# Mountain Caribou in Managed Forests: Recommendations for Managers

## Second Edition

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## DISCLAIMER

This report was commissioned by the Wildlife Branch and completed in 2000. The views expressed herein are those of the authors and do not necessarily represent those of the Ministry of Environment, Lands and Parks.

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## EXECUTIVE SUMMARY

Mountain Caribou, an ecotype of woodland caribou (*Rangifer tarandus caribou*), inhabit mature forests and alpine areas in southeastern and east-central British Columbia. During winter, the caribou feed mainly on the arboreal lichens *Bryoria* spp. and *Alectoria sarmentosa*, which are most abundant on old trees.

For more than 25 years, forest harvesting has been a management concern in Mountain Caribou ranges in the Engelmann Spruce-Subalpine Fir (ESSF) and Interior Cedar-Hemlock (ICH) biogeoclimatic zones. As the pressure on the timber supply increases, the demand for information on forest harvesting in caribou habitat also increases. This report focusses on winter ranges because it is there that direct conflicts with forestry activities are most severe.

The habitat requirements of Mountain Caribou, as they are understood today, are incompatible with most current forest management practices. To survive, Mountain Caribou need to be able to spread out over large areas of suitable habitat, where it is difficult for predators to find them. Suitable winter habitat for Mountain Caribou has characteristics of old forests (at least 150 years), including abundant arboreal lichens. Forests managed under any silvicultural system that eventually eliminates, or substantially reduces, the number of large, old, lichen-bearing trees will not provide winter habitat for caribou.

The Mountain Caribou in Managed Forests (MCMF) program began in 1988 to address the question: Can forest stands be managed, through silvicultural systems and habitat enhancement techniques, to sustain both timber harvest and caribou habitat over the long term? The program resulted in the establishment of a number of investigations and management trials, and a report, *Mountain Caribou in managed forests: Preliminary recommendations for managers*, published in 1994. Since 1994, there have been significant changes both to the knowledge base and to the regulatory framework. The objective of the revised edition of the report is to apply the best available information to the problem of maintaining habitat for caribou while economically harvesting timber. The report is intended primarily for forest and habitat managers and field staff, to be used in the context of land-use planning.

The range of Mountain Caribou corresponds closely with the distribution of the Interior Wetbelt in southeastern and east-central British Columbia. The Interior Wetbelt is characterized by mountainous terrain; a wet, snowy climate; infrequent fires; old, often uneven-aged stands; and forest productivity that ranges from high at low elevations to very low at high elevations. The age, structure, and microclimate of many old stands make them highly productive of arboreal forage lichens. Some of them, especially in the ICH, also support an unusually high diversity of lichens.

Forestry is the dominant extractive resource use in the Interior Wetbelt, and most harvesting has taken place in the last 30 years. Accompanying the expansion of forest harvesting has been an expansion of the forest road system, leading to more human activity in Mountain Caribou habitat. Intensive recreational activity — especially snowmobiling — may displace caribou from their winter ranges.

Mountain Caribou have recently been red-listed in British Columbia, which means they are considered endangered or threatened. The approximately 2300 animals have been divided into 13 subpopulations, some of which are isolated from one another. Mountain Caribou make elevational movements in response to factors such as snow conditions, forage availability, and predation pressure. During early winter they use the ICH and ESSF zones; the subpopulations differ in the degree to which they use low-elevation habitats. During late winter, Mountain Caribou nearly always use the upper ESSF and adjacent parkland habitats. They consistently show a preference for old forests and an avoidance of young stands.

At the regional and landscape levels, habitat management for caribou includes:

- ensuring that large contiguous areas of habitat are maintained in a suitable condition for use by caribou;
- providing linkage areas to ensure connectivity among caribou population centres;
- controlling access and human activity — especially backcountry winter recreation — in caribou ranges; and
- separating caribou from predation by avoiding the enhancement of Moose, deer, and Elk populations near caribou habitat.

Habitat management strategies for caribou exist, or are under development, in land-use plans in all administrative regions in which Mountain Caribou occur.

At the stand level, the overall goal for caribou habitat management is to maintain a stand that is suitable for use by caribou continuously through time. Both single-tree selection and group selection have the potential to maintain caribou habitat, provided the level of removal (by area, volume, or basal area) is low ($\leq$30%) and entries are infrequent (e.g., once every 80 years). Because there are different benefits to each system, managers should continue to practice and improve both approaches.

Some key points regarding operational application of partial cutting are:

- On slopes averaging less than about 45%, stands may be partially cut by hand-falling and ground skidding, or with a feller-buncher. Zero-tailswing feller-bunchers, rather than conventional machines, are recommended for single-tree selection.

- On slopes that average more than about 45%, selection harvesting using cable or helicopter systems is recommended. If group or single-tree selection is not chosen, then a strip selection system is suggested rather than clearcutting. However, this approach carries a higher risk to caribou than group or single-tree selection.

- Group selection openings should range from 0.1 to 1.0 ha in size, with a mean of 0.5 ha or smaller. Variation in the size and shape of openings is desirable and will enhance the structural diversity of the stand.

- Use of designated skid trails improves harvest efficiency and minimizes damage to residual trees.

- Selection silvicultural prescriptions should maintain the existing range of species and diameter classes found in the pre-harvest stand.

- In stands where trees have a naturally clumped distribution, as often occurs in the ESSF, it is desirable to maintain that structure by either removing or retaining entire natural clumps. Regeneration management should also encourage clumped rather than uniform spacing.

- Retention of undamaged advance regeneration and residual trees is recommended where feasible.

- Prescribed regeneration standards for operational plans must be appropriate to the site-specific habitat objectives and stand structure. In most cases, this will involve the lowering or modification of traditional stocking standards, and/or modification of spatial planting patterns.

- The species composition of the regenerating stand should be as similar as possible to that of the harvested stand. In caribou habitat, this is typically a mixture of short- and long-lived shade-tolerant conifers.

Results of partial cutting management trials begun in the 1990s are now providing information on 5- to 10-year treatment responses.

In partial cuts, the resources of the site are shared between the regeneration and the residual stand. Planted seedlings of many coniferous tree species are performing well under a wide variety of opening sizes in both ESSF and ICH silvicultural systems trials. As well, the growth rate of advance regeneration and residuals increases after partial cutting. However, the residual trees tend to outcompete seedlings planted near them. Planted seedlings grow better if they are 3–4 m from residual trees.

In the ESSF, wind damage has been very limited (<3%) in partial cuts with approximately one-third basal area or volume removal, but was substantially higher where harvest levels were 50% or higher. In the ICH, windthrow rates have been similar in partially cut areas and unlogged control areas.

Caribou and their sign have been seen in many MCMF partial cuts. So far, caribou responses have been difficult to assess scientifically because partial cuts have been small and scattered. Once partial cutting has been implemented over larger areas, there will be more opportunities to learn how it affects caribou.

The abundance of arboreal forage lichens in partial cuts is lower than in unlogged stands, primarily because there are fewer large trees. Information available so far suggests that light-entry partial cutting can maintain a suitable microclimate and stand structure for the growth of forage lichens on residual trees. There is likely to be a shift in genus composition in the direction of *Bryoria*, but that is probably not detrimental to caribou. It is not yet clear whether the development of lichen abundance on the regeneration in partial cuts will be rapid enough to maintain adequate forage for caribou after several entries.

Some current research is asking how well forests that are managed to maintain caribou habitat meet the needs of other organisms that are associated with old, structurally diverse stands. Results to date indicate that selection harvesting prescriptions with smaller openings are generally more effective in maintaining habitat for mature-forest wildlife species than prescriptions with larger openings. Habitat for some mature-forest species can be retained by protecting dying and dead trees, coarse woody debris, and an intact forest floor during harvesting and silvicultural activities. Because no one harvest prescription is best for all mature-forest species, using a variety or a mixture of small openings is better than applying a single prescription uniformly over the landscape.

The challenge of integrating forest management for timber production with management for Mountain Caribou and overall biodiversity is complex. This challenge is being addressed through a program of adaptive management in which managers as well as researchers are key participants. Successful adaptive management requires explicitly stated assumptions, careful monitoring, and a willingness to alter management if results indicate the need to do so. Significant advances have been made since 1994, but much remains to be learned. In the short term, silvicultural prescriptions and forestry development should follow a conservative management strategy that retains future options. Monitoring of the treatments and their effects is essential to the continuous improvement of the management strategy.

## 1.0 INTRODUCTION

Mountain Caribou, an ecotype of woodland caribou (*Rangifer tarandus caribou*), inhabit mature forests and alpine areas in southeastern and east-central British Columbia. During winter, the caribou feed mainly on the arboreal lichens *Bryoria* spp. and, to a lesser extent, *Alectoria sarmentosa*, which are most abundant on old trees.

For more than 25 years, forest harvesting has been a management concern in Mountain Caribou ranges. The issue has grown as timber harvesting expands into forest types that were previously avoided, particularly high-elevation subalpine fir (*Abies lasiocarpa*) and subalpine fir–spruce (*Picea engelmannii*) types, and certain cedar (*Thuja plicata*)-hemlock (*Tsuga heterophylla*) types. As a result, the demand for information on forest management in caribou habitat has increased. Because timber supply pressures in caribou habitat continue, forest and habitat managers have asked for recommendations designed specifically for British Columbia. This report focusses primarily on winter ranges because it is there that direct conflicts with forestry activities are most severe. Its purpose is to help managers and field staff plan forestry activities in Mountain Caribou winter range.

The habitat requirements of Mountain Caribou, as they are understood today, are incompatible with most current forest management practices. To survive, Mountain Caribou need to be able to spread out over large areas of suitable habitat, where it is difficult for predators to find them. They strongly prefer old-growth forests to young forests in all seasons. Forest harvesting can reduce and fragment areas of suitable habitat, making the caribou more vulnerable to predation. In addition, road access associated with timber harvest may lead to increased disturbance, human-induced mortality, and increased predation by wolves.

Suitable winter habitat for Mountain Caribou has characteristics of old forests (at least 150 years), including abundant arboreal lichens. Forests managed under any silvicultural system that eventually eliminates, or substantially reduces, the number of large, old, lichen-bearing trees will not provide winter habitat for caribou. Such silvicultural systems include clearcutting on normal rotations and selection systems with heavy, frequent stand entries.

Some habitat managers have tried to maintain caribou populations by protecting core ranges from industrial development. However, the strategy of total protection cannot reasonably be applied to all areas used by this wide-ranging species. The Mountain Caribou in Managed Forests (MCMF) program began in 1988 to address the question: Can forest stands be managed, through silvicultural systems and habitat enhancement techniques, to sustain both timber harvest and caribou habitat over the long term? The goal of the program was to produce integrated solutions for managing for Mountain Caribou and timber in southeastern and east-central British Columbia.

*Suitable winter habitat for Mountain Caribou has attributes of old forests, including abundant arboreal lichens.*

The MCMF program resulted in the establishment of a number of investigations and management trials in Mountain Caribou habitat. Although most of the trials were concentrated in an area east of Prince George and in the Quesnel Highland, researchers and managers throughout southeastern and east-central British Columbia contributed substantially to the concepts and strategies developed in the MCMF program. These strategies are expected to apply, with minor modifications for local situations, throughout the range of Mountain Caribou.

The preliminary results of MCMF activities were summarized in *Mountain Caribou in managed forests: Preliminary recommendations for managers* (Stevenson et al. 1994). Since 1994, there have been significant changes both to the knowledge base and to the regulatory framework within which forest management decisions are made:

- Managers have gained more operational experience with partial cutting in the Interior Wetbelt.
- Continued monitoring has increased understanding of the effects of partial cutting on a variety of forest attributes.
- Additional radiotelemetry of caribou and new lichen research have provided information relevant to forest management at both the landscape and stand levels.
- The *Forest Practices Code Act*, introduced in 1995, established new rules and procedures for forest planning and practices.
- New land-use plans that include Mountain Caribou habitat have been established or are in progress.
- New Workers' Compensation Board regulations govern the removal of dead trees during harvesting.
- Mountain Caribou, formerly blue-listed, have been red-listed by the Ministry of Environment, Lands and Parks.

Because of these changes, there has been demand for a revised edition of the 1994 MCMF report.

The objective of this revised edition is to apply the best available information about Mountain Caribou, arboreal lichens, and silvicultural systems to the problem of maintaining habitat for caribou while economically harvesting timber. The report is intended primarily for forest and habitat managers and field staff, to be used in the context of land-use planning. The key features of Mountain Caribou, their habitat, and the arboreal lichens that constitute their winter diet are reviewed. Management objectives for caribou habitat are described and related to British Columbia's land use planning process. The section on the application of selection silvicultural systems in caribou habitat is intended mainly for prescribing foresters and others who need operational details. The results of silvicultural systems trials in Mountain Caribou habitat are summarized, and a series of frequently asked questions are answered.

*This report is intended to help managers and field staff plan forestry activities in Mountain Caribou winter ranges.*

Managers who apply the information and recommendations are encouraged to communicate with their regional and district staff of the B.C. Ministry of Environment, Lands and Parks and their regional Forest Sciences Section of the B.C. Ministry of Forests about planning, implementation, and monitoring.

This report focusses on management of winter ranges and describes an approach to habitat management that has the potential to maintain the structural qualities that allow caribou to use the entire winter range area to forage and to avoid predators. However, management of winter ranges is only one aspect of an overall strategy for maintaining Mountain Caribou. Habitat management outside winter range areas, for example, is equally important to the survival of caribou. Practices that enhance habitat for Moose, deer, Elk, and their predators in adjacent areas may increase predation on caribou during summer, possibly tipping the balance toward extirpation. The broader ecosystem context in which management of caribou winter ranges takes place is outside the scope of this report. The report *Recovery plan for the Mountain Caribou* (*Rangifer tarandus caribou*) *in British Columbia* (Hatter et al. 2000) puts the management of winter ranges within the context of an overall conservation strategy for Mountain Caribou.

# 2.0 MOUNTAIN CARIBOU AND THEIR HABITAT

## 2.1 The Interior Wetbelt

The range of Mountain Caribou corresponds closely with the distribution of the Interior Wetbelt in southeastern and east-central British Columbia (Figure 1). The Interior Wetbelt is composed of the wet and very wet subzones of the Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zone, wet and very wet subzones of the Interior Cedar–Hemlock (ICH) zone, and very wet subzones of the Sub-Boreal Spruce (SBS) zone. The Interior Wetbelt landscape has the following general characteristics (Jull et al. 1998):

- interior mountain ranges that are generally windward to Pacific weather systems;
- high precipitation and deep snowpacks (>2 m), particularly at higher elevations;
- forests naturally dominated by old age-classes;
- low frequency and extent of natural fire; and
- mixed-species stands, often with a multi-layered structure, with abundant snags and coarse woody debris.

Much of the discussion in Sections 2.1.1 and 2.1.2 is summarized from Coupe et al. (1991), Ketcheson et al. (1991), Reynolds (1997), and Jull et al. (1998).

### 2.1.1 Climate and topography

*Location and distribution* — Interior wet-belt forests occupy the mountain ranges of east-central and southeastern British Columbia. The ESSF zone is the uppermost forested zone and lies below the alpine tundra and above the ICH or SBS zone. It occurs at elevations of 1500 to 2300 m in the southeast of the province, and 900 to 1700 m in the northern range of Mountain Caribou. The ESSF is the most extensive of all forested biogeoclimatic zones in British Columbia. The ICH is the predominant low- to mid-elevation forested zone below the ESSF, except north of about 54 degrees, where the SBSvk1 replaces the ICH.

*Ecological conditions* — The ESSF, SBS, and ICH zones in the Interior Wetbelt are influenced by Pacific air masses that produce the wettest climate in the interior of British Columbia. In these zones, snowmelt and seepage from upslope contribute to the hydrologic regime, minimizing summer soil moisture deficits. However, the difference in elevation between the ESSF and lower-elevation zones results in dramatic differences in overall climate, length of growing season, forest composition, and snowfall (Figure 2).

*Mountain Caribou distribution is closely tied to the Interior Wetbelt.*

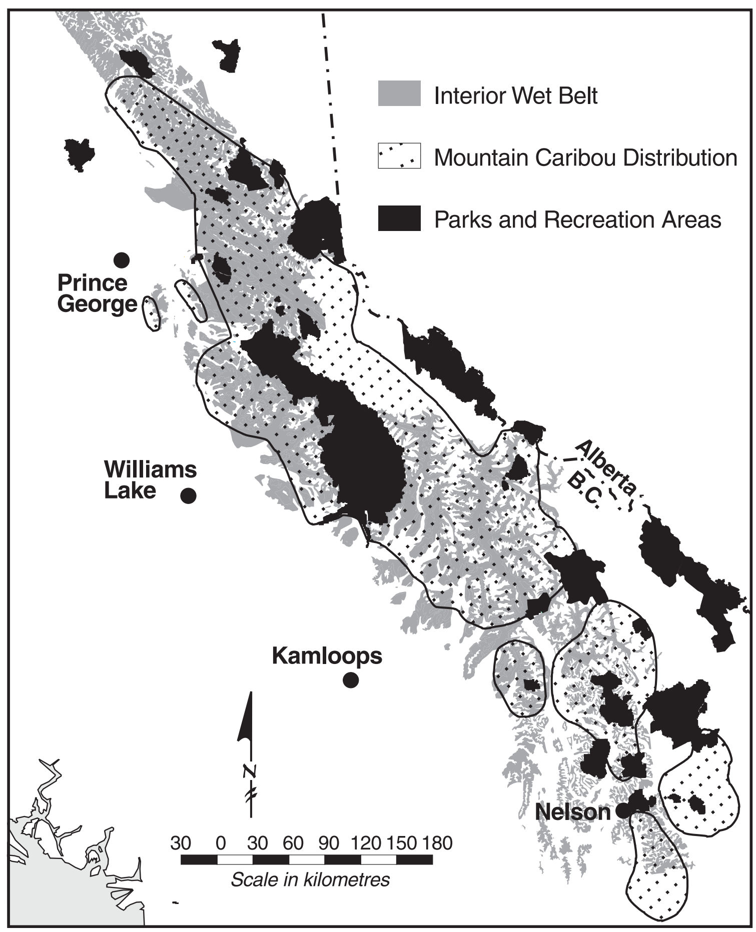



**Figure 1. Distribution of Mountain Caribou and the Interior Wetbelt.**

**Table 1. Summary of mean climatic characteristics for wet and very wet ESSF and ICH biogeoclimatic subzones, and very wet SBS subzones (adapted from Reynolds 1997).**

| *Biogeo-climatic subzones* | *Total Annual Precip. (mm)* | *Summer Precip. (mm)* | *Winter Precip. (mm)* | *Annual Snowfall (cm)* | *Mean Annual Temp. (°C)* | *Extreme Coldest Temp. (°C)* | *Extreme Warmest Temp. (°C)* | *Frost-free Period (number of days)* | *Growing Degree Days > 5°C* |
|---|---|---|---|---|---|---|---|---|---|
| ESSF (wet and very wet) | 1494 | 479 | 1065 | 1065 | -1.0 to + 0.3 | -39.3 | + 32.1 | 69 | 729 |
| ICH (wet and very wet) | 988 | 397 | 591 | 385 | + 4.1 | - 40.9 | + 35.3 | 98 | 1241 |
| SBS (very wet) | 1235 | 472 | 763 | 334* | + 2.6 | - 47.0 | + 36.1 | 93* | 1217* |

*Note: Summary includes data for Prince George, Cariboo, Nelson, and Kamloops forest regions only.*

* *No data from SBSvk1 subzone for this climate parameter. Cited data are from Aleza Lake and MacGregor stations in SBSwk1 subzone only.*

The wet-belt ESSF has a cold, wet, and snowy climate (Table 1). The snowpack typically averages 2 to 4 m. The upper ESSF is one of the most limiting areas for forest growth in British Columbia. At lower elevations the forest is continuous, but at upper elevations it thins to subalpine parkland. In most of the wet-belt ESSF, Engelmann spruce and subalpine fir are the only climax tree species, and stands at higher elevations are dominated by subalpine fir. In the southern part of the Interior Wetbelt, however, whitebark pine (*Pinus albicaulis)* and alpine larch *(Larix lyallii)* may also be climax (or persistent late-seral) species at subalpine elevations.

