine also occurs on other provincial Crown lands administered by Alberta Sustainable Resource Development. Although Whitebark Pine is not a commercially harvested species, Alberta SRD has taken measures both to ensure that Whitebark Pine is not inadvertantly harvested and that planning for harvesting, fire management and Mountain Pine Beetle management takes Whitebark Pine into account (Dhir *et al*. 2003). Recently proposed land use guidelines in southwestern Alberta include specific conservation measures related to Whitebark Pine and Clark’s Nutcracker (Blouin 2006a, 2006b).

In British Columbia, Whitebark Pine also occurs in a range of protected areas. It is estimated that about 26% of Whitebark Pine range in British Columbia occurs in protected areas (CFGC 2008). Whitebark Pine has been logged in some areas, although the extent is unclear (BC-CDC 2007). British Columbia government agencies have suggested voluntary conservation measures for consideration in planning and operational forestry activities (BC-MFR 2008).

# BIOLOGY

Whitebark Pine is a hardy species that is an important part of the high elevation environments. It is a “keystone mutualist” species (Mills *et al*. 1993), i.e., a species “so closely involved with other organisms that if it becomes extinct, or even seriously depleted, the effects will ramify throughout the ecosystem” (Lanner 1996). Whitebark Pine is linked to other species most prominently through its seeds, which are an important food source for a number of animals including squirrels (*Tamiasciurus* spp.), bears (*Ursus* spp.), and in particular, Clark’s Nutcracker (Kendall 1983, Mattson *et al*. 2001, Tomback 2001). Whitebark Pine also plays an important role in watershed function by aiding soil stability and regulating snowmelt (Farnes 1990). The species facilitates a return to forested landscapes following disturbances on high elevation, southerly exposures where harsh conditions may otherwise limit seed germination and establishment (Arno and Hoff 1989, Callaway 1998).

## Life cycle and reproduction

Whitebark Pine is a long-lived species, often attaining an age of over 500 years (Arno and Hoff 1989) and sometimes reaching more than 1000 years (Perkins and Swetnam 1996, Luckman and Youngblut 1999). The species generally does not produce cones until about 30-50 years of age and no sizable cone crops until 60-80 years of age (McCaughey and Tomback 2001, Ettl and Cotone 2004). Cone production peaks at about 250 years but can continue well past this age (McCaughey and Tomback 2001). Sexual reproduction is predominant with only occasional vegetative rooting of lower branches weighed down by snow (Arno and Hoff 1989).

Generation time has been estimated using the IUCN Guidelines (IUCN 2008), which describe various methods for making the estimate. Most appropriate is the method for *plants with seed banks* in which generation time is calculated as the juvenile period (age of first reproduction) + median time to germination.

While Whitebark Pine can begin to produce cones at 30-50 years, sizable cone production usually begins at 60-80 years. The mean age of first reproduction can be based on the age at initial cone production (i.e. mean of 40 years) or when cone production becomes sizable (i.e. mean of 70 years) or on both (i.e. mean of 55 years). The latter (55 years) is used here.

Whitebark Pine seeds that germinate to produce seedlings have been placed in the soil seedbank by Clark’s Nutcracker. Germination is generally delayed. Within three years, about 67% of the seeds typically have germinated (McCaughey and Tomback 2001) and germination of the remaining seeds lasts until about five years (Tomback *et al*. 2001a). Thus, the median time to germination is three years.

Generation time then equals 55 years (age of first reproduction) + 3 years (median time to germination) or 58 years. This is rounded off to 60 years for ease of computation. This value is also the midpoint of the range of possible values (i.e. 30+3=33, 80+3=83, mean = 60).

Other methods based on age and maximum reproductive output, give generation times of around 250 years. The Guidelines caution that estimates should not be biased in a non-precautionary way by under-estimating the generation time. The COSEWIC evaluation criteria on declining population that are applicable to Whitebark Pine specify a period of 10 years or three generations, up to a maximum of 100 years. Consequently, the 60-year generation time, in which three generations equals 180 years, defaults to a maximum period of 100 years. A generation time of 250 years also results in a default to 100 years. Thus, the shorter generation estimate is not biased.

The reproductive cycle is similar to other pines and follows a two-year path from cone initiation to seed maturity (McCaughey 1994). Pollen is wind-dispersed from May through mid-August. Most dispersal is local but long-distance dispersal does occur (McCaughey and Tomback 2001). Each female cone produces about 75 seeds on average. The wingless seeds are relatively large (7-11 mm), typically weigh about 150-200 mg (Arno and Hoff 1989, McCaughey and Tomback 2001), and average 52% lipid by mass (Lanner 1996). Whitebark Pine mast seeds every 3 to 5 years with intervening years having very low or no seed production (Morgan and Bunting 1992), although there is much variability in this.

The cone does not open (indehiscent) and the seeds remain in the cone after maturity until removed and dispersed, almost exclusively by Clark's Nutcracker.

Following dispersal, seeds not retrieved by Clark's Nutcracker or eaten by rodents, may exhibit delayed germination, and thus form a seed bank, which is unusual for pines. Following 1-3 or more overwinter cycles (McCaughey 1994), germination then appears to occur when moisture conditions are favourable (Tomback *et al*. 2001a). This strategy evens out the effects of masting (pulsed seed production) so that germination of a seed cohort occurs over several years and when conditions are favourable, thus enabling a continuity of regeneration in the absence of seed production.

Seedling survival appears to be related to microsite factors that modify temperature and moisture conditions. Sun scorch and desiccation are frequent causes of seedling mortality. Successful establishment is often episodic, being influenced by both delayed germination and sufficient moisture during the short growing season (Tomback *et al*. 1993).

## Herbivory

Significant herbivory occurs on seeds taken by both birds and mammals. Clark's Nutcrackers remove most seeds from cones and cache them. Many seeds are later retrieved from caches and eaten. Other birds, such as Steller's Jay (*Cyanocitta stelleri*), Pine Grosbeak (*Pinicola enucleator*) and Common Raven (*Corvus corax*), also harvest seeds. Cached seeds may be eaten by small rodents, such as the Deer Mouse (*Peromyscus maniculatus*) and chipmunks (*Tamias* spp.) (McCaughey and Tomback 2001, Lorenz *et al*. 2008).

Red Squirrels (*Tamiasciurus hudsonicus*) are the most important seed predator of Whitebark Pine (Hutchins and Lanner 1982, Lorenz *et al*. 2008). The squirrels harvest cones and store them in underground middens for later consumption of the seeds (Mattson *et al*. 2001). These middens are often raided by both Black Bears (*Ursus americanus*) and Grizzly Bears (*Ursus arctos*) as well as by other rodents (McCaughey and Tomback 2001). Both bear species also will take cones directly from trees (Kendall 1983).

Mountain Pine Beetle (*Dendroctonus ponderosae*) consumes the inner bark of mature trees; the effects of this are discussed below in the *Limiting Factors and Threats* section. Other insect herbivory, usually with minor consequences, is from various aphids, mealybugs, needle miners and bark beetles, other than Mountain Pine Beetle (Arno and Hoff 1989).

## Physiology

Whitebark Pine populations occur across a broad range of environmental conditions (Weaver 1990). In higher elevation, continental areas, minimum winter temperatures can drop below - 40°C while summer temperatures can be 30°C (Arno and Hoff 1989). Although a protective snow pack covers seedlings in most areas during winter, seedlings may experience lethal summer soil temperatures nearing 60°C at the soil surface (Weaver 2001). For mature trees, frost may cause significant damage during spring bud break or before new growth has hardened off in the fall. Seed germination occurs at temperatures of 10-40°C with rates slightly higher at 25-35°C (Jacobs and Weaver 1990). Optimal photosynthesis in young seedlings occurs near 20°C and optimal root growth has been observed at soil temperatures of 30°C (Jacobs and Weaver 1990). These temperature ranges and optima suggest that the absence of Whitebark Pine at lower elevations likely is due to competition with other tree species or pathogens rather than conditions exceeding its physiological tolerance.

Mean annual precipitation in Whitebark Pine environments can vary considerably, ranging from 600 to 1800 mm, mostly as snow (Arno and Hoff 1989). Even in seemingly dry sites, it is likely that drought is rarely experienced due to the high water holding capacity of the soil (Weaver 2001). However, Whitebark Pine is unlikely to survive where the water potential drops below - 0.5 Mpa, such as warm, lower elevation grasslands (Weaver 2001). Winter dessication and damage to exposed above-ground tissues by wind-blown snow and ice particles also limit the species' growth in timberline areas (Arno and Hammerly 1984).

### Dispersal

Whitebark Pine is almost entirely dependent on Clark's Nutcracker for successful seed dispersal and reproduction. Clark's Nutcracker appears to have co-evolved with Whitebark Pine as its only effective seed disperser (Lanner 1980, Tomback 1982a, 1982b, Lorenz *et al*. 2008). Nutcrackers feed almost exclusively on Whitebark Pine seeds when they are available and store the seeds for use throughout the year (Tomback 1978). Clark's Nutcrackers have a sublingual pouch that can hold up to 150 Whitebark Pine seeds, an adaptation that is unique among birds (Bock *et al*. 1973). With a full pouch, nutcrackers fly to a suitable site where clusters of up to 15 seeds are cached 2 to 3 cm below the soil surface (Tomback 1982a). The birds generally travel from several 100 m to over 10 km to cache seeds (Tomback 2001). Caching sites are varied but those most favourable for Whitebark Pine regeneration appear to include recently burned areas, as well as open areas of any type, such as avalanche sites (Tomback 2001).

Potential migration in response to climatic change is discussed below in the *Climate Change* section.

### Interspecific interactions

The importance of seeds to other animals, such as Red Squirrels and bears is described above in the *Herbivory* section. Interactions with White Pine Blister Rust (*Cronartium ribicola*) and Mountain Pine Beetle are described below in the *Limiting Factors and Threats* section, as is the competitive interaction with Subalpine Fir.

Red Squirrels are part of a three-way interaction with Whitebark Pine and Clark's Nutcracker that has had a significant influence on Whitebark Pine cone evolution and Clark's Nutcracker numbers (Siepielski and Benkham 2007). Where the ranges of all three species overlap, as throughout the Canadian range of Whitebark Pine, the tree has evolved adaptations to squirrel cone predation (cones are larger, with thicker scales and thicker seed coats but with fewer seeds per cone), which results in lower nutcracker numbers.

Interactions with fungi may be either positive or negative. As in all pines, Whitebark Pine is dependent on mycorrhizal fungi for normal growth and survival, mainly through nutrient uptake (Smith and Read 1997). More than 32 species of mycorrhizal fungi have been found in association with Whitebark Pine and these interactions are currently under further investigation (Trusty and Cripps 2007, Mohatt *et al*. 2008). However, non-mycorrhizal fungi may also be an important source of seed mortality (Hoff and Hagle 1990) and a variety of other fungi can cause damage to needles, stems and roots (Arno and Hoff 1989).

**Adaptability**

This section describes natural environmental and biological factors that affect Whitebark Pine at the stand level. The effects of White Pine Blister Rust, Mountain Pine Beetle, fire exclusion, and climate change are described below in the the *Limiting Factors and Threats* section.

At lower elevations, young seedlings often occur in association with partial cover of surrounding vegetation or other nearby objects (McCaughey and Tomback 2001). It is likely that these features moderate the temperature and moisture environment during early growth and enhance seedling survival. As noted by Mellman-Brown (2005) for the Beartooth Plateau, USA, the best habitats for Whitebark Pine recruitment were not consistent with Clark's Nutcracker seed-caching preferences. Browsing and fungal infection may still lead to considerable mortality in the early growth stage. As a stand matures, the main sources of Whitebark Pine mortality shift to competition with other plants, especially Subalpine Fir, periodic attack by Mountain Pine Beetle and Limber Pine Dwarf Mistletoe (*Arceuthobium cyanocarpum*) (Hoff and Hagle 1990, Bartos and Gibson 1990, Perkins 2001), and fire mortality associated with increased fire effects from the buildup of fuels.