*Wet-belt ICH, SBS, and ESSF share a wet climate, but the ESSF has more snowfall and a shorter growing season.*

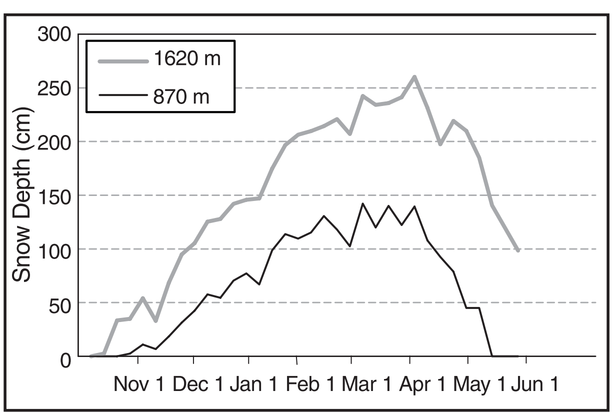



**Figure 2. Mean snow depth at 1620 m (upper ESSF zone) and 870 m (ICH zone) at Mount Revelstoke, 1993-1999.**

In contrast, the wet-belt ICH and SBS have a more temperate climate and a longer summer growing season (Table 1). These zones are among the most productive forestlands in the interior of British Columbia. In the ICH, tree species diversity is among the highest in the province. Western redcedar and western hemlock dominate climax ICH forests, while white spruce (*Picea glauca*), Engelmann spruce, and subalpine fir are also common, especially at higher elevations or in areas of cold air drainage. In wet-belt SBS, hybrid white spruce (*P. glauca x engelmannii*) and subalpine fir predominate in climax stands, while cedar and hemlock are rare or absent.

*Forest productivity* — Climatic differences between high-elevation ESSF and lower-elevation zones are reflected in differences in forest productivity, usually expressed as site index — the average height of the largest trees on a site at 50 years of age. (For further detail on site index, refer to BC Ministry of Forests 1997b). In the

ESSF zone, site indices of Engelmann spruce and subalpine fir are negatively correlated with both elevation and latitude (Klinka et al. 1996). Spruce site index decreases 2.9 m and subalpine fir decreases 2.5 m with every 100 m increase in elevation and 1 degree increase in latitude. Site indices for the upper and lower elevational range of the ESSF range from 9 to 18 m at 49 degrees latitude to 4 to 13 m at 56 degrees latitude (Klinka et al. 1996). Low site indices raise the question of the viability of forest harvesting at upper elevations in the ESSF:

> *Current harvest rates of old-growth forest stands and the method and distribution of logging in this zone suggest that there is currently a limited recognition of the upper-most limit for harvesting or an economic timberline . . . (This is) defined as the elevational limit above which utilization of the timber resource or managing for timber production should no longer be considered viable because forestry operations cease to be biologically and economically feasible.* (Klinka et al 1996, p. 193)

The ICH and SBS are generally much more productive for forest growth than the ESSF (BC Ministry of Forests 1997b). On zonal (mesic) sites in wet-belt ICH subzones in British Columbia, site indices range from 21 to 24 m for spruce, 18 to 21 m for western redcedar, 15 to 21 m for subalpine fir, and 15 to 18 m for western hemlock. Drier sites and well-drained moister sites will generally have lower and higher site indices than mesic sites, respectively.

### 2.1.2 Forest cover and dynamics

The wet and very wet subzones of the ESSF, ICH, and SBS are classified as ecosystems with rare stand-initiating events, or Natural Disturbance Type 1 (NDT1). Historically, these ecosystems were usually uneven-aged or multi-storied even-aged, with regeneration occurring in gaps created by the death of individual trees or small patches of trees. When disturbances such as wind, fire, and landslides occurred, they were generally small and resulted in irregular edge configurations and landscape patterns (BC Ministry of Forests and Ministry of Environment 1995).

*Wet-belt ESSF and SBS forests* — Forest succession and stand development in the western mountain ranges of British Columbia is not as well documented as fire-dominated boreal forest types (Weetman 1996), but recent studies have provided some information on the ecological processes that affect wet-belt spruce-fir forests.

*Forest productivity ranges from high in the wet-belt ICH and SBS to very low at upper elevations in the ESSF.*

Because of the cool wet climate, significant natural fires are limited or excluded for many centuries. Long fire-return intervals have been found north and east of Prince George — a mean of 1667 years has been estimated for the SBSvk (DeLong 1998), and 1429 years for parts of the ESSF (Hawkes et al. 1997). In the prolonged absence of fire, Engelmann spruce and subalpine fir appear to develop a stable, self-perpetuating mixed-species climax forest through complementary life history strategies (Aplet et al. 1988).

Self-perpetuation or "dynamic stability" of montane and subalpine spruce–fir forests has been documented extensively in western North America (Oosting and Reed 1952; Shea 1985; Veblen 1986; Veblen et al. 1991; Parish 1997; Lewis and Lindgren 1999; Parish et al. 1999; M. Jull and C. Farnden, unpubl. data). Whereas subalpine fir regenerates prolifically in climax forests, it has a shorter lifespan than spruce, and both young and old trees

*Small-gap disturbances are common and stand-destroying fires are extremely rare in the wet-belt SBS and ESSF. Typically, a self-perpetuating mature climax forest of Engelmann spruce and subalpine fir dominates these landscapes.*

have a higher mortality rate. In contrast, Engelmann spruce appears to have more specific regeneration requirements than subalpine fir, but has a lower mortality rate, achieves greater size, and has a much longer lifespan. As a result of these life histories, and contrary to some conventional wisdom, a greater abundance of subalpine fir in the subcanopy of these forests does not result in a gradual replacement of spruce.

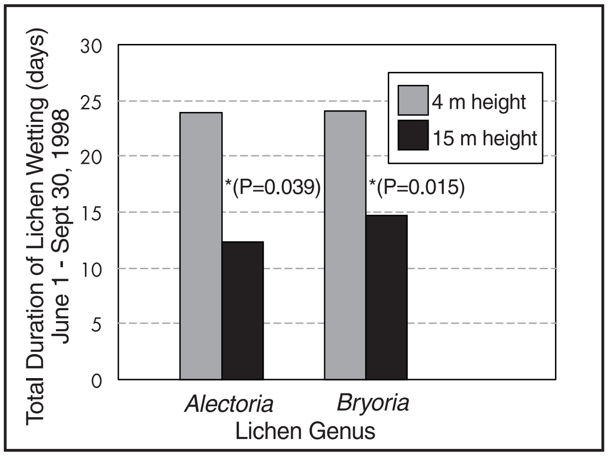



**Figure 3. Duration of wetting of *Alectoria* and *Bryoria* at two canopy heights in the ESSF, Pinkerton Mountain, June to September 1998.**

Recent studies of stand dynamics in wet-belt ESSF and SBS forests in British Columbia (Parish 1997; Lewis and Lindgren 1999; Parish et al. 1999) clearly support results obtained in these forest types elsewhere. The pattern of establishment, growth, release, mortality, and past and current species composition of old wet-belt spruce–fir stands indicates that the predominant disturbance regime is small-scale biotic disturbances by insects and diseases that kill individual trees or groups of trees. Endemic bark beetles are the most likely agent of gradual stand renewal. Continual small-gap disturbance has maintained a mixed-species spruce–fir composition and multi-aged stand structure over very long periods.

*Wet-belt ICH Forests* — Little information is available on the natural disturbance regime and dynamics of ICH forests; however, studies are in progress in the northern (A. Hoggett, pers. comm. 1999) and central (A. Arsenault, pers. comm. 1999) portions of the ICH. Preliminary results indicate that, like the wet-belt ESSF, wet ICH subzones have very long natural fire return

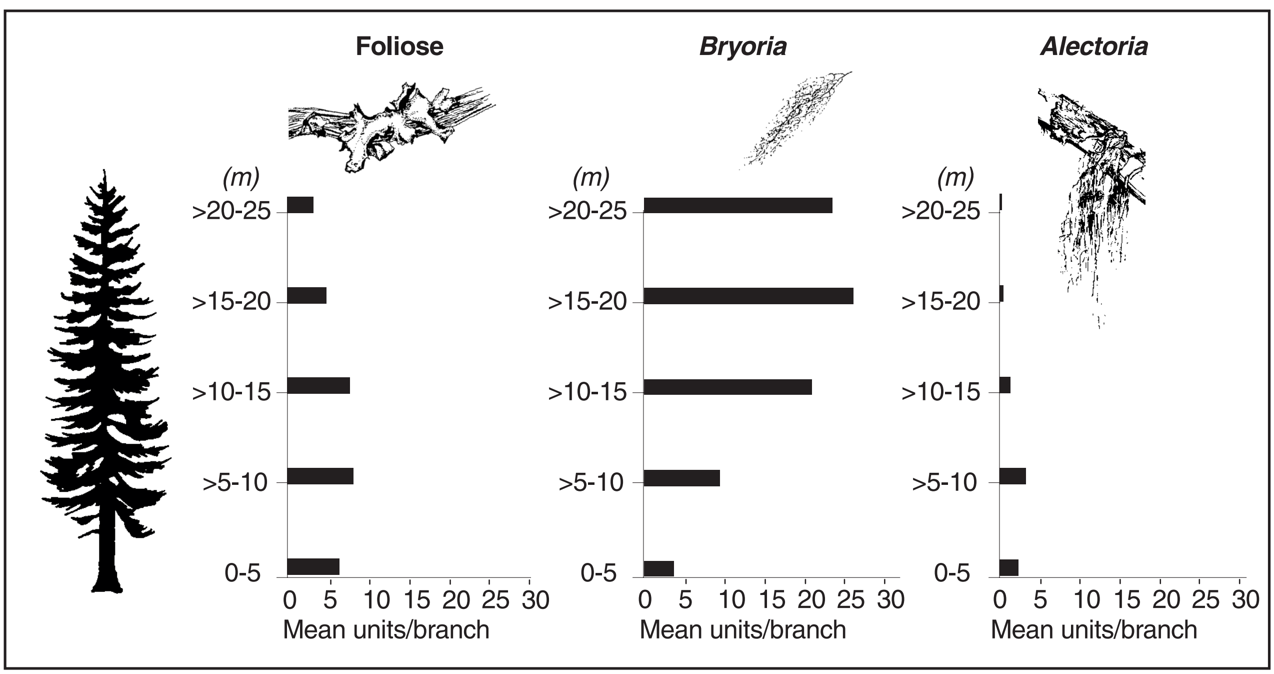



**Figure 4. An example of vertical zonation of lichen abundance in the ESSF.**

intervals, and most of the forests exist for many centuries without large-scale stand-replacing fires. Recent fire occurrence in the ICH has mostly been associated with human activities such as railroads, mining exploration, and escaped slashburns. In the northern ICH, stand disturbances by a defoliating caterpillar, the western hemlock looper (*Lambdina fiscellaria lugubrosa*), occur episodically over long time intervals. Sustained defoliation by hemlock looper kills or weakens trees, and sometimes kills entire stands, particularly hemlock growing on poor sites.

Topography is also a major factor influencing disturbance regime in the wet-belt ICH (Arsenault 1998). Forests located on seepage sites, lower slopes and benches, north and east aspects, and narrow, shaded valleys are often much older than forests on mid- and upper slopes. Stands such as these may develop special structural attributes associated with very old forests, such as large-diameter standing trees and coarse woody debris, hollow trees, very old woody substrates, and a high level of structural diversity on both horizontal and vertical dimensions. The canopy may be complex and multi-storied, offering a variety of niches for epiphytes, birds, mammals, and arthropods.

### 2.1.3 Ecology of arboreal lichens

The distribution and abundance of arboreal lichens in forest stands is intimately connected with the structure of those stands. Tree canopies provide vertical climate gradients along which lichen community composition is ordered (Coxson et al. 1984). In the upper canopy, lichens receive more light and readily intercept rain and snow. However, the upper canopy also has greater wind exposure, leading to rapid drying after each wetting event. In contrast, lichens in the lower canopy receive less light, but can stay wet for prolonged periods after each rainfall or snowmelt, due to the higher humidity and stiller air (Figure 3).

*The absence of fire for many centuries in some ICH stands creates old, complex forests, and unique forest structures and habitats.*

As a result of these vertical gradients, arboreal lichens grow in distinct zones in the canopies of

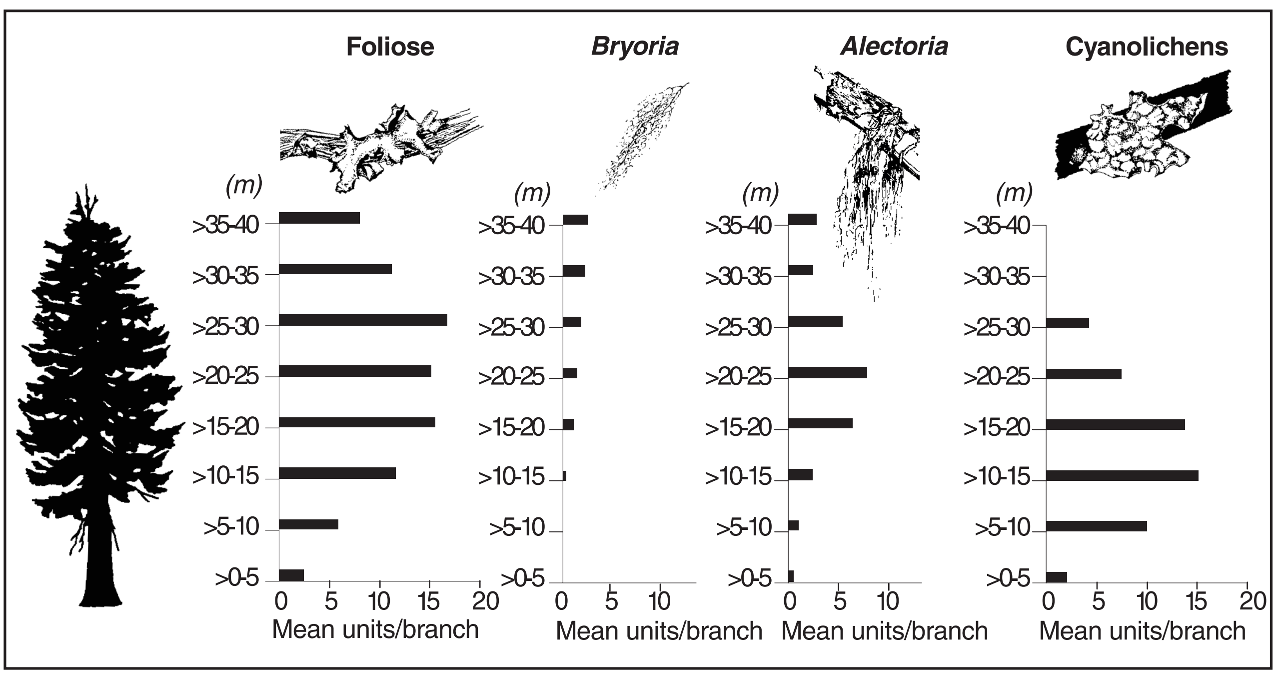



**Figure 5. An example of vertical zonation of lichen abundance in the ICH.**

wet-belt forests (Figures 4 and 5). In high-elevation ESSF stands, such as that illustrated in Figure 4, the upper canopy is dominated by the dark brown to black hair lichens of the genus *Bryoria* (including *Nodobryoria* [Common and Brodo 1995]). In the top several metres of the canopy *Bryoria* can form dense mats beneath live foliage, extending out even to branch ends, sometimes giving a dark appearance to these forests when viewed from a distance (Goward 1998). At mid-canopy heights, *Bryoria* is limited more to the inner defoliated part of branches, and may be less apparent from the ground (Goward 1998). In the lower canopy, the highly visible strands of the yellow/green lichen, *Alectoria sarmentosa*, are often dominant. Less visible, but present throughout the ESSF canopy, are gray-green foliose (leaf-like) lichens, such as *Hypogymnia physodes*. Combining these trends, total lichen loading is generally greatest at mid-canopy height in subalpine forests (Arseneau et al. 1997; Campbell 1998).