At higher elevations, factors associated with continuous forest cover are reduced. The open structure of high-elevation timberline produces discontinuous fuels for the propagation of stand-replacing fire (Agee 1993) and, coupled with harsh climatic conditions, likely limits the influence of insects and diseases. The survival of maturing Whitebark Pine individuals in these conditions is reliant on the species' ability to resist the abiotic environmental stress associated with timberline environments.

Techniques are well developed on how to gather Whitebark Pine seed, produce seedlings in a greenhouse, and plant the seedlings into natural stands, including seed transfer guidelines, and dealing with White Pine Blister Rust and fire exclusion (Burr *et al*. 2001, Hoff *et al*. 2001, Keane and Arno 2001, Schoettle and Sniezko 2007, Bower and Aitken 2008, Burns *et al*. 2008).

## POPULATION SIZES AND TRENDS

### Search effort

Information on the geographic distribution (extent of occurrence) is fairly complete, based largely on field surveys by provincial and federal government agencies over many years in support of broad resource inventory efforts (e.g., Holland and Coen 1982, Achuff *et al*. 1984a, 1984b, Meidinger and Pojar 1991, ESIS 2009, Klinkenberg 2009). Searches have occurred throughout and beyond the currently known distribution of the species. Total survey effort at this scale is large, comprising perhaps hundreds of person-years.

Specific information on stand locations (area of occupancy) is more limited, particularly since Whitebark Pine is generally not a commercially harvested species. Targeted, ground-based surveys have occurred in recent years (e.g., Smith *et al*. 2008). However, given the large effort required to cover the entire geographic range of Whitebark Pine with ground-based surveys, remote sensing methods are currently being developed to locate and delineate Whitebark Pine stands. A pilot project in Waterton Lakes National Park (McDermid and Smith 2008) has demonstrated this to be feasible and a project to cover the remainder of Whitebark Pine range in Alberta is underway. Stand location information based on ground surveys is less complete than for geographic distribution and so a model based on habitat and elevation has been used to estimate stand occurrence in this report.

Information on Whitebark Pine health (White Pine Blister Rust, Mountain Pine Beetle) is derived from provincial and federal government agency surveys (e.g., Campbell and Antos 2000, Zeglen 2002, CFS 2008, Smith *et al*. 2008). Surveys have been done throughout the range of Whitebark Pine in Canada and provide an estimate of variance in health conditions. Surveys for Mountain Pine Beetle in Alberta have focused on areas of actively spreading beetle activity.

### Abundance

The number of mature Whitebark Pine trees was estimated using stems/ha and the area of occupancy. Mature trees were considered as those with a diameter at breast height (DBH) >10 cm (Perkins 2001, Ettl and Cotone 2004). Estimates of mean stems/ha for Whitebark Pine in Canada are few. Campbell (1998) was used for British Columbia and Smith *et al*. (2008) was used for Alberta (Table 2).

**Table 2. Whitebark Pine densities (mean stems/ha) by DBH class in Alberta (Smith *et al*. 2008, n = 80) and British Columbia (Campbell 1998, n = 26).**

| | 11-20 cm | 21-30cm | 31-40 cm | 41-50 cm | 51-60 cm | >60 cm | total |
|---|---|---|---|---|---|---|---|
| AB | 184.3 | 56.7 | 15.1 | 4.2 | 1.4 | 1.0 | 263 |
| BC | 196.9 | 60.8 | 27.0 | 12.5 | 2.9 | 1.9 | 302 |

Total abundance of mature Whitebark Pine in Canada is estimated at 198.3 million trees (Table 3), which is best rounded off to 200 million trees.

**Table 3. Estimated abundance (number of stems) of mature Whitebark Pine in Canada.**

| Jurisdiction | Mean stems/ha | Area of occupancy (ha) | Abundance (stems) |
|---|---|---|---|
| AB | 263 | 109,900 | 28,903,700 |
| BC | 302 | 561,000 | 169,452,200 |
| Canada | | 670,900 | 198,355,900 |

## Fluctuations and trends

Whitebark Pine populations in Canada are declining currently due to the combined effects of White Pine Blister Rust, Mountain Pine Beetle, fire exclusion, and climate change (see *Limiting Factors and Threats* section below).

White Pine Blister Rust occurs throughout the range of Whitebark Pine in Canada (Zeglan 2002, Smith *et al*. 2008) and currently is the primary cause of population decline. Data on the effects of the rust are not uniform across the Canadian range. Four groups of information have been used in the analyses below (Table 4). Two groups have been remeasured and the other two have only one measurement.

**Table 4. White Pine Blister Rust infection levels, Whitebark Pine mortality levels and estimated Whitebark Pine population decline over 100 years. Sources: Campbell and Antos 2000; Zeglen 2002; Smith *et al*. 2008, 2009; Ainsley 2009.**

| | 1996 | 2003/2004 | 2009 | Decline over 100 years |
|---|---|---|---|---|
| **Canadian Rockies** | | | | 78% |
| infection all regions | - | 42% | 52% | |
| infection North | - | 43% | 49% | |
| infection Central | - | 25% | 36% | |
| infection South | - | 70% | 83% | |
| mortality all regions | - | 18% | 28% | |
| mortality North | - | 7% | 13% | |
| mortality Central | - | 8% | 20% | |
| mortality South | - | 47% | 54% | |
| **Waterton Lakes National Park** | | | | 97% |
| infection | 46% | 70% | 78% | |
| mortality | 24.5% | 66.5% | 69.4% | |
| canopy-kill | - | 20% | 30% | |
| **All Canada** | | | | 57% |

| **Alberta protected areas (2005-2009)** | infection | mortality |
|---|---|---|
| Willmore Wilderness Park | 6% | 3% |
| Whitegoat & Siffleur Wilderness Areas | 1% | 3% |
| SW of Calgary | 33% | 13% |
| **BC west of Rockies (1995-2000)** | 34% | 20% |

1. Waterton Lakes National Park (WLNP): Eight transects measured in 1996, 2003, and 2009 (Kendall 2003; Smith *et al*. 2008, 2009).
2. Canadian Rockies: One-hundred fourteen transects in Alberta and BC measured in 2003/2004 and 2009, including the eight WLNP transects (Smith *et al*. 2008, 2009).
3. Alberta protected areas (Willmore Wilderness Park, White Goat Wilderness Area, Siffleur Wilderness Area, southwest of Calgary): Thirty-nine transects measured once in 2005-2009 (Ainsley 2009).
4. British Columbia west of the Rocky Mountains: 536 plots measured once in 1995-2000 (Campbell and Antos 2000, Zeglan 2002).

Rust infection levels in the Canadian Rockies have increased from 42% in 2003/2004 to 52% in 2009 (Smith *et al*. 2008, 2009) or about 1.5%/year (weighted mean). Infection levels varied among the North, Central, and South regions but increased in all three. The North increased from 43% to 49%, the Central region increased from 25% to 36%, and the South increased from 70% to 83%. About 22% of the infected trees had active stem cankers and likely will be dead within 10 years. The eight WLNP transects showed an increase from 45% in 1996, to 70% in 2003, to 78% in 2009.

Infection levels in the Alberta protected areas (Ainsley 2009) ranged from 1% in the White Goat and Siffleur Wilderness Areas, to 6% in Willmore Wilderness Park, to 33% southwest of Calgary. While these levels are lower than other Canadian Rockies sites, the pattern of differences among them is consistent, with Willmore WP being in the North, White Goat-Siffleur being Central, and SW of Calgary in the South. The mean infection level for the combined Canadian Rockies and Alberta protected areas transects is 22.1%.

In British Columbia west of the Rockies, the rust infection level averaged 34% (range 18-53%) with a trend of increasing infection west to east across the province (Zeglan 2002). This is comparable to an earlier, albeit more limited study (Campbell and Antos 2000), which found an average infection level of 33% (range 0-100).

In the Canadian Rockies, the number of dead trees increased from 18% in 2003/2004 to 28% in 2009 (Smith *et al*. 2008, 2009) for a mean of 1.5%/year with increases in all three regions – North 7% to 13%, Central 8% to 20%, South 47% to 54%. Mortality was overwhelmingly due to White Pine Blister Rust since Mountain Pine Beetle has been at most low in these stands during this time. In the eight WLNP transects, mortality increased from 24.5% in 1996, to 66.5% in 2003, to 69.4% in 2009, for a rate of 3.5%/year.

Mortality in the Alberta protected areas (Ainsley 2009) averaged 5%, with 3% in both Willmore Wilderness Park and White Goat-Siffleur, and 13% SW of Calgary. This is consistent with the pattern elsewhere in the Canadian Rockies in which the highest mortality is in the South. The mean mortality level for the combined Canadian Rockies and Alberta protected areas transects is 22.1%.

In British Columbia west of the Rockies, rust-caused mortality averaged 10% (range 4-22%), with mortality from all causes averaging 19% (range 6-31%) (Zeglen 2002). This is comparable to an earlier, more limited study (Campbell and Antos 2000), which found a mean total mortality level of 21% (range 0-64%).

The population decline rate over 100 years (COSEWIC 2004) is estimated for the WLNP transects (1996-2009) as 97% (Table 5), based on a decline rate of 3.5%/year, a population of mature Whitebark Pine in WLNP of 562,520 stems – mean density = 149 stems/ha (Smith *et al*. 2008) and an area of Whitebark Pine forest = 3775.3 ha (Stuart-Smith 2008). For the Canadian Rockies (2003/2004-2009), the population decline rate over 100 years is estimated to be 78% (Smith *et al*. 2009).

**Table 5. Estimated Whitebark Pine population decline in Waterton Lakes National Park over 100 years (Smith *et al*. 2009).**

| Year | Population size | % decline |
|---|---|---|
| 0 | 562,520 | - |
| 10 | 398,024 | 29% |
| 20 | 281,631 | 50% |
| 30 | 199,275 | 65% |
| 40 | 141,001 | 75% |
| 50 | 99,679 | 82% |
| 60 | 70,594 | 88% |
| 70 | 49,950 | 91% |
| 80 | 35,343 | 94% |
| 90 | 25,008 | 96% |
| 100 | 17,695 | 97% |

Population declines in other portions of the Canadian range may not be as great since current rust infection levels are not as high as in these other areas. However, a rough estimate for the decline of the entire Canadian population of Whitebark Pine can be made using the estimated number of mature trees (198.3 million), a mean rust infection level of 38% of mature trees (Zeglan 2002, Smith *et al*. 2009), and a mortality rate of 21% of infected mature trees/decade, i.e. % trees with stem canker (Ainsley 2009, Smith *et al*. 2009) which causes death within 10 years (Hunt 1991). This estimate (Table 6) indicates a 57% population decline in 100 years.

**Table 6. Estimated Whitebark Pine population decline in Canada over 100 years. Sources: Zeglan 2002, Ainsley 2009, Smith *et al*. 2009.**

| Year | No. mature trees | % decline |
|---|---|---|
| 0 | 198,255,900 | - |
| 10 | 182,435,079 | 8.0% |
| 20 | 167,876,760 | 15.3% |
| 30 | 154,480,194 | 22.1% |
| 40 | 142,152,675 | 28.3% |
| 50 | 130,808,891 | 34.0% |
| 60 | 120,370,342 | 39.3% |
| 70 | 110,764,789 | 44.1% |
| 80 | 101,925,758 | 48.6% |
| 90 | 93,792,083 | 52.7% |
| 100 | 86,307,475 | 56.5% |

The estimate assumes that the rust infection level and stem canker level are constant over the 100 years. It is not unrealistic to expect these levels to be at current, if not greater, levels in the future, given the North American history of increasing infection and mortality due to White Pine Blister Rust (Kendall and Keane 2001). Stands currently in the lower range of infection level have many trees that can become infected over coming decades and the infection level is expected to increase, accelerating mortality.