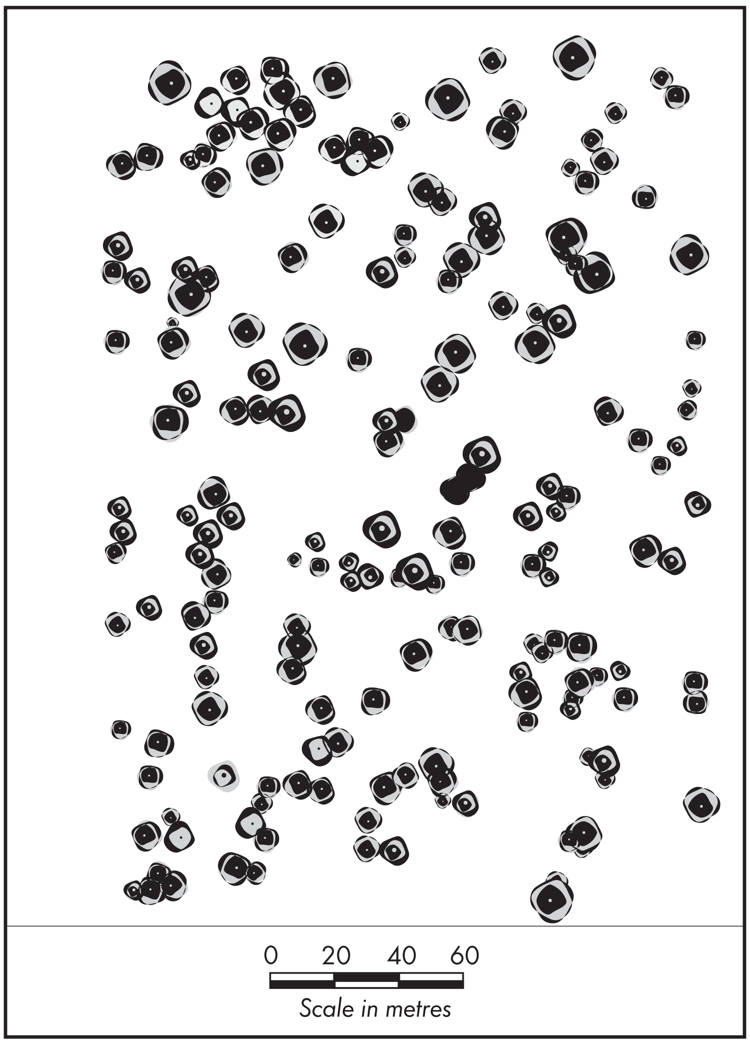



**Figure 6. Spatial distribution of the main canopy trees in an ESSF stand at Pinkerton Mountain, based on digitized imaging from 1:4000 scale aerial photographs.**

In lower elevation ICH forests the lichen zones may be displaced upward in the canopy, as in the stand illustrated in Figure 5. *Bryoria* is now most abundant in the uppermost canopy, whereas *Alectoria* reaches peak levels in the mid-canopy. These lichens are available to caribou only as litterfall on the forest floor and on freshly fallen trees.

In the mid- to lower canopy of ICH stands, additional species enter the vertical zonation. Large foliose cyanolichens (nitrogen-fixing lichens with a blue-green algal component), such as *Lobaria,* are often abundant. In the lower canopy many other species of foliose lichens and crustose lichens (lichens that appear as a surface crust on rock or wood) appear, including some rare old-growth–dependent species (Goward 1994).

The same gradients of light and moisture that characterize ESSF stands are also found in ICH forests. However, the canopy is more closed, mature trees are taller, and the wind regime in the ICH is generally more moderate than in the ESSF. For these reasons, the zone of still air and higher humidity extends further into the canopy. The composition of the lichen community is also affected by the great longevity of some trees in ICH stands.

In general, *Bryoria* — the preferred caribou forage — does not occupy sites where it would face prolonged wetting (Goward 1998). Lichens are a composite organism, each strand containing fungal hyphae that surround thousands of algal cells. These two organisms exist together in a delicately balanced symbiosis. We know that prolonged wetting leads to death of the algal component in many lichen species (Tysiaczny and Kershaw 1979). Frequent, shorter duration wetting events may be more beneficial to *Bryoria*.

This explanation is consistent with the distribution of *Bryoria* described above. It is abundant even on live foliage of highly exposed branches, but restricted to the defoliated portions of branches that are less exposed (Goward 1998). Although *Bryoria* does not seem to tolerate prolonged wetting, it does require repeated wetting for growth. On some sites in drier biogeoclimatic zones, *Bryoria* is limited to branches in the lowermost canopy, where wetting duration after precipitation is extended long enough to support continued lichen growth.

The physiological mechanism that allows nonvascular plants such as lichens to tolerate repeated wetting-drying events is the high concentration of sugars and polyols that buffer membrane functions when dry (Coxson et al. 1992). These substances may also explain the high palatability of *Bryoria* to caribou reported by Rominger et al. (1996). In contrast, *Alectoria* appears more sensitive to periods of prolonged desiccation, and may have lower concentrations of sugars and polyols.

The different ecological strategies of *Alectoria* and *Bryoria* may result in different responses to changes in canopy structure after harvesting. Partial cutting of ESSF stands may change the heights on the trees where the maximum growth rates of *Alectoria* and *Bryoria* occur, as the lichens respond to drier conditions in the canopy. Although overall lichen abundance in the stand will inevitably fall after partial cutting because trees are removed, the proportion of *Bryoria* on the remaining trees may increase after harvesting. On some sites, however, if stand structure is opened up too much, wind-scouring and desiccation may reduce existing lichens and limit new growth.

An opposite response is predicted for *Bryoria* in ESSF forests where restocking after harvest results in a more closed-canopy stand structure. In this case, the abundance of *Bryoria* is expected to decline, especially 40 to 80 years after restocking, when the crowns of developing trees may overlap, reducing light and air exchange in the stand. Furthermore, the small, heavily foliated branches of developing trees have limited ability to support lichen colonization (Esseen et al. 1996; Goward 1998).

Stand structure can also enhance microclimate effects on lichen growth and establishment. Many trees in ESSF forests grow in clumps in which a large tree is surrounded by younger trees (Figure 6). The foliage of the clumped trees can form an integrated mass, the outer perimeter of which effectively mimics a much larger tree in stature, form, and longevity. *Bryoria* abundance is significantly higher on the branches of clumped trees than on isolated trees within the same stand (Campbell and Coxson 2001). Stand management prescriptions that mimic these natural patterns for removal and retention may be more successful in maintaining caribou forage lichens.

*Stand management prescriptions that use natural clumps of trees as units for removal and retention may have considerably more success in maintaining caribou forage lichens.*

Wind is the primary mode of dispersal for *Alectoria* and *Bryoria*, although birds and arboreal rodents also transfer lichen propagules from one tree to another. Thallus fragments are important dispersal structures in both genera. Some species also produce fungal spores and small vegetative propagules. The tallest trees in a stand are especially important as dispersal sources, both because they support disproportionately high lichen biomass (Campbell and Coxson 2001) and because the distance that a wind-borne propagule can travel increases with the height of its release point.

#### 2.1.4 History of forest and land use

Forestry has been the dominant land use in the Interior Wetbelt throughout the twentieth century, but most of the timber that has been harvested has been removed in the last three decades. Outbreaks of spruce beetle or hemlock looper have resulted in increased forest harvesting in parts of the Interior Wetbelt.

Before pulp mills were built in the interior of British Columbia in the 1960s, most forest harvesting in Mountain Caribou habitat targeted spruce and Douglas-fir sawlogs and pole-sized cedar. A variety of harvesting systems were tried, including diameter-limit harvesting, low-volume selective logging, alternate cut-and-leave strips, and cutting of trees less than 11 inches (27.9 cm) dbh with retention of seed blocks (Stevenson and Hatler 1985). Some of these partial cuts resulted in silvicultural successes and others in failures, but the primary reason for abandoning partial cutting was economic – the need for higher utilization to meet the market demand for pulp and other timber products.

Since 1966, when utilization standards for merchantable timber were changed, the vast majority of blocks harvested in the Interior Wetbelt have been clearcut. As early as the 1970s, however, some partial cutting was done in the ESSF in the southern Selkirks and the North Thompson area in an effort to maintain habitat for Mountain Caribou. Some of these blocks were cut to a diameter limit and others were salvage or insect control blocks in which only damaged trees were removed. In the 1990s there was an increase in both experimental and operational partial cutting in caribou habitat, but partial cuts remain a very small proportion of the total area harvested each year in Mountain Caribou range.

*Forest harvesting, road access, and backcountry recreation in Mountain Caribou ranges have increased dramatically in the last three decades.*

Accompanying the expansion of forest harvesting has been an expansion of the road system. Although the basic transportation system for the province — main and secondary highways — expanded by only 18% between 1950 and 1990, forest roads expanded 4100% (from 850 to 35 000 km) during the same time period (B.C. Ministry of Environment, Lands and Parks 1998).

One consequence of road development has been increased human activity in remote areas. Stevenson and Hatler (1985) noted a number of areas where backcountry recreation, especially snowmobiling, was thought to adversely affect caribou on high-elevation winter ranges. Since 1985, the geographic extent and intensity of winter backcountry recreation has dramatically increased. The combination of more road access to high elevations, more powerful machines capable of traversing difficult terrain, and more people practicing the sport, has led to snowmobile activity in many new areas (Simpson and Terry 2000). Biologists have repeatedly observed declining use by caribou of areas of intensive snowmobile activity.

Agriculture, settlement, utility, and transportation corridors occur throughout the range of Mountain Caribou, but are largely concentrated in major valley bottoms. These developments have fragmented, or have the potential to fragment, caribou habitat. Damming of rivers for hydroelectric power has affected caribou by flooding valley bottom habitat; in the southern half of Mountain Caribou range, nearly every major valley has been affected. Mining has generally had a low impact on caribou as it affects only small areas, but in a few cases mineral exploration or mine development has resulted in the construction of roads into caribou habitat that was otherwise inaccessible.

## 2.2 Caribou Distribution and Ecology

All caribou in British Columbia are of the woodland subspecies, but because of differences in foraging behaviour and habitat use, three ecotypes — northern, mountain, and boreal — have been recognized (Heard and Vagt 1998).

**Table 2. Current population size, trend and density of Mountain Caribou subpopulations (Hatter et al. 2000).**

| Subpopulation | Population | | Range | | Density |
|---|---|---|---|---|---|
| | Size [a] | Trend | Potential ($km^2$)[b] | Occupied ($km^2$)[c] | (no./1000 $km^2$) |
| Hart Ranges | 450 | Stable | 21,970 | 9,529 | 47 |
| North Cariboo Mtns | 425 | Stable | 6,690 | 4,925 | 86 |
| Wells Gray South | 400 | Stable | 11,238 | 9,984 | 40 |
| Revelstoke | 375 | Stable | 8,560 | 7,728 | 48 |
| Central Selkirks | 215 | Stable | 5,706 | 4,757 | 45 |
| Wells Gray North | 200 | Declining | 7,654 | 6,110 | 33 |
| Narrow Lake | 65 | Stable | 432 | 425 | 151 |
| Central Rockies | 50 | Stable | 9,734 | 6,968 | 7 |
| Barkerville | 40 | Stable | 1,509 | 2,530 | 16 |
| South Selkirks | 35 | Declining | 3,456 | 1,392 | 25 |
| South Purcells | 20 | Declining | 6,829 | 2,953 | 7 |
| Monashee | 15 | Declining | 1,745 | 2,073 | 7 |
| George Mountain | 10 | Declining | 442 | 441 | 23 |
| **Total** | 2300 | | 85,964 | 59,815 | 41 |

[a] Numbers are estimated 1999 late winter population: some populations are more intensively and frequently surveyed, leading to more accurate trends.
[b] Current potential range.
[c] Current occupied range.

Mountain Caribou live in the wet-belt mountains where they use the deep snowpack in high-elevation winter ranges as a platform to reach arboreal lichens in tree canopies. The entire world population of about 2300 Mountain Caribou lives in British Columbia, although about 35 of them also range into northern Idaho and Washington. Although the population has been divided into 13 subpopulations (Simpson et al. 1997), some of these subpopulations are connected through regular animal movement, while others are isolated (Figure 7). Widespread habitat alteration by fire and timber harvest, changes in numbers and distribution of predators and other prey species, and historic over-hunting have likely been the cause of declines of many subpopulations and the disappearance of Mountain Caribou from portions of their historic range.

*Mountain Caribou use the deep snowpack in high-elevation, late winter ranges as a platform to reach arboreal lichens in tree canopies.*

### 2.2.1 Geographic distribution and status

The 13 subpopulations are distributed from northeast of Prince George in the McGregor Mountains through the Columbia Mountains to the U.S. border in the southern Selkirks (Table 2). Approximately 2000 of the 2300 animals are in a loosely connected population distributed from the northern end of their range to the Trans-Canada Highway between Salmon Arm and Golden. South of the Trans-Canada Highway, the subpopulations are smaller and are largely isolated from each other. Although there are indications that caribou numbers are stable in portions of the central core, most of the smaller, isolated subpopulations appear to be in decline (Table 2).

*Mountain Caribou have been red-listed in British Columbia.*

Mountain Caribou have recently been red-listed by the British Columbia Ministry of Environment, Lands and Parks, meaning that they are considered endangered or threatened. The British Columbia Conservation Data Centre has given the ecotype a ranking of S2, which means "imperilled provincially because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction." In May 2000, they were designated as threatened by the Committee on the Status of Endangered Wildlife in Canada.

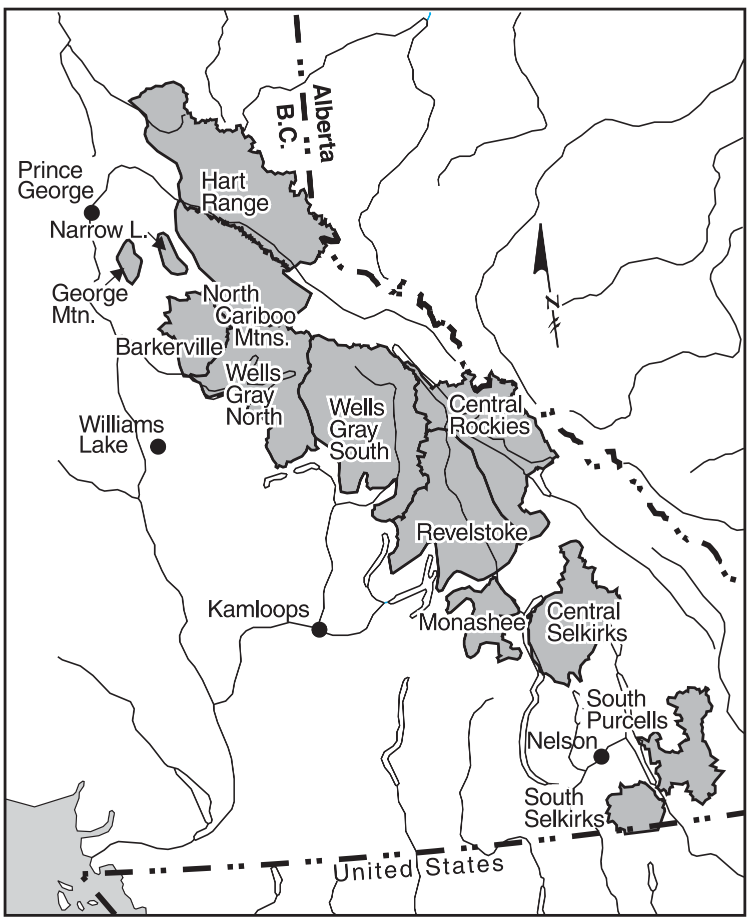



**Figure 7. Current distribution of Mountain Caribou subpopulations.**

### 2.2.2 Seasonal patterns of habitat use

Mountain Caribou are among the most intensively studied animal species in British Columbia. Movements, home-range fidelity, and habitat preferences have been documented by locating 300 radio-collared caribou approximately 15 000 times across all 13 subpopulations (Simpson and Woods 1985; Antifeau 1987; Rominger and Oldemeyer 1989; Servheen and Lyon 1989; Seip 1990; 1992; Apps and Kinley 1998, 2000; Hamilton 1999; Terry et al. 2000; Young and Roorda 2000; Apps et al. 2001). Across their range and in all seasons, Mountain Caribou prefer old forests to younger stands. Although all Mountain Caribou exhibit similarities in seasonal habitat use, varying predation patterns and snow conditions have resulted in significant differences among subpopulations and individuals within subpopulations. Caribou habitat-use patterns have usually been categorized into four seasons based on elevational movements (Table 3).

*Early winter* — Caribou in the rugged Columbia Mountains near Revelstoke, where the snowpack is very deep, show the double elevational migration that typifies these animals (Figure 8). The late winter snowpack is so deep that arboreal lichen is generally absent from the lower 3–4 m of subalpine trees. When snow falls early in winter and buries autumn foods of sedges and forbs, the caribou consistently move lower in the ICH and forage on box wood (*Pachistima myrsinites*) and lichen on litterfall and on windthrown trees (Apps et al. 2001). In the ICH, where it is abundant, *Alectoria* can be an important forage item (Rominger et al. 2000). Due to the deep snow, wolves and Cougar are less abundant and predation rates, even at low elevations, are not excessive (Flaa and McLellan, 2001).

**Table 3. Seasonal habitat use by Mountain Caribou (individual animals may deviate from this pattern).**

| | Early winter<br>late Oct. — mid Jan. | Late winter<br>mid Jan. — April | Spring<br>mid April — late May | Summer — fall<br>June — late Oct. |
|---|---|---|---|---|
| **Habitat** | Continuum ranging from lower ESSF zone to ICH zone | Primarily subalpine parkland in upper ESSF zone; occasionally AT zone | Two distinct patterns:<br>• snow-covered habitats in ESSF<br>• snow-free habitats in lower ESSF or ICH | Upper ESSF and AT zones |
| **Forage** | Arboreal lichens, especially as litterfall and on windthrown trees<br>Low evergreen shrubs (especially *Paxistima*) when available<br>Some conifer foliage<br>Occasional browsing on shrubs | Arboreal lichens available on standing trees<br>Some conifer foliage | Arboreal lichens (snow-covered habitats)<br>New green vegetation (snow-free habitats) | Herbaceous green vegetation |
| **Mortality factors** | Wolf and Cougar predation<br>Poaching | Accidents, especially avalanches<br>Wolverine predation | Bear and wolf predation | Wolf, bear, and Cougar predation<br>Early calf mortality is high but mechanisms are not well understood |
| **Key habitat attributes** | Arboreal lichens, especially as litterfall and on windthrown trees.<br>Understory dominated by low evergreen shrubs, not tall shrubs or conifers<br>Snow interception by conifers | Arboreal lichens available on standing trees | Use of snow-covered habitats is likely a predator-avoidance mechanism. In snow-free habitats, caribou select sites where obstructions to visibility and movement are low | Availability of rugged, mountainous summer ranges a key factor in separating caribou from wolves.<br>In plateau areas, large patches of contiguous habitat important for predator avoidance |
| | | | Some cows move downslope in early spring then reascend to calve; others remain high.<br>Most bulls use snow-free habitats | Calving occurs in ESSF or sometimes AT, usually near snowline |

At the other extreme, caribou in the southern Purcell Mountains rarely descend to the ICH (Figure 8). Most populations show patterns that are intermediate between these extremes. When early winter snow covers their autumn foods, the caribou feed on lichens from windthrown trees and from standing trees in the ESSF (Rominger and Oldemeyer 1989; Apps and Kinley 1998; Terry et al. 2000). During years of low snowfall in early winter, they are more likely to use the ICH (Young and Roorda 2000), probably because the shallow snowpack does not permit access to lichens at higher elevations.

*Late winter* — Once the snowpack at high elevations deepens and settles to where it supports caribou enough that they can reach arboreal lichen on standing trees, animals in all subpopulations are found primarily in the upper ESSF and the subalpine parkland. During this season, *Bryoria* is the most important forage lichen for caribou (Rominger et al. 1996). If the snowpack does not reach sufficient depth, fewer caribou use high-elevation forests; however, such low snowfall years appear rare.

Fewer direct conflicts with forestry occur on late winter ranges than on early winter ranges. In the MCMF study area east of Prince George and in the Revelstoke area, more than half of the late winter locations were in subalpine parkland or alpine areas.