The estimate also considers recruitment of mature trees from seedlings and saplings to be negligible. Several factors contribute to this conclusion. First is the increasing infection and mortality level of Whitebark Pine regeneration (stems < breast height) due to White Pine Blister Rust. The infection level increased by 10% from 2003/2004 to 2009 in the Canadian Rocky Mountains (Smith *et al*. 2008, 2009). Also, the number of immature trees (> breast height and <10 cm DBH) declined 13.4% (-381 stems) from 2003/2004 to 2009 (Smith *et al*. 2008, 2009). This decline is due primarily to mortality of immature trees since only 1.8% (87 stems) of 2003/2004 regeneration became immature trees by 2009 and the mature tree size classes >10 cm also decreased (Smith *et al*. 2008, 2009).

Similarly, estimates from the US indicate that, due solely to rust-caused mortality, only about 3% of seedlings reach an age of 100 years (calculated using age class survival rates in Ettl and Cotone 2004 and Keane *et al*. 1990).

A second factor is the trend of decreased seed dispersal as Red Squirrels and Clark's Nutcracker's consume an increasing proportion of the reduced seed production, which is declining due to White Pine Blister Rust infection (many mature trees are reproductively dead or compromised by partial crown kill). When cone production falls below a certain threshold, Clark's Nutcrackers no longer use the stand and thus, seed dispersal and consequent regeneration opportunities are lost (McKinney and Tomback 2007).

Third is reduced regeneration survival due to declining habitat quality from fire exclusion and climate change (see *Limiting Factors and Threats*).

Additionally, given the fragmented distribution of Whitebark Pine stands, inter-stand seed dispersal becomes more unlikely and isolated stands become more susceptible to extirpation (Ettl and Cottone 2004). Thus, the probability of recruitment of mature trees is considered to be essentially negligible.

Overall, while these estimates of population decline contain a number of uncertainties, they are indicative of the impact of White Pine Blister Rust on future Whitebark Pine numbers in Canada.

However, White Pine Blister Rust is not the only cause of mortality in mature trees. Mountain Pine Beetle is currently reaching epidemic levels in large areas of western Canada and spreading to portions of Whitebark Pine range not observed before (Logan and Powell 2008). In the USA as well, Mountain Pine Beetle has reached epidemic levels in Whitebark Pine forests (Gibson *et al*. 2008). Under epidemic conditions, typically around 90% of mature Whitebark Pine trees in a stand will be killed (Campbell 2007, Gibson *et al*. 2008, Schwandt 2009, Wilson 2009).

Elsewhere, a modelled prediction of the response of Whitebark Pine to blister rust only in Mt. Rainier National Park, WA, indicates that the median time to quasi-extinction (<100 trees) is 148 years and the population has a 94% chance of becoming quasi-extinct (a decline of >99.8%) in 175 years (Ettl and Cottone 2004). Metapopulation dynamics also affected the population decline with smaller subpopulations declining much faster than larger ones. This study used population structure data from Mt Rainier National Park but many of the vital rates used came from other portions of the species' range. Thus, the results likely are indicative of a broader area. Because cone production decreases well before tree death (i.e., not all mature trees produce cones due to upper crown death from blister rust), the decline due to White Pine Blister Rust may be even faster than indicated by the model. In addition, because the model did not include the effects of Mountain Pine Beetle, climate change or fire exclusion, the outcome underpredicts the population decline.

Another modelled projection predicts a severe reduction in Whitebark Pine populations due to White Pine Blister Rust, Mountain Pine Beetle, fire exclusion, and declining habitat quality (Keane *et al*. 1990). A Whitebark Pine population decline of 2.1%/year has been observed in western Montana over 20 years (Keane and Arno 1993).

In summary, given these multiple, interacting threats, it is anticipated that the population of Whitebark Pine will decline in Canada by more than 50% in the next 100 years.

## Rescue effect

There are populations of Whitebark Pine in the USA that are close to or essentially contiguous with Canadian populations in Alberta and British Columbia. Seed dispersal by Clark's Nutcrackers to areas of suitable habitat in Canada is theoretically possible. However, USA populations of Whitebark Pine, in many cases, have suffered greater declines than Canadian populations (Keane and Arno 1993, Keane *et al*. 2002, Burns *et al*. 2008, Gibson *et al*. 2008). The effects of this decline on Clark's Nutcracker are not clear but its numbers can be expected to decrease given its relationship with Whitebark Pine (Tomback and Kendall 2001), thus decreasing seed dispersal (Siepielski and Benkham 2007). Nor are the predicted effects of climate change any less in the USA (Warwell *et al*. 2007) than in Canada. Consequently, the probability of successful mitigation from USA populations of an extirpation or population decline in Canada is extremely low. No rescue effect seems possible at this time.

# LIMITING FACTORS AND THREATS

Four human-influenced factors imminently threaten Whitebark Pine throughout its range: 1) White Pine Blister Rust, an introduced species, 2) Mountain Pine Beetle, 3) fire exclusion, and 4) climate change.

## White Pine Blister Rust

White Pine Blister Rust originated in Eurasia and was introduced accidentally to North America early in the 20th century (Peterson and Jewel 1968, Littlefield 1981, McDonald and Hoff 2001). Subsequently, the rust has spread throughout most of the distribution of all five-needled pines of North America (Liebhold *et al*. 1995, Tomback and Achuff 2009). Whitebark Pine has been affected severely; throughout the species' range with only a few stands showing no infection (Stuart-Smith 1998, Campbell and Antos 2000, Zeglen 2002), and in many areas there is greater than 90% infection and over 50% mortality due to rust (Kendall and Keane 2001, Smith *et al*. 2008).

The extent of White Pine Blister Rust infection depends not only on the distribution of Whitebark Pine, but also on that of its alternate host (required to complete its life cycle), primarily native currant and gooseberry shrubs (*Ribes* spp.), which are widespread in western North America (Zillar 1974). Recent evidence indicates that native species of Indian Paintbrush (e.g., *Castilleja miniata*) and Lousewort (e.g., *Pedicularis bracteosa, P. racemosa*) may also serve as alternate hosts (McDonald *et al*. 2006, Zambino *et al*. 2007).

The pine is infected by wind-borne basiodiospores from the alternate host that attack the needles, usually in late summer (McDonald and Hoff 2001). After the initial infection of the needles, hyphae grow down the vascular bundle and enter the phloem in the branch or stem. As the rust spreads through the phloem, the nutrient supply can be cut off to branches and portions of the upper stem. Two to four years following infection, cankers form and rupture the bark surface. Although a canker may become large enough to girdle the affected stem, infection may not be the direct cause of death. Concentrations of nutrients in cankers attract rodents, which chew the canker, thus removing vascular tissue and girdling the stem (Wilson and Stuart-Smith 2002). The loss of vascular tissue, as well as invasion by secondary pathogens into the wound are the main causes of mortality.

Besides direct mortality, White Pine Blister Rust also can greatly reduce or prevent seed production by killing the upper portions of the tree, which is where most cones are produced on the most recent two years of branch growth. Thus, top-killed trees are often effectively non-reproductive even though they may still be alive.

White Pine Blister Rust infection also results in lower cone production, fewer cones surviving to the seed dispersal stage, and a reduced likelihood that seed will be dispersed by nutcrackers (McKinney and Tomback 2007). Loss of seed dispersal services by nutcrackers could result in a virtual complete loss of regeneration over large portions of the range of Whitebark Pine.

White Pine Blister Rust also interacts with Mountain Pine Beetle in that Whitebark Pines infected with White Pine Blister Rust are more susceptible to beetle infestation (Kendall and Keane 2001, Six and Adams 2007).

Whitebark Pine is a primary initiator of high-elevation tree islands in much of its range, where it facilitates plant succession by providing habitat suitable for other species to establish. White Pine Blister Rust infection of Whitebark Pine tree islands threatens to disrupt treeline dynamics, confounding the understanding of treeline response to climatic warming, reducing the ability of Whitebark Pine to migrate to favourable sites, and hastening local population extirpation (Tomback and Resler 2007, Resler and Tomback 2008).

Phenotypically rust-resistant Whitebark Pine trees are known in natural forests, albeit at low frequencies (Hoff *et al*. 2001). Mahalovich *et al*. (2006) have found a small but notable amount of rust resistance in widespread USA seed sources. Similarities with other pines (e.g., Western White Pine (*Pinus monticola*), Limber Pine) suggest that resistance may be genetically based. Studies to determine levels of genetic resistance and resistance mechanisms are currently underway (Burns *et al*. 2008). Following identification of resistant genes, a rust-resistance breeding program might be undertaken to develop rust-resistant trees for planting. However, this process will likely take several decades at best (Hoff *et al*. 2001) and, even if genetic resistance is identified, genetic variation in virulence of White Pine Blister Rust may overcome tree resistance (McDonald and Hoff 2001).

## Mountain Pine Beetle

Although Mountain Pine Beetle is a native species that has co-existed with Whitebark Pine for more than 8500 years (Brunelle *et al*. 2008) and occurs throughout most of the range of Whitebark Pine in Canada, epidemic population levels recently have spread to much of the range in Alberta and British Columbia (CFS 2008). Mountain Pine Beetles kill trees by tunnelling beneath the bark and laying eggs. The larvae feed on the phloem (inner bark), thereby disrupting nutrient translocation and cause tree girdling (Amman 1977). The beetles also carry fungi, which grow in the phloem and underlying sapwood, further disrupting the movement of water and nutrients (Kim *et al*. 2005). Typically, around 90% of mature Whitebark Pine trees in a stand will be killed (Campbell 2007, Gibson *et al*. 2008, Rankin 2008, Schwandt 2009, Wilson 2009). Human-caused factors have been significant in the epidemic: climatic warming from greenhouse gas emissions and fire exclusion (Carroll *et al*. 2003, Taylor *et al*. 2006, Logan and Powell 2008, Raffa *et al*. 2008).

Climatic warming results in less severe winter temperatures, warmer summer temperatures, and a longer growing season, all of which contribute to increased Mountain Pine Beetle survival, growth and reproduction in Whitebark Pine stands (Carroll *et al*. 2003, Taylor *et al*. 2006, Logan and Powell 2008). In the past, beetles in Whitebark Pine stands frequently took 2-3 years to complete their life cycle (Amman *et al*. 1997). With warmer conditions, 1-year life cycles are now more common, permitting faster population growth and reducing the probabilities of mortality from low winter temperatures, predation by birds, and fungal disease. Continued climatic warming is expected to further increase favourable conditions for beetle epidemics (Logan and Powell 2008).

Fire exclusion has increased the amount of landscape occupied by susceptible age-class pine trees, including Lodgepole Pine and Ponderosa Pine (*P. ponderosa*), which often occur at elevations below Whitebark Pine. This has allowed the buildup of epidemic Mountain Pine Beetle conditions in large portions of the landscape, with subsequent spread to Whitebark Pine stands (Raffa *et al*. 2008).