*Spring* — In spring, snow melts first at low elevations and new shoots of sedges, grasses, and forbs emerge and are high in digestible energy and protein. Caribou in some subpopulations move from high elevation winter ranges to low elevations to feed on the new growth. Cutblocks and power lines as well as closed forests are used by caribou at this time of year. As in early winter, some subpopulations use low elevations to a greater degree than others. Where predators are commonly found in valleys, caribou may not use low elevations in the spring as often as in areas with few predators. In general, there is less direct conflict with forestry in spring habitats than winter habitats.

*Summer/fall* — In late May, just before female caribou give birth, they usually move to remote,

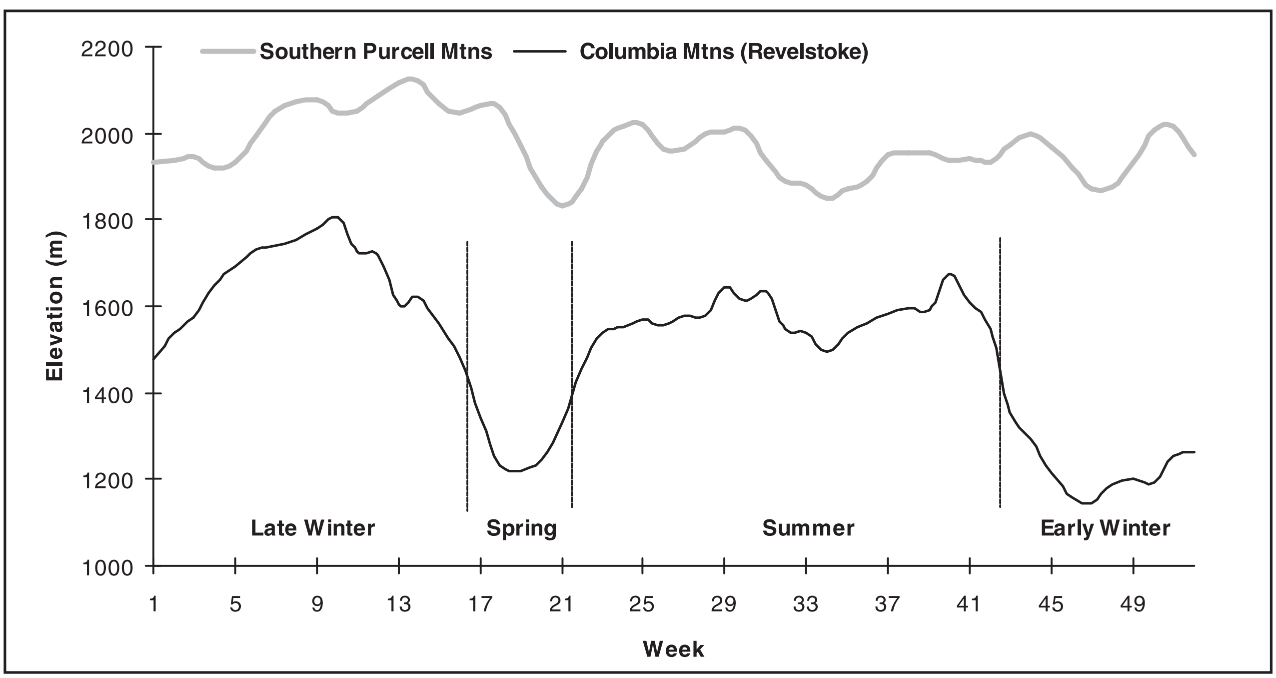



**Figure 8. Running three-week average elevation use by caribou in the southern Purcell Mountains (1991-1997) and the Columbia Mountains (1992-1998).**

mountainous areas near the snowline. Although food is sparse at these elevations, there are few predators to kill their newborn calves. As spring conditions progress from valleys to higher elevations, caribou in all subpopulations are found in a greater variety of habitats than at other times of the year; however, northerly, subalpine basins are most commonly used. As in spring, there are fewer direct conflicts between summer/fall caribou habitat and forestry than with winter habitat. However, habitat changes at a broad landscape scale may affect the intensity of predation on caribou when they are on spring or summer ranges.

*Range fidelity* — Individual caribou do not always use the same seasonal ranges each year but may move among areas (Simpson and Woods 1985). On some seasonal ranges, caribou are found each year, but they are not always the same individuals. Intermittent use of seasonal ranges has also been noticed.

### 2.2.3 Landscape-level habitat factors

*Space and habitat continuity* — Availability of suitable space affects caribou numbers (Bergerud 1980; Bergerud et al. 1984). The amount of space required by a caribou population to make them unpredictable and thus a non-profitable prey species may be significantly more than the space required to obtain sufficient forage.

To efficiently exploit space, suitable habitats should be connected, particularly during winter when costs of moving through deep snow can be onerous. Mountain Caribou consistently show a strong preference for old forests and an avoidance of young stands (Simpson and Woods 1985; Seip 1992; Terry et al. 1996; Apps and Kinley 1998, 2000; Young and Roorda 2000). Although caribou will cross openings such as recent clearcuts, there is an energetic cost if the snow penetration is high. More restrictive to caribou movement than openings, however, are areas with thick vegetation, such as young forests. Caribou appear to avoid crossing densely vegetated areas in any season, perhaps because predators are difficult to detect there. Forest development plans should ensure that harvest blocks are located in space and time to ensure that suitable habitats are not isolated.

*Access* — Vehicle access into caribou ranges increases the risk of illegal hunting and human disturbance. Illegal hunting is a minor mortality factor, but some animals are shot, perhaps mistaken for Elk or deer.

During winter, subalpine parklands attract recreational users as well as caribou. Roads and trails to high-elevation cutblocks often result in greatly increased snowmobile activity on late winter ranges. Caribou may tolerate low levels of snowmobile use, but are displaced from areas of heavy use (Simpson 1987;

*In the ICH zone, more lichen may be available on fallen trees or branches than is within reach on standing trees.*

Simpson and Terry 2000). Other winter recreation activities, such as heli-skiing and backcountry skiing, also disturb caribou. The degree of threat posed by these activities is thought to increase as the size of the affected habitat becomes larger (Simpson and Terry 2000).

Caribou have been found to avoid linear corridors in forested areas, and to be at greater risk of predation when they are near them (James and Stuart-Smith 2000). Ploughed roads and packed trails increase the mobility of wolves and Cougar. In some areas, wolves have used snowshoe and snowmobile trails to access caribou ranges (Bergerud 1978; J. Edmonds, Alberta Fish and Wildlife, Edson, Alberta, pers. comm.) This phenomenon has also been reported in the range of Mountain Caribou.

*Caribou may tolerate low levels of winter recreation, but are displaced from areas of heavy use by snowmobiles, backcountry skiers, and heli-ski operations.*

To some extent, these problems can be addressed through access and recreation management planning. In some areas, resource agencies have worked with snowmobile clubs and commercial operators to control use of key caribou winter ranges.

*Habitat separation from predators* — In the Wells Gray and Quesnel Highland areas, Seip (1992) related the level of wolf predation on caribou to the degree that caribou share ranges with Moose and wolves. A similar relationship has been noticed in the South Purcells and South Selkirks, but there it was with deer, Elk, and Cougar. Predation by wolves or Cougar is low during late winter, but can be high in spring and summer. Management practices that enhance the value of caribou ranges to Moose, deer, and Elk (for example, by increasing edge or encouraging the growth of browse species) may result in increased predation on caribou. As habitat enhancement for Moose, deer, and Elk may be incompatible with habitat management for caribou, managers should plan landscape-level zoning accordingly.

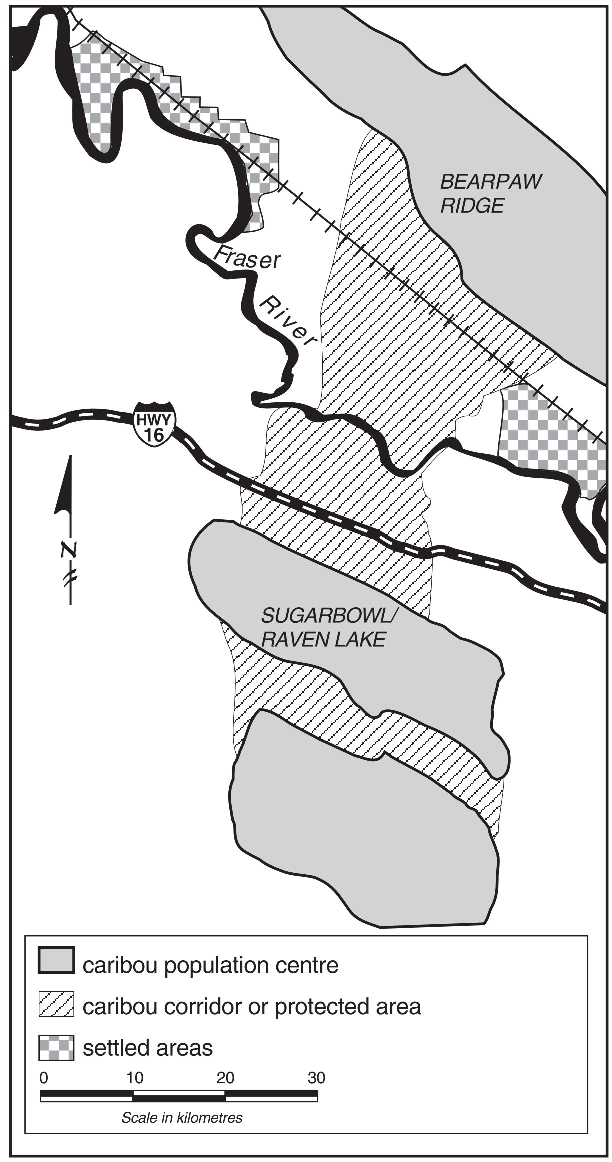



**Figure 9. A corridor designed to link caribou population centres separated by a fracture zone.**

# 3.0 MANAGEMENT OBJECTIVES FOR CARIBOU HABITAT

## 3.1 Ecological Scales of Objectives

### 3.1.1 Regional scale

Habitat management for Mountain Caribou at the regional and provincial scale will be most effectively accomplished through provincial and regional strategies and be reflected in regional land and resources plans (e.g., Kootenay/Boundary Land Use Plan) and Land and Resource Management Plans (LRMPs). Core caribou ranges, including existing areas of use, potential range where appropriate for linking core ranges, and corridor/linkage areas should be mapped and considered in these plans. Suitable wintering areas should be determined from several years of monitoring a geographically representative sample of radio-collared animals. These wintering areas should be delineated using a combination of telemetry locations, habitat suitability/capability models based on telemetry data, aerial surveys, local knowledge, and general habitat characteristics noted on aerial photographs.

Several subpopulations are small and isolated. These "island" populations are more susceptible than larger connected populations to extirpation due to chance events such as accidents, avalanches, and predation by bears, wolves, wolverines, or Cougars. The more isolated the island populations are, the more unlikely that they will be naturally augmented or recolonised by immigration from adjacent populations. Small island populations are surrounded by an edge of suitable/unsuitable habitat, and the smaller the island, the more often caribou are close to the agents that cause the habitat to be unsuitable.

Current and potential "fracture zones" and "linkage areas" must be identified to minimize population fragmentation. Fracture zones are areas between caribou population centres that, because of their resource value to humans, become settled by people or are intensively managed for forestry, agriculture, transportation corridors, recreation, or other uses. Fracture zones vary in size. An example of a fracture zone is the Fraser River valley east of Prince George, between the Sugarbowl–Raven Lake complex and Bearpaw Ridge, which is about 30 km long and 10 km wide (Figure 9). Linkage areas are portions of the fracture zones that are the best remaining sites for corridors that will enable continued movement between caribou population centres. Generally, linkage areas consist of mature and old forest types, although caribou will cross open wetlands and clearcuts when snow is not restricting. Corridors may be managed through low levels of timber harvest or extended rotations to provide mature forest characteristics across the fracture. Foraging habitat within linkage areas is unlikely to be critical, whereas acceptable movement habitat is. Research on this important aspect of caribou ecology has been hampered by the short time required for caribou to make these

*Dense young stands may be barriers to movement by caribou.*

relatively long movements. Increased use of GPS collars that can locate the animal several times a day will help clarify this issue.

The different habitat requirements of caribou, history of timber harvest, and land-use planning processes have created different strategies in different regions or forest districts. For example, in the Prince George and Cariboo regions, caribou use lower elevation ICH forests less frequently than they do in parts of the Nelson Forest Region. As a consequence, the Prince George and Cariboo regional plans include large areas to be left unharvested, but these areas are mostly in the upper ESSF. These plans also include a large area, mostly in the lower ESSF, where forests will be partially cut to maintain caribou habitat values. Fewer areas are identified for specialized harvesting to maintain caribou habitat in the ICH. In portions of the Nelson Forest Region, however, caribou use low-elevation ICH forests extensively in the early winter and spring. Clearcut timber harvest has been extensive in some of these areas and future options are more limited. In these areas, the Kootenay Boundary Land Use Plan stresses retention of a target percentage of the caribou habitat zone in older age-classes.

As an example of zoning at a regional scale, the caribou zones recommended by the Cariboo-Chilcotin Land Use Plan (CCLUP), Caribou Strategy Committee (2000) in a portion of the Quesnel Highland are shown in Figure 10.

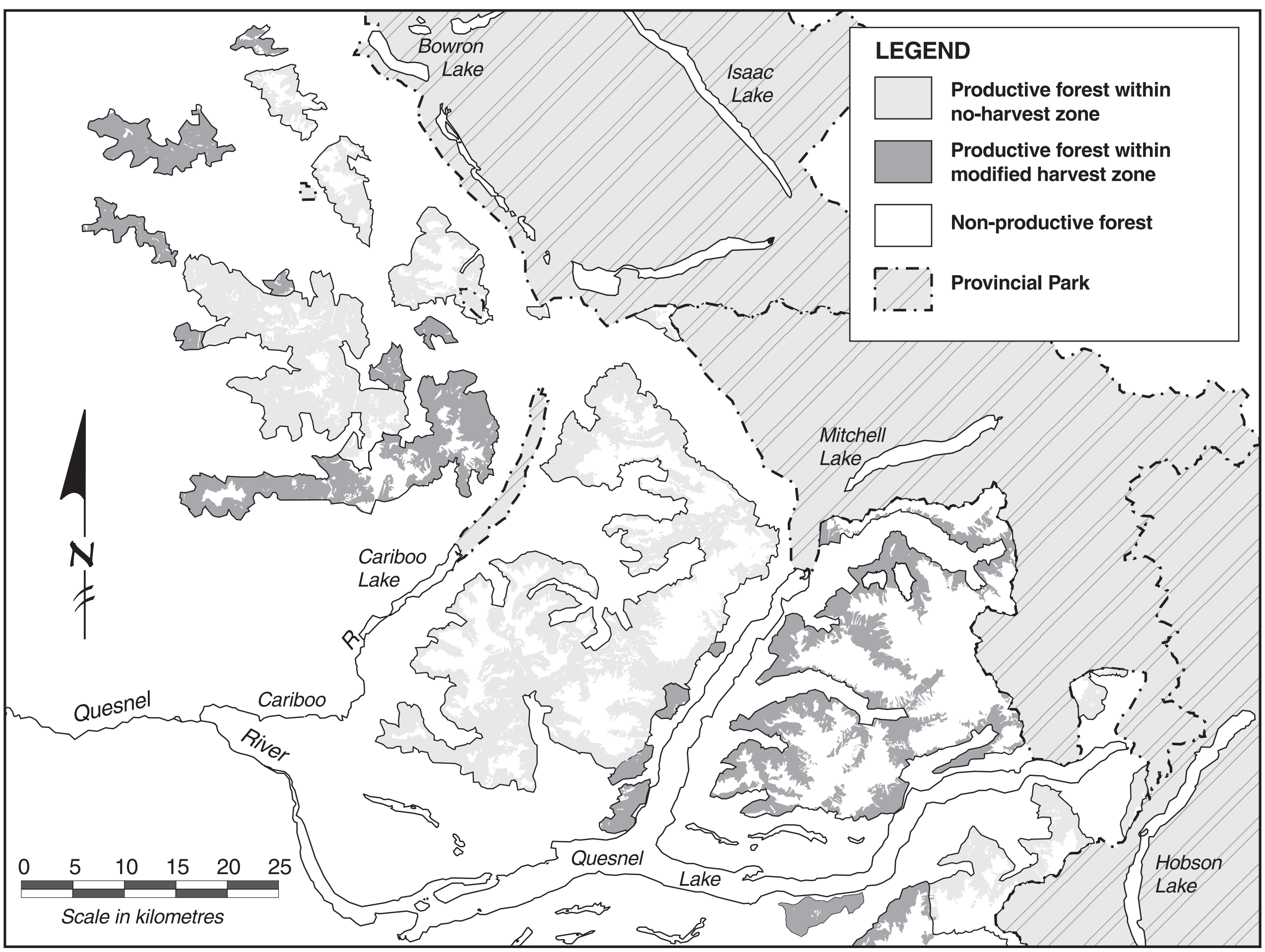



**Figure 10. Areas of no harvest and modified harvest in a portion of the Quesnel Highland, as recommended by the CCLUP Caribou Strategy Committee (2000).**

### 3.1.2 Landscape scale

Habitat management at the landscape scale must be accomplished under the direction and intent of higher level plans and be incorporated in landscape unit plans. Caribou wintering areas or caribou zones should have been identified in higher level or regional-scale plans. Within these areas, the no-harvest zone and special management zone for caribou should be delineated in landscape unit plans.

Caribou appear to avoid young forests. It is therefore important to locate no-harvest and selection-harvest areas in a way that maintains connectivity. Important caribou ranges should not be separated by areas that have been or will be clearcut.

If possible, significant parts of landscape units should be developed over a short time period. Roads should then be deactivated and the area not accessed again for timber extraction for several decades. By scheduling harvesting in this way, development is concentrated in time and space, thereby having the least impact on caribou. If there are areas of caribou habitat that have not been heavily fragmented by past harvest, they should be kept undeveloped as long as possible and cutting should be focussed in already fragmented areas by aggregating cut blocks.

*If possible, significant parts of landscape units should be developed over a short time period.*

### 3.1.3 Stand scale

The overall goal for stand-level management in caribou habitat is to maintain a stand that is suitable for caribou use at all times. The habitat management objectives and suggested silvicultural

## An Approach to Regional and Landscape Zoning

**Preparation**

Identify and map seasonal ranges, fracture zones, and linkage areas. Use telemetry locations, habitat suitability/ capability models based on telemetry data, aerial surveys, local knowledge, and general habitat characteristics.

**Delineate**

***No harvest zone* —** Map designated areas in which forest harvesting and other resource extraction is prohibited. Include large, contiguous blocks of high elevation ESSF forest, parkland, and alpine used as winter range and adjacent middle and low elevation forests used as winter range or serving as linkage areas. Incorporating ICH is especially important where those forests are used extensively during winter.

***Special caribou management zone*** — Map areas where timber harvesting and silvicultural practices will be designed to maintain caribou habitat values. Include peripheral winter range habitat and linkage areas.

***Integrated resource management zone*** — Designate remaining areas as normal integrated resource management zones. The primary caribou management concern is to avoid enhancing Moose, deer, and Elk populations close to caribou habitat.

***Linkage zone*** — Map portions of the fracture zones between areas of caribou habitat that are the best remaining sites for corridors that will enable continued movement between population centres. These corridors may be managed through low levels of timber harvest or through extended rotations to provide mature forest characteristics across the fracture.

**Access management**

Do not construct roads through no-harvest zones unless absolutely necessary. Develop access management plans for special caribou management zones. Work with user groups to develop recreation/snowmobile access plans for both zones.

**Table 4. Stand-level management objectives for Mountain Caribou winter habitat.**

| Habitat management objective | Applicable zone: ICH & ICH/ESSF ecotone | Applicable zone: ESSF | Rationale/comments | Suggested silvicultural objectives |
|---|---|---|---|---|
| Maintain pre-harvest species composition | • | • | Caribou prefer B & BS forest types to S & SB<br>Caribou prefer stands dominated by Cw and Hw to stands dominated by Sw or Pl | Maintain pre-harvest species composition |
| Abundant arboreal forage lichens available in the lower canopy | | • | Lichens in the lower canopy are especially important as forage in the ESSF<br>Lichen availability is low on trees with few low branches, on dense, tangled branches, and on needle-bearing portions of branches<br>In the ESSF, lichen abundance is enhanced by a clumped stand structure | Significant component of trees ≥ Lichen Class 3, including some of Classes 4 and 5[a]<br>Low branches with an inner defoliated zone<br>Moderate branchiness below 4.5 m<br>Maintain a clumped stand structure where it occurs naturally |
| Abundant arboreal forage lichens in the canopy as a whole | • | • | Lichens in the whole canopy are important:<br>• as sources of litterfall<br>• as forage on windthrown trees<br>• as a dispersal source<br>Lichen-bearing snags produce litterfall as the branches break and bark sloughs off | Significant component of mature, lichen-bearing trees<br>A component of declining trees/snags (Wildlife Tree Classes 2-4)[b] |
| Snow interception | • | | Fresh soft snow covers ground forage and litterfall, and makes movement difficult | Manage for snow interception in all or part of stand:<br>• high canopy closure<br>• dense, wide, long crowns<br>• multi-layered structure |
| Maintain low evergreen shrubs where they occur; avoid enhancing forage for Moose, deer, and Elk | • | | Low evergreen shrubs important before snow is deep, especially in the ICH<br>Enhancing habitat for other ungulates may increase wolf and Cougar populations or attract them to caribou ranges | Minimize disturbance of soil and vegetation |
| Minimize visual obstructions | • | • | Caribou seem to prefer areas where they can see around them; there is evidence that they avoid areas where tall shrubs, conifer regeneration, or obstructions restrict visibility<br>This management objective applies also to stands used by caribou during snow-free seasons | Regeneration density control to lower limits of silvicultural acceptability<br>Maintain a clumped stand structure where it occurs naturally |
| Maintain freedom of movement | • | • | Caribou seem to prefer areas where movement is not obstructed by debris or vegetation | Avoid excessive physical obstructions (e.g., windrowed slash, many down trees) |

[a] Armleder et al. 1992.
[b] Wildlife Tree Committee 1993.

objectives for caribou habitat are given in Table 4. Because the way caribou use habitat differs in the ICH and the ESSF, the table shows the biogeoclimatic zones to which each objective applies.

## 3.2 Regional Approaches to Land-Use Planning for Caribou Habitat

Mountain Caribou are found in four Ministry of Forest regions and four essentially corresponding Ministry of Environment, Lands and Parks regions. Caribou habitat management strategies giving operational direction either exist or are under development in each of these regions.

The current strategies and guidelines for the management of Mountain Caribou and their habitat in the Kootenay and Cariboo regions are nested within the Kootenay Boundary Land Use Plan (KBLUP) and the Cariboo–Chilcotin Land Use Plan (CCLUP). The strategies and guidelines apply to all forest districts with Mountain Caribou populations within the plan areas except the Revelstoke portion of the Columbia Forest District where the Ministers Advisory Committee (MAC) provided an independent land-use plan. The comprehensive caribou strategies and guidelines for the CCLUP include both the mountain and northern ecotypes and were finalized in October 2000. The strategies and guidelines for the KBLUP were finalized in January 2001. The MAC plan is near completion.

In the Omineca Peace (Prince George Forest Region) the strategies for management of Mountain Caribou habitat largely evolved within the Prince George Forest District and were extended to the Robson Valley Forest District. They are now nested within the Prince George Land and Resource Management Plan (LRMP) and the Robson Valley LRMP. In the past five years there have been only minor amendments to the strategies and associated guidelines, and these amendments have been largely associated with the zoning maps.

*Recreation plans should be developed in cooperation with user groups.*

In the Kamloops Region, Mountain Caribou are found in the Clearwater, Salmon Arm, and Vernon forest districts. Management strategies and guidelines for habitat management that evolved many years ago in the Clearwater Forest District are now nested within the Kamloops LRMP. Those strategies and guidelines have had only minor amendments based on new information on distribution and habitat use. Strategies and guidelines for management of Mountain Caribou habitat in the Salmon Arm and Vernon forest districts have recently been completed as part of the Okanagan Shuswap LRMP.

Table 5 summarizes the key elements from the various land-use plans in the administrative regions.

**Table 5. Regional forest management prescriptions for Mountain Caribou habitat (based on Table 6 in Hatter et al. 2000)**

| Land-Use Plans/ Forest Districts (FDs) | Prince George LRMP[a] *(Prince George FD)* | Robson Valley LRMP [b] *(Robson Valley FD)* | Caribou Chilcotin LUP[c] *(Quesnel, Horsefly, & 100 Mile FDs)* | Kamloops LRMP[d] *(Clearwater FD)* | Okanagan Shuswap LRMP[e] *(Vernon & Salmon Arm FDs)* | Kootenay Boundary LUP[f] *(Columbia, Arrow, Invermere, & Kootenay Lake FDs* |
|---|---|---|---|---|---|---|
| Subpopulations affected by forest development plans | Hart Ranges, North Cariboo Mountains, George Mtn, Narrow Lake | North Cariboo Mountains, minor part of the Hart Ranges | Barkerville, Wells Gray North | Wells Gray South | Monashee, Revelstoke, & Wells Gray South | Revelstoke, Central Rockies, Central Selkirks, South Purcells, South Selkirks |
| High-elevation and late winter habitat (ESSF) | No harvest with areas identified as having High value to caribou until proven management strategies are developed in areas of medium habitat suitability. High valued areas are excluded from the TSR. | Deferred forest harvesting within high valued habitat for 10 years or until proven management strategies are developed in areas of medium habitat value. | Within caribou range, 65% of habitat identified as no-harvest areas. Remaining 35% designated for modified harvest (described below). | Maintain a minimum of 33% of the caribou habitat such that it retains old growth attributes. Silviculture systems other than clearcutting recommended; clearcuts restricted to 15 ha. | No parkland harvesting. At least 20% of THLB[g] to be reserved now; 7-year research program will determine need for additional reserves or special management areas. | No harvest in parkland and designated caribou no-harvest areas. Elsewhere between parkland and the Caribou Line, maintain 70% in age class 8 or older. |
| Transitional or early winter habitat (ICH & ESSF) | In medium habitat implement alternative silviculture systems to maintain caribou habitat values over a 240-year rotation. | In medium habitat implement alternative silviculture systems to maintain caribou habitat values over a 240-year rotation. | In modified harvest areas, including key early winter range, implement alternative silviculture systems to maintain caribou habitat values. | In transitional habitat maintain 20% of the area such that it retains old-growth attributes through treed islands, ecosystem networks, and riparian buffers. | At least 20% of THLB[g] to be reserved now; 7-year research program will determine need for additional reserves or special management areas. | Below the Caribou Line maintain 30% of the forested area in age class 8 or older (10% age class 9) and an additional 20% in alternative silvicultural systems to maintain caribou habitat values in the ESSF. In the ICH, 40% in age 8 or older (10% age class 9). |

**Table 5. con't.**

| Land-Use Plans/ Forest Districts (FDs) | Prince George LRMP[a] *(Prince George FD)* | Robson Valley LRMP[b] *(Robson Valley FD)* | Caribou Chilcotin LUP[c] *(Quesnel, Horsefly, & 100 Mile FDs)* | Kamloops LRMP[d] *(Clearwater FD)* | Okanagan Shuswap LRMP[e] *(Vernon & Salmon Arm FDs)* | Kootenay Boundary LUP[f] *(Columbia, Arrow, Invermere, & Kootenay Lake FDs* |
|---|---|---|---|---|---|---|
| Movement corridors | Maintain integrity of corridors through extended rotations (240 years) and other criteria. | Maintain integrity of corridors through extended rotations (240 years) and other criteria. | No specific strategies; follow strategies for modified harvest areas. | Must be 1-1.5 km wide with at least 30% of the timber sufficient in age/ size to intercept snow. | At least 30% of the timber within corridors must provide snow interception and exhibit pruning of lower branches. | No specific strategies except maintain continuous broad corridors of old-growth and mature at regular intervals to connect pockets of old growth forest. |
| Access management | Where there is harvesting in or adjacent to caribou habitat, minimize amount of open winter roads. Recommend constraint on backcountry recreation that is incompatible with caribou conservation. | Where there is harvesting in or adjacent to caribou habitat, minimize amount of open winter roads. Recommend constraint on backcountry recreation that is incompatible with caribou conservation. | Define parts of the caribou range sensitive to recreational activities, especially snowmobile use, and address through sub-regional planning. | No specific strategies, but some local recreation plans exist. | Manage summer and winter backcountry recreation through local planning. Develop access management plans. Include caribou concerns in mine planning. | Avoid access to parkland. Develop recreation access plan for caribou area. Assess CBR proposals. Work with snowmobile club to restrict snowmobile access to areas away from late winter habitat |

[a] Prince George LRMP.
[b] Robson Valley LRMP.
[c] CCLUP Mountain Caribou Strategy, October 2000.
[d] Kamloops LRMP, Appendix 10: Timber Harvesting Guidelines for North Thompson Caribou Habitat
[e] Okanagan–Shuswap LRMP Final Recommendations. Mountain Caribou Habitat RMZ. J. Morgan, pers. comm.
[f] Kootenay Boundary LUP.
[g] Timber Harvesting Land Base.

# 4.0 SILVICULTURAL SYSTEMS FOR MAINTAINING CARIBOU HABITAT

## 4.1 Rationale for Partial Cutting in Caribou Habitat

At the stand level, the goal for management of caribou winter ranges is to maintain each stand continuously as suitable habitat. Clearcutting obviously does not meet this goal because the complete removal of trees also causes the complete removal of arboreal lichens. Although caribou will cross clearcuts, these areas do not provide attributes needed by caribou during winter.

The general objective is to maintain late seral stand conditions with trees that have abundant arboreal lichen available as forage (see Section 3.1.3). Partial cutting systems can provide these conditions continuously if relatively low volumes are removed and long time periods are allowed between cuts. Openings that are small but variable in size and shape create structural diversity within a matrix of old forest. This approach reasonably emulates natural disturbance patterns and is compatible with the silvics of the tree species involved (see Section 2.1.2). It provides the basis for the prescriptions recommended in the following sections.

*The goal for management of caribou winter ranges is to maintain each stand continuously as suitable habitat.*

On areas already clearcut, it will take a rotation or more before arboreal lichens are re-established with sufficient biomass to be useful to caribou. Efforts to rehabilitate caribou habitat after clearcutting have met with limited success. Even with techniques such as lichen inoculation and careful stand density control, clearcut areas would not provide even modest lichen-bearing habitat for many decades. Clearcutting fragments caribou habitat, making caribou more vulnerable to predation. Therefore, it is much better to use partial cutting and to maintain large, contiguous areas of caribou habitat rather than rely on clearcutting and restoration.

*Concentrate development to have the least impact on caribou.*

If Mountain Caribou are to be maintained, forest harvesting approaches will have to avoid enhancement of habitat for Moose, deer and Elk. More of these ungulates can lead to more wolves and Cougar and greater predation on caribou. As well, forest harvesting can change the distribution of these species, resulting in greater overlap with caribou range. Clearcutting often promotes early seral vegetation that attracts these ungulates, whereas partial cuts can be designed to minimize the enhancement of early seral vegetation.

## 4.2 Operational Application of Selection Systems

Forest development activity in caribou range must be spatially and temporally concentrated and access must be minimized to have the least impact on caribou. To accomplish this, large cutblocks are encouraged, while block layout should minimize windthrow concerns.

Harvesting activity should be distributed to minimize the number of open roads. Road layout should be planned to enable access control both during and after development. This would include creating single access points to large areas and making provision for gates where appropriate. Roads within blocks should be designed to provide good access for future stand entries.

Significant parts of landscape units should be developed over a short period of time. Roads should then be deactivated and the area not accessed again for timber extraction for decades. Conversely, on a district scale, the timber harvest from caribou range should be an even flow through time as opposed to harvesting all the caribou range within a district over a short period (e.g., 20 years). Partial cutting systems that maintain caribou

**Table 6. Advantages of single-tree and group selection systems for Mountain Caribou habitat.**

| Potential Advantages | |
|---|---|
| Single-tree Selection | Group Selection |
| More flexibility in selecting trees to harvest, therefore high lichen-bearing trees can be retained. | Less risk of damage to residual stems and less associated loss of lichens. |
| More flexibility in developing multi-layered stand structure on a micro level rather than producing series of even-aged clumps as with group selection. | More snags are distant from work areas and therefore retained during harvesting. |
| Impact of logging homogeneously distributed throughout the stand. | Logging costs lower than single tree selection. |
| Dispersed regeneration less likely to deter caribou use than even-aged clumps of regeneration. | More options for post-harvesting silviculture available. |
| Entire stand is structurally suitable for caribou use at any one time. | Influence of residual stand on regeneration can be varied through opening size selection. |
| Advance regeneration is retained, providing growing stock and substrate for lichen colonization. | Leaves much of the stand with no disturbance since logging only occurs in openings. |
| | Typically smaller percentage of cutblock in skid trails. |
| | Risk of windthrow may be lower. |
| | Better snow interception areas within stand. |

habitat include two types of uneven-aged selection systems: group selection and single-tree selection (Figure 11). A comparison of the merits of each system is provided in Table 6, while a description of the key elements of selection systems compatible with maintaining caribou habitat is provided in Tables 7 and 8. Because there are different benefits to each system, and it is not clear which system is better for caribou, managers should continue to practice and improve both approaches. In general, single-tree selection is most likely to be appropriate in stands with a pre-existing uneven-aged structure, whereas the success of group selection is less dependent on the pre-harvest stand structure.

Selection silvicultural prescriptions should be designed to maintain the existing range of species and diameter classes found in the pre-harvest stand. Species or diameter-class "high-grading" of desirable species or large trees should be avoided.

The maximum level of removal in caribou habitat should not exceed 30% by volume, basal area, or area. This percentage applies to the harvestable area within a cutblock and excludes roads, landings, wildlife tree patches, and other reserves. A maximum of 30%, rather that 33%, acknowledges the possibility of some windthrow after harvesting, and also provides the opportunity to designate up to 10% of the block for retention at a later time, should that be necessary to provide a component of very large trees with abundant lichens. A harvest level of 33% may be acceptable if 10% of the block has already been designated as wildlife tree patches. Wildlife tree patches in caribou habitat should be selected on the basis of lichen abundance, as well as for other ecological considerations.

*Both group selection and single-tree selection have the potential to maintain caribou habitat.*

In selection harvesting blocks, as in other harvesting operations, all dangerous trees that could fall into work areas must be removed. In the past, Workers' Compensation Board (WCB) regulations required that all dead or dying trees be removed during harvesting, regardless of whether they were actually dangerous. Current regulations (Workers' Compensation Board of British Columbia 1998) and interpretations define

**Table 7. Harvesting prescription for implementing a group selection silvicultural system in Mountain Caribou habitat.**

**Prescriptions for Group Selection**

- ≤ 30% volume removal on an area basis, including skid trails.
- 80-year cutting cycle.
- Openings should be 0.1 to 1.0 ha, with a mean opening size ≤ 0.5 ha.
- Shape of the openings can vary to incorporate natural clumps of trees within the stand while allowing efficient skidding.
- Distribute openings throughout the block so that the second and third entries can also be well distributed (Figures 13 and 14).
- Keep openings at least 2 tree lengths apart where possible.
- Calculate the area in skid trails to estimate the volume coming from trails as this contributes to the 30% removal.
- Flag boundaries of openings.
- Use GPS to map openings and to track the target volume removal by area, including skid trails.
- Use designated skid trails between openings.
- Retain standing dead trees within the safety regulations of WCB.
- Harvest carefully to minimize damage to residual stems.
- Conventional or zero tailswing feller-bunchers can be used to implement the prescription.

the characteristics of a dangerous tree, and the Wildlife/Danger Tree Assessor's Course trains workers to determine which potentially dangerous trees must be removed during harvesting and which may be safely retained. As many dead or dying trees bear substantial quantities of arboreal lichen, and provide other important biodiversity values, it is important to retain the ones that are not dangerous.

*Wildlife/Danger Tree training helps operators ensure that the work area is safe without unnecessarily removing trees that are not hazardous.*

To address potential windthrow concerns, silviculture prescriptions (and other operational plans where appropriate) should include pre-harvest assessments and documentation of wind-related biophysical hazards, treatment risks, and measures for windthrow mitigation. (For an example see BC Ministry of Forests windthrow cards [British Columbia Ministry of Forests 1998a, 1998b, 1998c, 2000]).

Information about the abundance and distribution of arboreal lichens in a planning unit can be useful to managers. To meet the need for consistent estimates of the abundance of forage lichens within reach of caribou, MCMF researchers developed a photo-based assessment manual. The field guide *Estimating the Abundance of Arboreal Lichens* (Armleder et al. 1992) allows the observer to classify trees by refering to photographs of trees with a known biomass of lichens below 4.5 m. Because the assessments can be done quickly, the method can be used as part of reconnaissance surveys, timber cruises, and habitat monitoring programs. The accompanying user's guide (Stevenson et al. 1998) explains how to carry out lichen assessments and how to use them as a tool for planning in caribou winter ranges.