Additionally, Whitebark Pine appears to be more susceptible to Mountain Pine Beetle attack and to produce proportionally more brood than other pines (Amman 1982, Bockino 2007). The interaction of Mountain Pine Beetle and White Pine Blister Rust is also of grave concern. Not only are trees weakened by White Pine Blister Rust infection more susceptible to beetle infestation (Kendall and Keane 2001, Six and Adams 2007) but beetles may kill the remaining Whitebark Pine trees in a stand that have not been killed or rendered non-reproductive by White Pine Blister Rust. Whitebark Pine appears to be recruiting well in some areas in the USA, with particular success in stands recently killed by Mountain Pine Beetle (Larson and Kipfmueller 2010).

## Fire exclusion

Fire is the primary disturbance that permits regeneration of Whitebark Pine throughout most of its range (Arno and Fiedler 2005). Avalanche and the severity of treeline environments also create and maintain suitable regeneration habitat but to a much smaller degree. Fire activity in western Canada has generally decreased since the early part of the 20th Century (Taylor and Carroll 2004, Van Wagner *et al*. 2006). Fire exclusion, which includes both fire prevention and suppression, affects Whitebark Pine populations in several ways. A reduction in fire frequency or severity causes a decrease in early seral habitat, which has a greater availability of light and nutrients (Hungerford *et al*. 1991). This decrease in early seral habitat and the increase in more shade-tolerant species, such as Mountain Hemlock, Subalpine Fir, and Engelmann Spruce, results in a decrease in seed caching, seedling establishment, and growth into mature trees (Arno and Hoff 1989, Arno 2001). Increased competition with these species also increases physiological stress, resulting in greater susceptibility to insects and disease (Arno and Hoff 1989).

Increased forest in-growth also increases the risk of changing the historical fire regime. Mixed- or low-intensity fires are generally favourable to Whitebark Pine, reducing competitive species but retaining older, seed-producing trees within the stand (Keane *et al*. 1990, Morgan *et al*. 1994). Higher intensity fires, supported by increased fuel loadings, are more likely to kill mature trees, thus reducing seed available for regeneration, often in stands already reduced by White Pine Blister Rust or Mountain Pine Beetle (Agee 1990, Bradley *et al*. 1992, Arno 2001). Prolonged fire exclusion may also increase the frequency and severity of Mountain Pine Beetle and Dwarf Mistletoe effects by reducing the heterogeneity of stand ages and tree bole sizes (Kendall and Keane 2001).

## Climate change

Whitebark Pine distribution is heavily influenced by temperature (Arno and Hoff 1989, McKenzie *et al*. 2003, Schrag *et al*. 2007), especially at its upper elevational limits and thus is expected to be much affected by climate change. Model predictions with the 2X $CO_2$ scenario (Bradley *et al*. 2004) indicate particularly intense summer warming at higher elevations and at latitudes between $35^o$ and $55^o$ N, which includes much of the range of Whitebark Pine. In British Columbia, warming over the past decade approximately matches increases predicted earlier (Hamman and Wang 2006). In response to climate change, Whitebark Pine can *migrate* to areas of suitable climate, *adapt* to changed climatic conditions or be *extirpated*.

Migration has been the usual response of plants to climate change in the past (Bradshaw and McNeilly 1991, Huntley 1991, Jackson and Overpeck 2000). However, given predicted rates of climate change (IPCC 2001, Hall and Fagre 2003), Whitebark Pine is unlikely to be able to migrate to suitable habitat throughout most of its range. The latitudinal migration rate of Whitebark Pine is estimated to be on the order of 100 m/year, while the rate required to track suitable habitat under a 2X CO2 scenario is about 1 km/year (Malcolm *et al*. 2002, Aitken *et al*. 2008). Upward elevational migration, while involving shorter distances, will be severely constrained in many areas by lack of adequate soil or terrain that extends upward enough to remain favourable, i.e., suitable habitat for many local populations will move upward above the mountain tops (Grabherr *et al*. 1994, Bartlein *et al*. 1997, Romme and Turner 1991, Hamman and Wang 2006, Lenoir *et al*. 2008). Successful migration is likely further complicated by the need for mycorrhizal fungi (Mohatt *et al*. 2008), which may be specific to Whitebark Pine, also to be dispersed to new suitable habitat. Migration rates for these fungi are unknown.

Whitebark Pine response to changing climate is predicted to suffer significant adaptational lag due to its occurrence in relatively small, fragmented populations with low fecundity and a late age of seed production (Savolainen *et al*. 2007, Aitken *et al*. 2008). Calculations for other Northern Hemisphere pine species with more favourable life history characteristics suggest that one generation of selection is insufficient to adapt to climatic warming and that adaptation may require 10 generations or >1,000 years (Rehfeldt *et al*. 1999, 2001, 2002).

At lower elevations, Whitebark Pine will face increased competition, particularly from Subalpine Fir and Engelmann Spruce, which are predicted to increase (Wilson 2001, Koerner 2003, Schrag *et al*. 2007). This competition will reduce suitable sites for seedling establishment, leading to reduced regeneration rates and declining populations, and increase stress on mature trees, resulting in reduced seed production and increased susceptibility to White Pine Blister Rust and Mountain Pine Beetle. Increased amounts of competing vegetation will likely result in a more severe, stand-replacing fire regime, which is not favourable to Whitebark Pine.

In addition, warmer temperatures are expected to increase Mountain Pine Beetle effects in Whitebark Pine stands, as winter beetle mortality is decreased, beetle generation times are shortened, and more favourable conditions occur during dispersal flights (Logan and Powell 2008).

In British Columbia, Whitebark Pine is predicted to decline rapidly, losing about 70% of current habitat by 2055, while gaining relatively little new suitable habitat (Hamman and Wang 2006). Climate change alone is predicted to reduce the distribution of Whitebark Pine in the USA by >90% by 2100 (Warwell *et al*. 2007). More localized analyses indicate similar reductions (Romme and Turner 1991, Mattson and Reinhardt 1994, Bartlein *et al*. 1997, Koteen 2002, Schrag *et al*. 2007). A North American, range-wide analysis (McKenney *et al*. 2007) predicts a 42% loss of range area for Whitebark Pine by 2100, However, this analysis, based solely on climatic variables, overestimates the current range extent and thus likely underestimates future range reduction.