*Group selection* — The level of basal area or volume removal is controlled by area regulation (Smith 1986) and is measured as the percentage of the area harvested, including skid trials. To maintain caribou habitat, no more than 30% of the stand area should be harvested every 80 years. Harvested openings should not necessarily be geometric shapes but rather aggregations of pre-existing clumps of trees, 0.1 to 1.0 ha in size, to maintain the pre-existing clumpy stem distribution. This approach works with, rather than against, the existing spatial structure of the stand, and avoids arbitrary division of natural clumps. To ensure variability in openings, mean opening size should not exceed 0.5 ha. This average may be applied across a single cutblock or across all the cutblocks being managed as caribou habitat within a cutting permit. Openings should be well distributed throughout the block. Variation in the size and shape of openings is desirable and will enhance the structural diversity of the stand. Table 7 provides more detail about the harvesting prescription.

*Single-tree selection* — The level of removal and timing of future stand entries is usually controlled by BDq regulation (Alexander and Edminster 1977; Guildin 1991). The residual stand is defined by setting stand targets for residual basal area (B), maximum residual diameter (D), and the shape of the post-harvest diameter distribution curve (q).

B should be set at 70% or more of the pre-harvest condition. As a general rule, the basal area for a treatment unit should not be reduced below 20-25 $m^2$/ha. Larger trees carry the highest lichen biomass and are typically more windfirm than codominants and intermediate trees. Therefore, D should be equivalent to the largest diameter class in the pre-harvest stand to ensure substantial post-harvest representation of larger trees. Alternatively, a lower D can be set and a basal area reserve established (i.e., no harvesting of trees above the reserve value). We suggest using a relatively low q value that allows for retention of more basal area in larger trees. Once the target BDq curve has been determined, marking or harvesting rules can be described as the number of trees per hectare to cut in each diameter class. Table 8 presents more detail on the harvesting prescription.

A clumped stand structure can also be encouraged in single-tree selection by marking decisions that favour either retention or removal of small clumps of trees.

*Species selection for regeneration* — Old wet-belt ESSF and ICH forests typically are mixed, multi-layered mature stands of moderately to highly shade-tolerant conifer species. A common stand characteristic of both ESSF and ICH stands in caribou habitat is a species mixture of a relatively long-lived shade-tolerant conifer species with a relatively short-lived, but also shade-tolerant conifer species. In the ESSF, this species mix is spruce–subalpine fir, whereas in the ICH, this species mix is typically western redcedar–western hemlock. The fundamental character of these stands needs to be maintained to maintain and promote a high abundance of arboreal lichens, thereby providing habitat for caribou.

**Principles for Tree Species Selection**

- The species mix and composition of the regenerating stand should be as similar as possible to that of the harvested stand.
- The regenerating stand should be composed of a mixture of shorter- and longer-lived shade-tolerant conifer species.
- Timber management considerations for species selection should be consistent with the maintenance of long-term caribou habitat.
- Short-lived, shade-intolerant tree species (e.g., lodgepole pine, hardwoods) should not be permitted as preferred or acceptable regeneration under an operational plan because the silvics and stand characteristics produced by such species are incompatible with long-term maintenance of caribou habitat.

**Table 8. Harvesting prescription for implementing a single-tree selection silvicultural system in Mountain Caribou habitat.**

**Prescriptions for Single-tree Selection**

- $\leq$ 30% basal area or volume removal, including skid trails.
- 80-year cutting cycle.
- Use a BDq curve to decide how much to cut in each diameter class to achieve $\leq$ 30% basal area removal.
- q should be set low to allow good representation of larger trees; e.g., q = 1.2.
- Diameter (D) should be equivalent to the largest pre-harvest diameter class to allow good representation of larger trees; e.g., D = 80 cm.
- Consider using a somewhat lower value for D and establishing a basal area reserve above D (i.e., no harvesting of the largest trees on the site).
- Generally, basal area (B) of live trees should not be below 20-25 $m^2$.
- Minimize the amount and width of skid trials; e.g., minimum 40 m apart and maximum 4-5 m wide.
- Calculate the area in skid trails to estimate the volume coming from trails because this contributes to the percentage removal.
- Implement the prescription by marking-to-cut using these additional marking criteria:
    a) tree species: maintain the Abies/spruce stem mixture in the stand; target any pine that may be present;
    b) tree class/quality: take the worst, leave the best by marking the poorer grades of trees from the stand;
    c) lichen loading: if a choice is to be made between two trees of equal status, mark-to-cut the one with the least arboreal lichen; and
    d) mark entire natural groups of trees (typically 3-5 trees) rather than thinning groups.
- Use designated skid trails.
- Retain standing dead trees within the safety regulations of WCB.
- Harvest carefully to minimize damage to residual stems.
- Use a zero tailswing feller-buncher or hand-falling to implement the prescription.

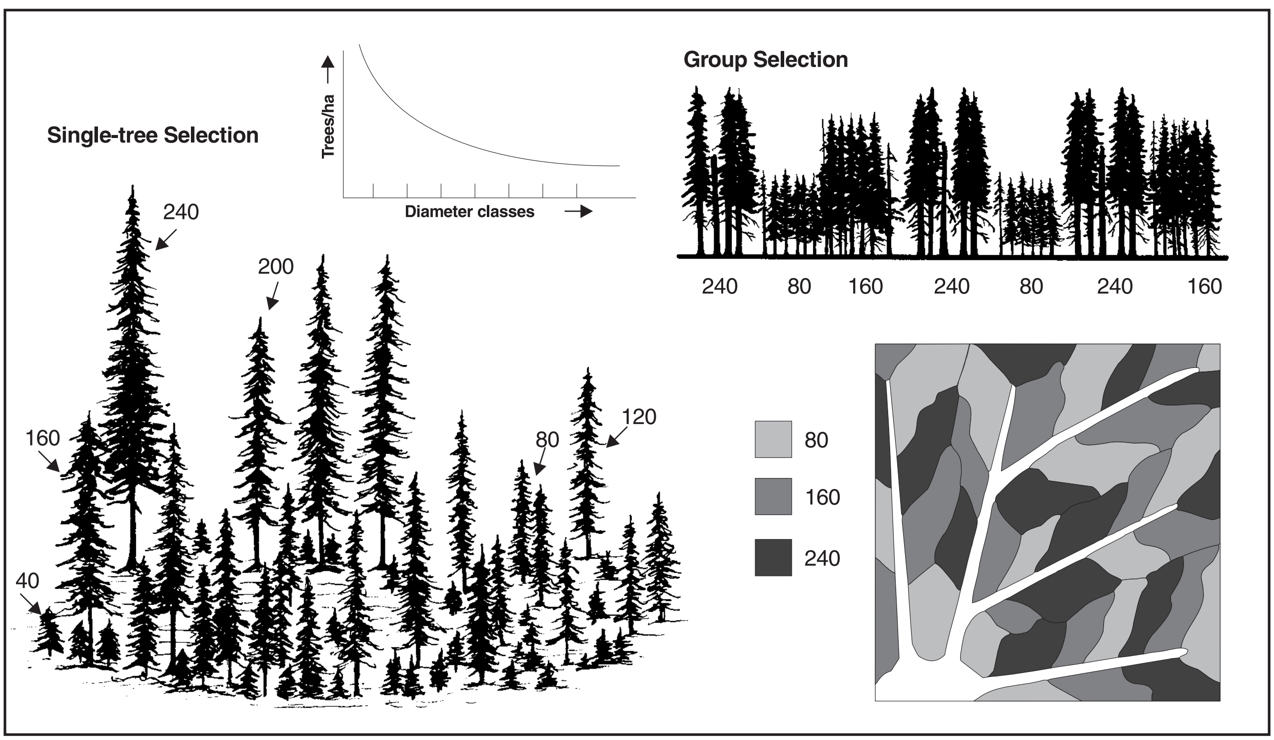



**Figure 11. Silviculture systems suited to maintaining the stand characteristics required by caribou.**

### 4.2.1 Selection systems in the Engelmann Spruce–Subalpine Fir Zone

*Harvesting* — Harvesting in caribou habitat can be conducted in any season, but more harvesting usually occurs in winter because of wet conditions in the ESSF.

For various operational and safety reasons, machine falling with a feller-buncher is typical for the ESSF/ICH on slopes less than about 45%. Experience has shown that better results (i.e., less damage to residual stems and loss of fewer lichen-bearing branches) are achieved using feller-bunchers versus hand-falling and line skidding, especially in single-tree selection systems.

Both conventional and zero-tailswing feller-bunchers have been used to apply the harvesting prescriptions. Large conventional machines can cut and lift bigger trees at maximum reach than can the typically smaller zero-tailswing models. Carefully used conventional machines have produced excellent results in group selection prescriptions, whereas zero-tailswing models have performed better in applying single-tree selection treatments.

Use of designated skid trails with both types of feller-bunchers in selection systems makes the falling and skidding more efficient and minimizes damage to residual tress. Skid trails should be kept as narrow as possible with 4-5-m-wide trails typically achievable. Tracked and rubber-tired skidders have both been used effectively, with the decision on which to use based on a variety of factors including slope, snowpack, skidding distance, and specific terrain conditions.

*Harvesting on moderate slopes* — Mature and old stands on slopes less than 45% are most heavily used by caribou (Figure 12) and therefore should have the highest priority for maintaining habitat value. Some types of ground-based logging equipment can effectively operate on slopes up to 40 to 50%. Harvesting prescriptions are provided in Tables 7 and 8, and Figures 13 and 14 show examples of layouts for selection harvesting blocks.

*Harvesting on steep slopes* — Stands on slopes of more than 45% are used less by caribou (Figure 12) and are more difficult to harvest with a selection system. However, some cable and helicopter systems are compatible with implementing group selection prescriptions on steeper ground and are recommended to ensure the maintenance of caribou habitat (Figure 15). The harvesting prescription would be essentially the same as for gentler ground; any differences would be related only to conducting successful cable or helicopter logging operations.

*Low basal area or volume removal using group or single-tree selection with long cutting cycles has the best chance of maintaining caribou habitat.*

The quality of caribou habitat will be eroded if the decision is made not to use the group or single-tree selection systems on these steeper slopes. To maintain some habitat value, we recommend using a strip selection system with 30% of the cutblock harvested every 80 years, in

*Windthrow assessments are especially important where strip selection is being considered.*

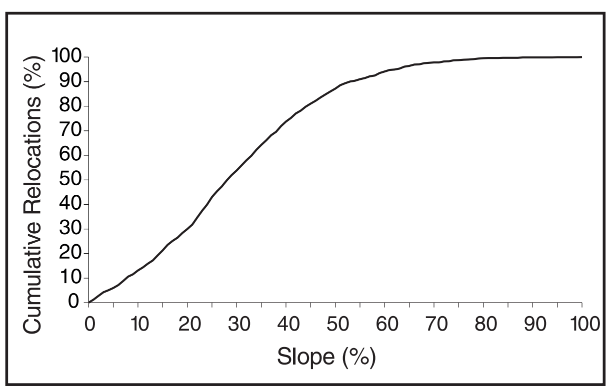



**Figure 12. Cumulative frequency distribution of slope use by radio telemetry–equipped Mountain Caribou for all seasons combined in the Cariboo Forest Region (1993-1998).**

strips not more than 2-3 tree lengths wide (Figure 16). This will result in part of each stand having older lichen-bearing trees at all times, thereby providing some habitat attributes for caribou. This approach is far less desirable than the other selection systems. Long strips are more likely than small openings to channel wind, increasing the risk of windthrow and wind-scouring of lichens. The proponent should do a windthrow assessment and be confident that windthrow will not be a problem, especially if strip selection is used. At certain stages of stand development, strips are more likely to interfere with caribou movements than small openings.

*Retaining advance regeneration can help achieve stand structural goals.*

*Post-harvesting phase* — The goal is to manage stands in such a way that the attributes necessary for caribou are always present. Therefore, the clumpy stem distribution that is typical of ESSF forests should be maintained and encouraged (see Section 2.1.2). Regeneration goals should be appropriate to the site-specific habitat objectives and stand structure. In most cases, this will involve the lowering or modification of traditional stocking standards. As well, spatial planting patterns may need to be customized to the site. Management for moderate numbers of trees in a clumped distribution is expected to minimize obstructions to visibility for caribou, and produce forage lichens earlier.

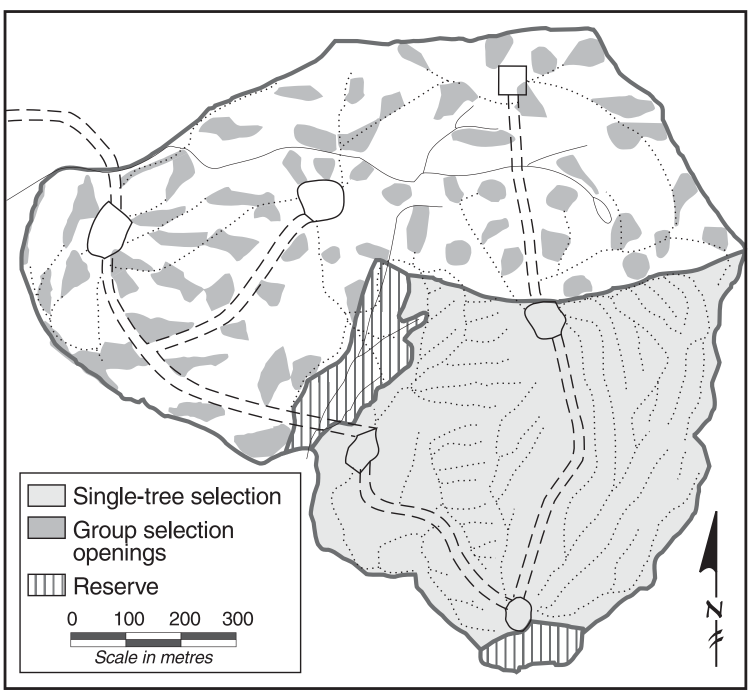



**Figure 13. A block at Pinkerton Mountain that included group selection and single-tree selection. Group selection opening sizes ranged from 0.1 to 0.4 ha.**

*Site preparation* — In the ESSF, both planted and natural regeneration of conifers appear to establish and grow best on raised microsites, either of natural or artificial origin. Mechanized excavator mounding is a commonly used method for creating warmer microsites and reducing vegetative competition for planted seedlings, although other forms of site preparation are also used. It is easily used in group selection systems. Concern for protecting advance regeneration may limit its use in single-tree selection systems. Clumpy mounding (2 – 5 adjacent mounds) is recommended to promote an aggregated stem distribution in the harvested openings.

*Advance regeneration* — For partial-cut systems in caribou habitat, retention of advance regeneration and larger residual stems provides age and size classes of trees not provided for many years by planted seedlings and newly-established natural regeneration. In many cases, studies have shown that advance regeneration and larger residual stems release well and provide vigorous, high-quality growing stock (as discussed in Section 5.1.5). However, advance regeneration and residual stems may be retained after harvest for many objectives other than timber management. Therefore, where necessary, the choice of harvest system, equipment, and harvesting layout should take into account objectives for post-harvest retention of these tree layers.

It is recommended that the prescribing professional adequately distinguish in a prescription or operational plan between residual trees retained as future crop trees and those retained for non-timber objectives. If introduction of pathogens due to logging damage is a concern, a post-harvest "sanitation" or improvement cutting of non-merchantable damaged stems can be prescribed.

*Natural regeneration* — Cone and seed production for spruce and subalpine fir in high-elevation forests varies greatly temporally and spatially. Natural regeneration may be successful in harvested openings smaller than 1 ha, provided high seed production occurs shortly after logging and an appropriate seedbed is available. However, height requirements in stocking standards may need to be adjusted for high-elevation forests. Unfortunately, the unreliability of cone and seed production at high elevations makes natural regeneration in any given year unpredictable.

*Artificial regeneration* — Seedlings should be planted to achieve a clumpy stem distribution. Although there is no single ideal pattern, one example might be to plant an average of four seedlings per clump and to space clumps approximately 5 – 7 m apart to achieve a stocking of about 800 – 1200 stems per hectare. Acceptable inter-tree spacing should be reduced to 1.0 m to facilitate cluster planting, but on average, trees would be spaced more than 1 m apart even within clumps. Planting on clumpy mounds (up to a maximum of 5 mounds) will achieve the desired spatial arrangement of stems. However, even without mounding, planting on naturally raised microsites may promote an aggregated stem distribution. Natural features such as raised microsites can enhance seedling growth.

*The clumpy stem distribution that is typical of the ESSF should be maintained and encouraged.*

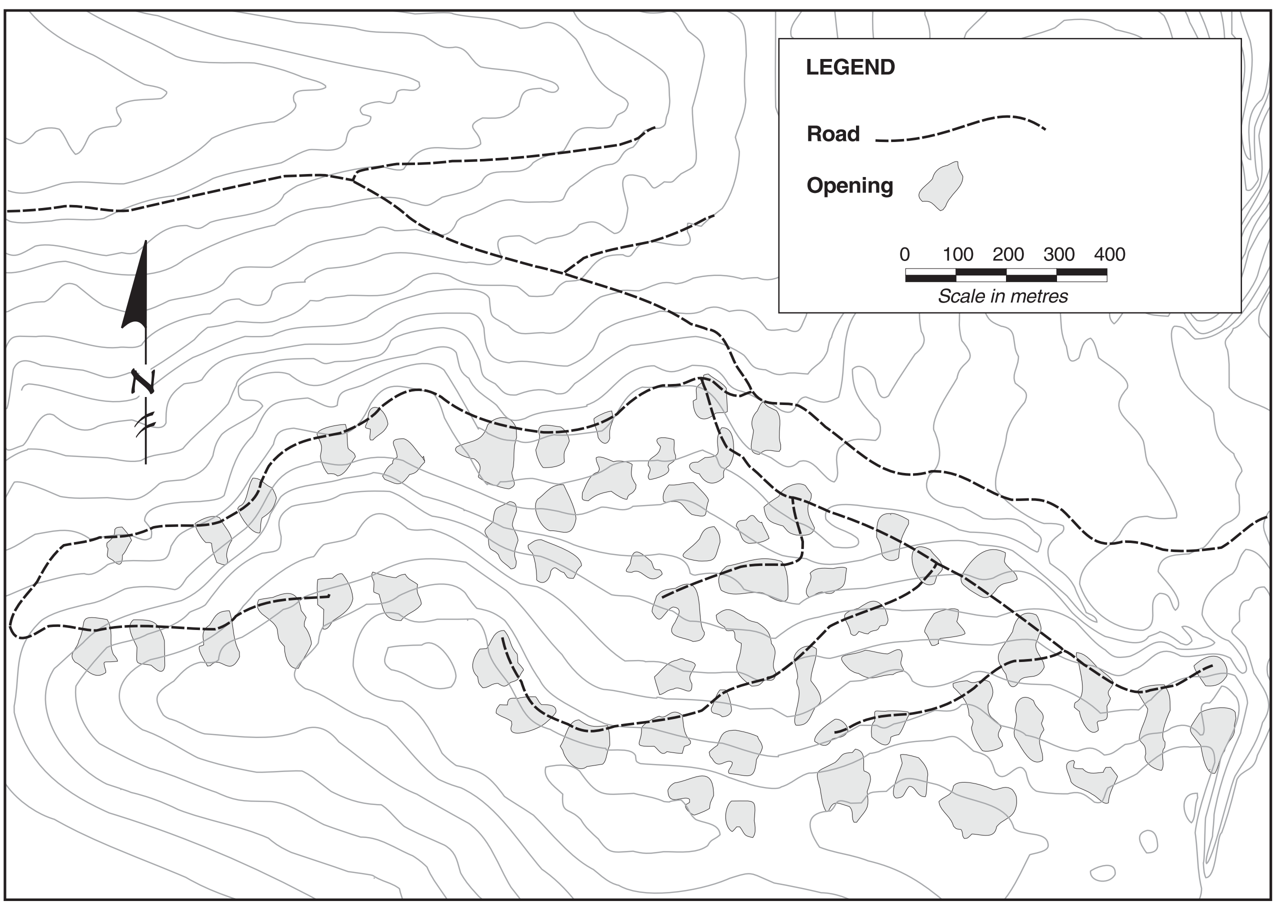



**Figure 14. A group selection block at Mount Tom. Opening sizes ranged from 0.1 to 1.0 ha.**

Plot sizes for stocking and free-growing surveys will have to be increased to adequately sample this aggregated distribution. The pre-harvest stem distribution of *Abies* versus spruce should be reflected in the planted stock. Lodgepole pine should not be planted in Mountain Caribou habitat.

### 4.2.2 Selection systems in the Interior Cedar–Hemlock Zone

Operational experience with partial-cut silvicultural systems in old-growth stands of the wet-belt ICH has been limited. However, several past and current examples of successful ICH partial-cuts provide some useful guidance (Thibodeau et al. 1996; Coates et al. 1997; Waters 1997; Jull et al. 1999). In general, many of the elements of successful partial-cutting prescriptions in the ESSF zone will be mirrored in those used in the wet-belt ICH.

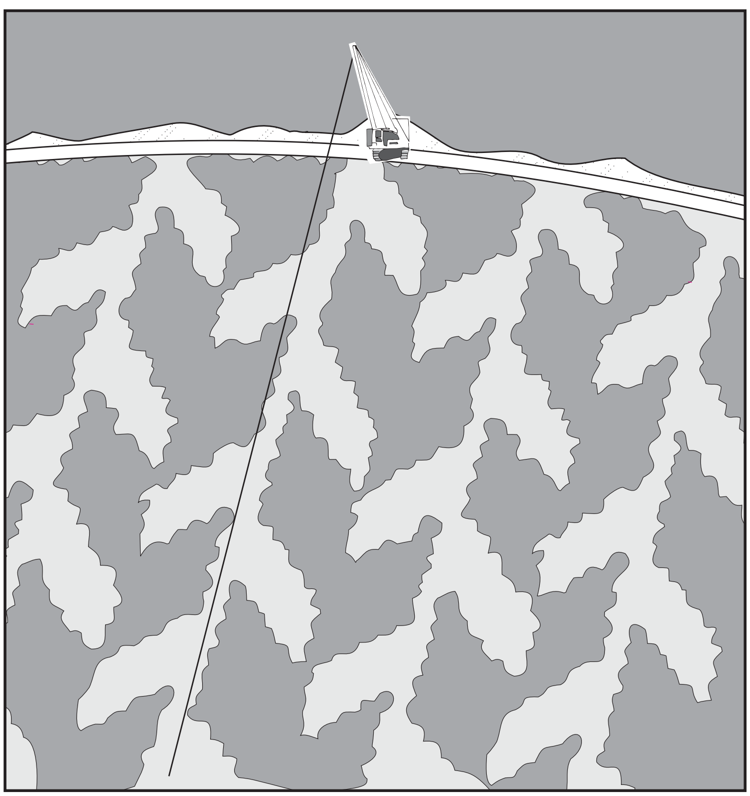


**Figure 15. Harvesting with 30% volume removal group selection on a steep slope (>45%) using cable yarding with individual openings. The next 30% would be removed in 80 years. This is only one of several possible patterns for applying group selection on steep slopes.**

For example, the management objective will be to maintain most of the stand in a late seral condition suitable as caribou habitat. Key elements will be long cutting cycles combined with low percentage harvest removals not exceeding 30% basal area or volume removal at any given stand entry. Examples that would meet this objective would be 30% basal area or volume removal at intervals of 80 years, or 25% removal at intervals of 60 years.

Key differences in partial-cutting applications between the ESSF and ICH are:

- Group selection is more likely than single-tree selection to be practical in wet-belt ICH stands. Factors favouring group selection in these old stands include worker safety, retention of large trees with wildlife attributes, regeneration of mixed-species stands, and relative ease of harvesting and layout.
- Recommended group selection opening sizes in the ICH are the same as those in the ESSF: 0.1 to 1.0 ha, with a mean opening size of 0.5 ha or less.
- In the ICH, stands with many large stems (> 60–70 cm dbh) and high levels of butt rot and internal defects will have to be hand-felled unless there are technological innovations in harvest machinery.
- In Mountain Caribou habitat in the ICH, stands should be regenerated with a species composition similar to natural late-seral stands. A diverse stand of long-lived species should be encouraged with western redcedar and western hemlock as dominant species, mixed with spruce, subalpine fir, and some Douglas-fir. Regeneration of short-lived, early-seral species such as

lodgepole pine should be discouraged because their silvics, life cycle, and habitat attributes are undesirable for caribou habitat.

- Retention of residual trees within group selection openings is encouraged, both to encourage arboreal lichen dispersal in harvested openings and to maintain vertical and horizontal diversity. Where windthrow hazard is a concern, retention of cedar is recommended, because the large, highly-tapered stems of western redcedar tend to be highly windfirm. Retention of a small number of large trees in group selection openings has been demonstrated operationally (Waters 1997; Jull et al. 1999).

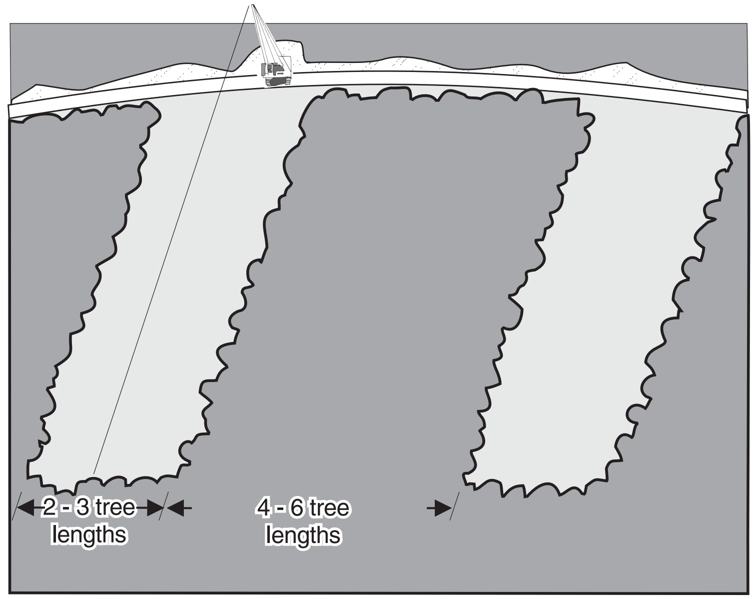



**Figure 16. Harvesting with a 30% volume removal strip selection on a steep slope (>45%) using cable yarding. The next 30% would be removed in 80 years.**

# 5.0 RESULTS OF MANAGEMENT TRIALS

## 5.1 Silvicultural Systems Trials in ESSF and ICH Forests

### 5.1.1 Research and available information

To ensure that operational plans adequately manage and conserve Mountain Caribou habitat, forest managers must consider the best information available. Results of operational research trials are essential to assess various partial-cutting methods, logging equipment, and questions regarding biological responses to prescribed treatments.

In the 1990s, numerous operational-scale trials of partial-cutting silvicultural systems were implemented and monitored in wet-belt ESSF and ICH forests. Many of these trials were conducted in Mountain Caribou habitat through the MCMF program and subsequent related projects (Table 9). Other important silvicultural systems trials were established in the ESSFwc subzone at Sicamous Creek (Hollstedt and Vyse 1997) and in the ICHmc subzone at Date Creek near Hazelton (Coates et al. 1977).

*Single-tree selection prescriptions may be modified so that closely aggregated trees are either all removed or all retained.*

Results of these trials are now providing information on treatment responses from 5 to 10 years post-harvest, allowing managers to better assess the outcomes, benefits, and risks of different management approaches in caribou habitat.

Older studies of partial-cutting practices are also useful in assessing the response of some stand attributes, such as stem growth and pathological agents. These studies must be interpreted with caution because of differences in harvesting methods and management objectives. The focus of most of these older trials was on regeneration and timber management, not caribou habitat. However, several blocks that were partially cut to maintain caribou habitat in the southern Selkirks in the 1970s and early 1980s have recently been reassessed (Miller et al. 1999).

Likewise, subalpine spruce–fir management guidelines from the United States (e.g., Alexander and Edminster 1977; Alexander and Engelby 1983; Alexander 1987) can provide operational guidance on partial cutting. However, the substantial ecological differences between wet-belt ESSF forests in British Columbia and subalpine spruce–fir types in the United States must be considered.

### 5.1.2 Silvicultural systems and opening sizes

In the ESSF, silvicultural system trials have tested a range of harvest opening sizes, from small (single-tree selection, 0.01-ha openings) through intermediate (0.1 or 0.2 ha), to larger openings more typical of conventional clearcuts or large patch cuts (1 to 10 ha or larger). In most cases, basal area or volume removal levels have been set at 30%, either because of caribou or windthrow concerns. Silvicultural systems therefore range from single-tree selection through group selection to clearcut systems.

In earlier trials, most openings were geometric (circles, squares, teardrops) for ease of operational layout and for experimental design (Sutherland et al. 1992; Armleder and Stevenson 1996; Hollstedt and Vyse 1997). Critics of geometric layouts, however, point to the unappealing regularity of these systems when viewed from above. Also, from an ecological perspective, geometric layouts ignore natural stand structure and clumpiness. Geometric partial-cutting layouts, combined with grid planting patterns, would tend to replace irregularly clumped stands over time with a mosaic of regularly spaced even-aged patches.

An emerging trend in selection prescriptions in caribou habitat is clump selection whereby natural clumps of two or more trees with overlapping crowns are either cut or retained. In group selection blocks, edges of openings are irregular so that individual clumps of trees are not broken up. Single-tree selection prescriptions are modified so that closely aggregated trees are either all removed or all retained. This approach maintains the integrity of the uncut clumps and the lichens within them, and may also enhance the windfirmness of the residual stand. This approach has been used successfully at Pinkerton Mountain in the Prince George Forest District (Stevenson et al. 1999), and is planned at other trial sites in the Cariboo and Prince George forest regions.

### 5.1.3 Harvest methods

To date, most ESSF and ICH silvicultural system trials have used ground-based harvesting systems on slopes less than 45%. Harvest methods successfully used in all partial-cutting treatments include:

- hand-falling and ground skidding with small tracked line skidders;
- feller-buncher felling to designated skid trails and forwarding with grapple skidders.

As discussed in Section 4, conventional feller-bunchers have worked well in group selection and clear-felling situations, whereas zero-tailswing bunchers work well in both small-group and single-tree selection environments.

Studies comparing hand-falling to feller-bunchers under different partial cutting treatments found that the harvest system had more effect on logging productivity and costs than the silvicultural system in both ESSF (Mitchell 1996) and ICH (Thibodeau et al. 1996).

Only recently have researchers begun to examine the use of aerial harvesting systems in partial-cutting trials in the ICH and ESSF. Pavel (1999) examined logging productivity in a cable-yarded strip shelterwood system on steep slopes at a coastal-transition ICH site near Hazelton. A study of helicopter logging of single-tree selection, group selection, and small-patch cut blocks on steep slopes in ESSF caribou habitat is planned in the MacGregor Mountains east of Prince George (H. Sup-Han, UNBC, pers. comm.).

### 5.1.4 Regeneration and species composition

*Planted regeneration survival and growth* — Contrary to earlier ideas, large clearcuts are not required for satisfactory regeneration; plantings of many coniferous tree species are performing well under a wide variety of opening sizes in both ESSF and ICH silvicultural system trials.

In the ESSF, 5- to 7-year survival and growth of both Engelmann spruce and subalpine fir in planted openings of 0.2 ha is comparable to performance of seedlings in large clearcuts (Lajzerowicz 1999; Newsome et al. 2000; M. Jull and A. Eastham, unpubl. data). However, spruce and fir seedlings fare poorly in 0.01 ha openings (Newsome et al. 2000)

**Planted Regeneration — Key Results**

- Generally, in the ESSF, growth of planted Engelmann spruce and subalpine fir in openings $\geq$ 0.1 ha is similar to that in clearcuts, but growth is reduced in openings 0.01 ha or smaller.
- In the ESSF, planted seedlings grow better if they are 3–4 m or more from residual trees.
- On frost-prone sites, a residual overstorey reduces frost damage to seedlings.
- Western redcedar, western hemlock, subalpine fir, hybrid spruce, lodgepole pine, and Douglas-fir have all been successfully established in group selection openings in the ICH.

**Table 9. Mountain Caribou integrated management trials.**

| Study Area | Subzone | Forest District | Prescription | Study Components[a] | Year and Season of Treatment | Contact Persons; Licensee[b] |
|---|---|---|---|---|---|---|
| **Selection harvesting blocks** | | | | | | |
| George Cr.<br>CP 32 | ESSFwc3 | Prince George | Overstorey removal:<br>• 35 cm diameter limit<br>• feller-buncher<br>• WCB variance to retain safe snags | L | Winter 1989/90 | S. Stevenson;<br>PGW |
| Pinkerton<br>CP 376 | ESSFwc3 | Prince George | Single tree selection:<br>• q=1.3<br>Overstorey removal:<br>• 55-cm diameter limit partly feller-buncher, partly hand-felled | L | Fall 1991-fall 1993 | S. Stevenson;<br>Northwood |
| Lucille | ESSFmm1 | Robson Valley | Several prescriptions, all hand felled:<br>• single tree selection (STS)<br>• irregular shelterwood<br>• group selection<br>Sanitation cut | L,M,R,V,W | Winter 1991/92 | S. Stevenson, M. Jull; RVFD |
| Research Cr.<br>CP 113-1 | ESSFwc3 | Horsefly | Group selection<br>• 10 m diameter openings<br>• 20 m diameter openings (.03 ha)<br>• feller-buncher<br>• safe snags retained | L,M,R | Winter<br>Dec-Jan 1990/91 | H. Armleder,<br>M. Waterhouse;<br>WELD |
| Blackbear Cr.<br>TSL A43738 | ESSFwc3 | Horsefly | Group selection<br>• 0.03,0.13,1.0 ha openings<br>• feller-buncher<br>• safe snags retained | B,L,S,R | Summer<br>Aug 1992 | H. Armleder,<br>M. Waterhouse;<br>WELD |
| Blackbear Cr.<br>TSL A43738 | ESSFwc3 | Horsefly | Group selection<br>• 0.03,0.13,1.0 ha openings<br>• feller-buncher<br>• safe snags retained | B,L,M,R,V | Winter<br>Nov-Dec 1992 | H. Armleder,<br>M. Waterhouse;<br>WELD |
| Grain Cr.<br>TSL A43737<br>BLK 1 | ESSFwc3 | Horsefly | Group selection<br>• 0.03,0.13,1.0 ha openings<br>• feller-buncher<br>• safe snags retained | B,L,R,V | Winter<br>Nov-Dec 1992 | H. Armleder,<br>M. Waterhouse;<br>WELD |
| Grain Cr.<br>TSL A43737<br>BLK 1 | ESSFwc3 | Horsefly | Group selection<br>• 0.03,0.13,1.0 ha openings<br>• feller-buncher<br>• safe snags retained | B,L,R,S,V | Winter<br>Dec-Jan 1992-93 | H. Armleder,<br>M. Waterhouse;<br>WELD |
| Fleet Cr. | ICHwk3 | Robson Valley | Group selection<br>• 0.24-ha openings<br>• hand-felled | L,R,V,W | Winter 1993/94 | S. Stevenson, M. Jull; RVFD |
| Keystone | ICHwk1 | Columbia | Patch cuts<br>• 1-2 ha openings | L,W | Winter 1995/96 | B. McLellan;<br>RCFC |

**Table 9. con't.**

| Study Area | Subzone | Forest District | Prescription | Study Components[a] | Year and Season of Treatment | Contact Persons; Licensee[b] |
|---|---|---|---|---|---|---|
| Pinkerton CP 377 | ESSFwc3 | Prince George | Single-tree selection<br>• q = 1.2<br>Group selection<br>• 0.1-0.4 ha openings<br>Zero-tailswing feller-buncher | B,L,M,R,V,W | Late winter 1998 | S. Stevenson, M. Jull, D. Coxson; Northwood |
| Mount Tom | ESSFwc3, ESSFwk1 | Horsefly Quesnel | Adaptive management trial<br>Group selection (~1000 ha)<br>• opening size 0.1–1.0 ha<br>• feller-buncher | B,L,R,S,V,W | Winter 2000–03 | H. Armleder, M. Waterhouse; Weldwood, West Fraser |
| Bearpaw Ridge CP 17E BLK 34 | ESSFwk2 | Prince George | Several prescriptions<br>• patch cuts (≤ 1 ha)<br>• group selection (0.1-0.5 ha)<br>• single tree/clump selection<br>Helicopter logging | B,L,R,V,W | Summer 2000 | S. Stevenson, M. Jull; CanFor |
| Lunate Creek | ICHwk3 | Prince George | Group selection (0.1-0.4 ha) | B,L,R,V,W | Winter 2000-01 | S. Stevenson, M. Jull, D.Coxson; PGFD |
| **Second-growth management trials** | | | | | | |
| Haggen Burn | SBSvk | Prince George | Thin to 1600-1900 stems/ha<br>Inoculate 3000 trees with lichen | L | Thinned fall 1989<br>Inoculated fall 1990 | S. Stevenson |
| LaForme Cr. | ICHwk1 | Revelstoke | Thinning by selective girdling | L | Fall 1989 | J. Krebs, Columbia Basin Fish & Wildlife Comp.Program |

[a] B = Biodiversity L= lichens; M = microclimate ; R = regeneration; S = snow surveys; V = vegetation; W = windthrow

[b] CanFor = Canadian Forest Products Ltd.; Northwood = Northwood Pulp & Timber Ltd.; PGFD = Prince George Forest District Small Business Enterprise Program; PGW = Prince George Wood Preserving Ltd.; RCFC = Revelstoke Community Forest Corporation; Rustad = Rustad Bros. & Co. Ltd.; RVFD = Robson Valley Forest District Small Business Enterprise Program; WELD = Weldwood of Canada Ltd.

and other uniform-overstorey treatments with few openings (Lajzerowicz 1999; M. Jull and A. Eastham, unpubl. data).