Thus, the effects of climate change are expected to be negative for both migrational and adaptational responses of Whitebark Pine, to increase the negative effects of inter-specific competition, Mountain Pine Beetle and White Pine Blister Rust, and to result in widespread extirpation of local populations.

### Interaction of threats

In summary, while each of the four human-influenced factors (White Pine Blister Rust, Mountain Pine Beetle, fire exclusion, climate change) taken singly poses significant threats to Whitebark Pine, these factors interact to further increase the severity of the impacts.

White Pine Blister Rust infection reduces seed production and dispersal, which likely will cause a virtually complete loss of regeneration in many rust-affected stands. White Pine Blister Rust also increases the likelihood and severity of Mountain Pine Beetle attack. Increased stress from competitors due to fire exclusion and climate change (e.g., drought stress) increases susceptibility to both rust and beetle attack. Climate change, warmer temperatures in particular, increase the probability and severity of beetle attack and may increase fire intensities, which is generally unfavourable to Whitebark Pine. Mountain Pine Beetle can kill the remaining trees in a stand already reduced by White Pine Blister Rust.

The rate of natural migration of Whitebark Pine is much less than needed to cope with climate-driven environmental change. Both White Pine Blister Rust and Mountain Pine Beetle appear to be able to disperse at least as rapidly as Whitebark Pine. Thus, escape by Whitebark Pine from these two threats through migration appears impossible.

Adequate, timely mitigation of these threats, while potentially possible, is extremely problematic (Tomback *et al*. 2001b). Development of rust-resistant trees for such a wide-ranging species will likely take decades and require significant amounts of resources. Abatement of climate change and consequent Mountain Pine Beetle epidemics again will require decades and is a major uncertainty in public policy currently. Restoration of fire regimes favourable to Whitebark Pine is feasible but expensive. It may be difficult to find resources for a non-commercial species such as Whitebark Pine. Thus, these threats are expected to be ongoing, minimally for decades, and mitigation may be weak.

## SPECIAL SIGNIFICANCE OF THE SPECIES

Whitebark Pine is a keystone species at the centre of a high-elevation network of plants and animals, thereby enabling increased biodiversity in the upper subalpine. It provides food and habitat for many species of birds and mammals, and has an obligate relationship with Clark’s Nutcracker, its primary seed disperser (Kendall 1983, Lanner 1996, Mattson *et al*. 2001, Tomback 2001). Whitebark Pine also facilitates plant community succession by providing suitable habitat for other plants (Tomback and Resler 2007, Resler and Tomback 2008). It helps regulate snowpack and runoff, and provides stability for upper watersheds (Arno and Hoff 1989, Farnes 1990).

Whitebark Pine seeds have been used as food by Aboriginal peoples (Turner 1988, Lanner 1996).

## EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Globally, Whitebark Pine was assessed as V*ulnerable* in 1998 on the IUCN Red List (IUCN 2007), citing a population reduction due to loss of habitat quality and the effects of White Pine Blister Rust and Mountain Pine Beetle. A V*ulnerable* species is considered at “high risk of extinction in the wild in the medium-term future” (IUCN 2007).

In the NatureServe (conservation data centre) system, Whitebark Pine has a global rank of G3G4 (*Vulnerable)* (NatureServe 2009) based on a “significant, on-going” population decline due to the combined effects of White Pine Blister Rust, Mountain Pine Beetle, climate change and fire suppression. The rank appears to be based primarily on the current, large number of individuals rather than the population trend, which is noted to be “severely declining to declining.”

At the national level, NatureServe ranks Whitebark Pine as N3? (*Vulnerable*) in Canada (NatureServe 2009). However, this national rank is constrained by the S3? rank in BC, which appears to underestimate the status of Whitebark Pine there, given the estimated rate of decline (see below). In the USA, Whitebark Pine is ranked N3N4 (*Vulnerable to Apparently Secure*)*.*This appears to be based on state ranks of S4 (*Apparently Secure*) in Idaho, Montana and Oregon, S3 (*Vulnerable*) in Wyoming, and SU (*Unranked*) in California, Nevada, and Washington (NatureServe 2009). These ranks appear outdated based on current information, which suggests a higher risk level.

In Alberta, Whitebark Pine is currently ranked as S2 (*Imperiled*). It was assessed by the Alberta Endangered Species Conservation Committee as *Endangered* and the Minister of Sustainable Resource Development listed it as *Endangered* under the Alberta *Wildlife Act* (ASRD 2009). However, no regulations currently exist to permit listing of plants under the Alberta *Wildlife Act* and thus, Whitebark Pine has no legal protection. A recovery team was formed in December 2008 and a recovery plan is expected in late 2009. In the interim, provincial land management agencies are using existing mechanisms to protect Whitebark Pine and its habitat.

In British Columbia, the species was recently ranked S3? (*Special Concern/ Vulnerable*) and is blue-listed (BC-CDC 2007). The reason for ranking cites an expected population decline of 75-90%, which suggests a higher risk category. While blue listing provides no legal protection, British Columbia government agencies have suggested voluntary conservation measures for consideration in planning and operational forestry activities (BC-MFR 2008).

In the USA, the Natural Resources Defense Council petitioned the US Fish and Wildlife Service in December 2008 to list Whitebark Pine as *Endangered* under the US *Endangered Species Act* (NRDC 2008). An initial response is expected in July 2010.

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Brendan Wilson is a researcher in the Selkirk Geospatial Research Centre and an instructor at Selkirk College, Castlegar, BC. He has a B.Sc. in Applied Environmental Biology from the University of Technology in Sydney (Australia), and a PhD from the University of Alberta. Brendan has worked in subalpine forest ecosystems in both Australia and Canada for the past 20 years.

## COLLECTIONS EXAMINED

No collections were examined for this report.