Light and soil temperature appear to be more important than soil moisture and soil nitrogen in limiting the success of planted regeneration in ESSF partial-cuts (Lajzerowicz 1999). Subalpine fir was more shade tolerant than spruce where seedlings were planted under a uniform overstorey. In the ESSF, planting seedlings within 3 to 4 m of residual leave-trees may reduce seedling growth. To improve performance of planted seedlings in partial cuts, Lajzerowicz (1999) recommended creating openings by clumped harvesting, or by reducing the overstory basal area densities, or both.

Reduced seedling growth under residual trees or in very small openings is not evidence of impaired site productivity, but rather indicates that larger overstorey trees outcompete seedlings planted near them. Vigorous growth of spruce and fir advance regeneration and large leave-trees in response to partial cutting is well documented (DeGrace 1950; Herring 1977; Johnstone 1978; Bergstrom 1983) and the rooting zone of these trees extends a substantial distance from the bole.

Increased root extension should be considered in silvicultural prescriptions than intend to inter-plant seedlings among larger, well-established leave-trees. Regeneration objectives for planted trees in these situations should be modified downward because more growing space is occupied by existing trees.

On ESSF sites with frequent frosts during the growing season, a residual overstorey protects seedlings from frost damage (Stathers 1999; Farnden 1994). At Lucille Mountain, frost damage to foliage of Engelmann spruce seedlings was 48% in a clearcut, 23% in 0.2-ha patch cuts, but only 6% in an irregular shelterwood treatment following a severe August 1992 frost (M. Jull, unpubl. data).

A variety of tree species have been successfully established in group selection prescriptions in Interior cedar–hemlock forests. In the ICHwk3 subzone near McBride, Rogers and Jull (2000) found that in 0.25-ha openings there were no significant differences in 5-year survival and growth of planted western redcedar, hybrid white spruce, and Douglas-fir seedlings, and all species were growing well. In the Date Creek ICH partial-cutting trials, Coates and Burton (1999) also examined growth of seedlings of planted western redcedar, western hemlock, spruce, subalpine fir, and lodgepole pine 5 years after planting. In shaded environments (<40% full sunlight), western redcedar had the best tree size and growth rate of all species, whereas at light levels higher than 70% full sunlight, lodgepole pine was the best performing species planted. The most variability in tree size and growth was between 30% and 70% full sunlight, and there was no significant difference between tree size and growth rates for any tree species between 40% and 70% full sunlight. Based on those results, Coates and Burton (1999) recommended that tree species selected for planting be carefully matched to the range of light levels found in partial cuts.

*Natural regeneration establishment* — At Lucille Mountain, the cone crop in the stand adjacent to the clearcut was similar to stands with 0.2-ha patch cuts and with single-tree selection harvesting, but seedfall was lower in the clearcut each year (Eastham and Jull 1999). Five years after harvest, the selection and patch cuts had seven times as many spruce and 10 times as many subalpine fir germinants as the clearcut treatment. Seed availability limited the establishment of subalpine fir and spruce in the clearcut. Availability of seed and mineral soil limited spruce establishment in the selection and small patch cuts whereas subalpine fir germination was limited primarily by the availability of disturbed forest floor seedbeds. Natural regeneration in subalpine forests could be increased by 1) modifying harvest patterns to enhance conifer seed distribution; and 2) preparing seedbeds before anticipated heavy seedfalls.

Seed dispersal distance limits natural regeneration in harvested areas, and dispersal is influenced by prevailing winds (Alexander and Engelby 1983). Dobbs (1976) measured white spruce seed distribution across a 400-ha clearcut in the Prince George Region and found that seedfall declined sharply from the clearcut edge to 100 m, but some seed travelled as far as 300 m.

**Advance Regeneration – Key Results**

- In the ESSF, growth of spruce and subalpine fir advance regeneration increases after overstorey removal.
- Diameter growth release occurs 1–3 years after harvesting, whereas height growth release is delayed until 3–7 years or more after harvesting.
- Growth release of spruce and subalpine fir is negatively affected by the density of the residual overstorey.
- No equivalent information is currently available for wet-belt ICH sites.

Exposing mineral soil increases natural regeneration in partial-cutting treatments. In the wet cold ESSF subzones of southeastern British Columbia, undisturbed seedbeds had fewer subalpine fir and spruce germinants than burned seedbeds or mineral soil (Feller 1997). In that study, competing vegetation decreased the number of subalpine fir but not spruce germinants. Eastham and Jull (1999) found that more subalpine fir seeds than spruce seeds germinated on the undisturbed seedbeds, particularly in the single-tree selection treatment.

In the U.S. Rocky Mountains, Fiedler et al. (1985) found that partial-cutting treatments favoured the establishment of the shade-tolerant spruce and fir more than did clearcutting. Mineral soil was more favourable for germinant establishment on lower-elevation sites, whereas forest floor (duff) was more favourable on higher-elevation sites. Spruce and fir natural regeneration on all seedbeds was gradual, and supplemental planting would be needed if full stocking had to be achieved rapidly.

### 5.1.5 Effects of partial cutting on residual stand growth

Numerous studies have examined the response of spruce–fir stands to partial cutting. Most have been retrospective studies of growth, vigour, and quality of residual stems after heavy volume-removal diameter-limit cuts. Alexander (1987) and Coates et al. (1994) have reviewed these topics. The following summarizes several studies applicable to wet, cool ESSF forests in BC.

Herring (1977) examined the health, growth response, and suitability of subalpine fir advance regeneration at five cut-over areas between 1300 and 1600 m elevation in the moist to wet ESSF zone between Salmon Arm and Clearwater. There was no direct relationship between stem age at release and growth response. After overstorey removal, delays in diameter growth release were commonly 1–2 years and height-growth delays were 3–5 years. After the initial delay, the advance regeneration was capable of excellent growth. The major factors affecting growth were tree competition and site quality. The introduction of stem decay in subalpine fir was primarily associated with logging damage via scarring or stem breakage. Treatments that reduce the average age of advance regeneration at release were recommended to reduce pathological risk.

Bergstrom (1983) retrospectively assessed the diameter growth release of subalpine fir on seven diameter-limit cutblocks harvested in the mid-1960s in the wet ESSF zone near Adams Lake. Trees taller than 3 m at time of logging were sampled. The average annual response in diameter and height growth was 0.42 cm/yr and 0.28 m/yr, respectively. The residual trees had a low incidence of stem decay and were considered to have good crop potential. Average basal area and volume increment was 0.76 $m^2$/ha/yr and 4.59 $m^3$/ha/yr, respectively. Bergstrom recommended that uneven-aged management be considered for diameter-limit cut stands.

**Windthrow – Key Results**

- In the ESSF, wind damage has been very limited (>3%) in partial cuts with 33% or less volume removal, but substantially higher where harvest levels were 50% or higher.
- In the ICH, windthrow rates have been similar in partially cut areas and unlogged control areas.

A replicated silvicultural systems study in the Engelmann spruce–subalpine fir forests of Idaho, Wyoming, and Utah examined advance regeneration response under a range of harvest intensities from partial cuts to clearcuts (McCaughey and Schmidt 1982). Diameter growth response occurred about 3 years after the harvest, whereas height growth was found to have a response delay of 7 years or more after release. Advance regeneration response of spruce and subalpine fir differed very little, but growth release of both species was negatively affected by the density of the residual overstorey.

Less information is available on the growth response of advance regeneration in the ICH. DeLong (1997) found that advance regeneration (< 3 m tall) in the ICHwk1, ICHmw2, and ICHmw1 released well, with little incidence of rot except on stems with scars or logging damage. Most of the cedar advance regeneration originated from layering (vegetative rooting of branches), but was of good form and vigour. As maintaining advance regeneration and larger residual stems is desirable for a variety of non-timber objectives, more research is needed on the silvicultural acceptability and long-term productivity of advance regeneration in the ICH.

### 5.1.6 Windthrow

Historically, wet-belt ESSF and ICH forest types have been widely believed to be less windfirm than other forest types in British Columbia. The abandonment of selection, alternate strip-cut, and seed-block partial-cutting methods by the late 1960s has been attributed to excessive windthrow (Benskin 1975; Mitchell 1996). However, Glew (1963) examined the response of spruce-fir timber sale areas near Prince George that were partially cut between 1952 and 1961. Glew concluded that regeneration problems and logging damage were more problematic than wind damage in these stands. Despite perceptions that high-elevation stands partially cut before 1970 were all subsequently windthrown or infested by insects or disease, Nyberg (1998) observed that partially cut spruce–fir forests are windfirm and healthy if the harvest intensity and site and stand conditions are appropriate. Refer to Section 4.2 for more information about windthrow assessment procedures.

*"Despite uncertainties, forest managers can still do much to reduce losses from wind, although they can never expect to eliminate damage completely . . . But by being aware of past experiences and revising plans in the light of new information, the forest manager can at least be satisfied that all possible has been done to reduce losses from wind."*

*A.S. Harris (1989)*

Over the last 10 years, levels of wind damage to partial-cuts in both the ESSF and the ICH have been modest and, in general, much less than initially forecast.

Several early ESSF partial-cutting trials in caribou habitat have tested harvest removal levels of 50% of basal area/volume or higher. These include operational trials at George Mountain in 1990/91 (CPs 32 and 37) in the Prince George District, and at Lucille Mountain (EP 1119) in the Robson Valley District. None of these trials contain uncut control areas for comparison, but post-harvest windthrow rates are acknowledged to be substantially higher than in other ESSF partial-cutting trials where harvest removals were restricted to 33%.

At George Mountain, there was no systematic monitoring of windthrow losses, but field observations and helicopter inspections indicate an estimated loss of 30 to 40%, beginning with a heavy storm about 1.5 years after harvesting. The most severe losses occurred in portions of the block where the harvest level was highest.

Wind speed and windthrow incidence have been monitored at the Lucille Mountain trial (M. Jull, unpubl. data). The site has high topographic wind exposure; maximum wind gusts typically exceed

72 km/hr several times annually, and have exceeded 100 km/hr every few years. Wind damage incidence by stems-per-hectare (uprooting and windsnap) in group selection, irregular shelterwood, and single-tree selection treatments were 6%, 10.3%, and 8.6%, respectively, whereas the windward edges of the nearby clearcut lost 10-20% of tree basal area within one tree length of the stand edge. Most of the damage was caused by two 1996 wind events of more than 90-100 km/hr. Intermediate diameter classes (17.5–37.5 cm) had the highest risk of wind damage, especially when unprotected by larger sheltering trees. Larger trees had low to moderate probability of wind damage, perhaps because of their previous history of long-term wind exposure and acclimatization in the upper canopy.

In contrast to Lucille Mountain, wind data from the Pinkerton Mountain selection trial (Jull and Sagar, unpubl. data) indicates that, despite even greater wind exposure than Lucille Mountain, the Pinkerton 30%-removal partial cuts to date have had very low levels of wind damage (<1% and similar to the uncut control area).

At the Sicamous Creek ESSF trial, windthrow of subalpine fir increased in the 2.7 years after harvesting from 0.6% of basal area per year in the uncut control, to 0.8–1.8% in the harvested treatments, with highest rates in the individual-tree selection units and 0.1-ha group selection treatments (Huggard et al. 1999). Engelmann spruce had similar patterns of windthrow but lower overall rates (0.2–0.7% basal area per year in harvested treatments).

In ESSF group selection trials in the Horsefly Forest District, overall rates of windthrow of both live and dead trees was less than 1% by stems/ha or basal area 5 years after harvest (Newsome et al. 2000). There was no significant effect of treatment on windthrow rates.

In the Date Creek ICH silvicultural systems trial, there was no difference between rates of wind damage in partially cut and uncut stands 2 years after harvesting. Overall rates of wind damage averaged 2%, well below the management threshold of 8% identified by forest managers in the area. There was no trend in rates of damage by species except for western hemlock, which had a higher rate of wind damage than other coniferous species (Coates 1997).

At the Fleet Creek group selection trial in the ICH, where 20% of the volume was removed, the post-harvest rate of windthrow of trees within 20 m of harvested openings was 0.3% of all trees more than 20 cm dbh. Up to the latest data collected (1999), windthrow rates are extremely light in these stands. In the unharvested control area, wind damage rates are nearly identical, at 0.33%. Windthrow rates at the Keystone ICH trial have been similar (Waters 1997; Quesnel and Waters 1999).

## 5.2 Effects of Management on Habitat

### 5.2.1 Habitat use by caribou

Forest harvesting may affect habitats used by caribou in many ways. Some changes may alter the ecological relationships among caribou, other ungulates, and predators. The effects of forest harvesting change over time as the vegetation develops.

Partial cutting is likely to have less effect than clearcutting on habitat attributes important to caribou. In the Fleet Creek study in the wet cool ICH near McBride (Jull et al. 1999), sight distances for caribou and the abundance of early winter forage plants had not been adversely affected 3.5 years after group selection harvesting. Cover of tall shrubs and levels of browsing by other ungulates were low.

Caribou and their sign have been observed in many MCMF partial cuts since harvesting was completed. However, the conclusions that can be drawn from incidental observations of caribou use are limited. Caribou responses to partial cutting have been difficult to assess scientifically because partial cuts have been small and scattered. Once partial cutting has been implemented over larger areas, there will be more opportunity to learn how it affects caribou. The use of partial cuts by caribou may change over time as regeneration develops and more harvest entries take place.

### 5.2.2 Arboreal forage lichens

Much research has been directed at understanding the responses of arboreal lichens to changes in forest structure brought about by partial cutting.

After harvesting, there is an immediate loss of arboreal lichens that is roughly proportional to the level of timber removal. Some additional lichens are lost when dangerous trees are felled. Sometimes caribou forage on lichen from felled trees, but those lichens are available only briefly.

After harvesting, lichens on the remaining trees are more exposed to wind. The first block logged as part of the MCMF program (CP 32 at George Creek) experienced excessive loss of lichens from the residual trees, as well as high levels of windthrow. These wind effects probably resulted from a combination of high windthrow hazard due to topographic exposure, a high level of volume removal (52%), and an inappropriate prescription (overstorey removal to a 35-cm diameter limit). In subsequent partial cuts, overall loss of forage lichens from the lower crowns of residual trees has been minor, although a few individual trees lost large amounts. Ongoing studies at Pinkerton Mountain (CP 377) will show how partial cutting affects lichen abundance throughout the canopy, not just in the bottom few metres.

Lichen abundance on individual trees in older partial cuts seems generally to be adequate for caribou requirements. Eight to 10 years after logging in the southern Selkirks, lichen biomass per branch was similar in partial cuts and adjacent uncut stands (Rominger et al. 1994). The proportion of the lichen that was *Bryoria* was slightly higher in the partial cuts. In 1998, habitat attributes of other partial cuts in the southern Selkirks were compared to known caribou foraging sites (Miller et al. 1999). The partial cuts had more lichen in the lower canopy and a higher proportion of *Bryoria* than foraging sites, but significantly fewer trees. Individual trees in these partial cuts appeared to have adequate lichen abundance and a favourable genus composition 10 to 20 years after logging.

Studies of growth and physiology of arboreal lichens are beginning to explain why these changes in lichen abundance in the lower canopy might occur, and to provide a model that will allow predictions of lichen responses to changes in forest structure on different sites. At two areas in the ESSF where growth rates of *Alectoria* and

**Stand–level Habitat Attributes for Caribou that may be Affected by Forest Harvesting**

- Characteristics of the snowpack, which affect ease of movement by caribou.
- Density of the vegetation and of obstructions, which affect how well caribou can see around them and flee from predators.
- Abundance of green plants used as forage by caribou, especially the low shrubs and perennial herbs with persistent green leaves that they use in early winter.
- Abundance of woody browse plants, which affects the numbers of Moose, Elk, and deer, and thus of predators.
- Availability of arboreal lichens, the main winter forage of Mountain Caribou.

*Bryoria* in the lower canopy were monitored after partial cutting, *Alectoria* grew slower in the partial cuts than in the unharvested stand. At Pinkerton (CP 376), *Bryoria* maintained the same growth rate in the partial cut as in the uncut stand (Figure 17). At Lucille Mountain, *Bryoria* maintained the same growth rate in the treatment unit where trees were retained in clumps, but had a lower growth rate in the irregular shelterwood treatment, where the trees were more uniformly distributed. In the Quesnel Highland, in contrast, growth rates of *Bryoria* in the year after partial cutting were 12% lower in the unit with 0.03-ha openings than the uncut control, and 22% lower in units with larger openings (0.13 ha and 1.0 ha) than the uncut control. *Alectoria* seems to be adversely affected by any opening of the forest canopy. *Bryoria* has a greater tolerance for exposure, but shows reduced growth under some partial-cutting regimes.

By opening up the canopy, partial cutting alters the microclimate. At all heights, the microclimate will be slightly windier, drier, and have greater temperature extremes in a partial cut than in an unharvested stand. These microclimatic changes are likely to affect the physiological activity, growth rates, and fragmentation rates of the lichens in the canopy. So far, the observed changes after partial cutting are consistent with the downward displacement of *Bryoria* described in Section 2.1.3. In the ESSF at least, *Bryoria* appears to become more abundant than *Alectoria* after partial cutting. This change is likely beneficial to caribou, unless the site is so dry or exposed that there is a decline in biomass on individual trees. In the ICH, a displacement of layers would not likely affect caribou adversely, but might have a negative impact on the old-growth indicator lichens of the lower canopy.

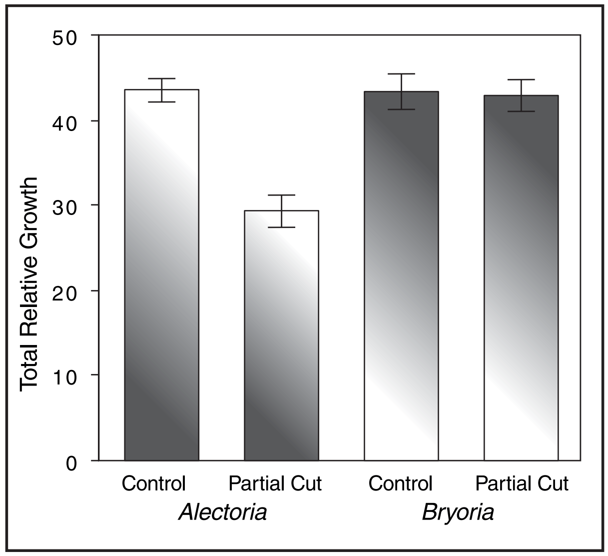



**Figure 17. Growth rates of *Alectoria* and *Bryoria* at Pinkerton Mountain (CP376) (1992–1994).**

**Arboreal Forage Lichens – Key Results**

- High levels of volume removal increase the risk of lichens blowing off the trees in the residual stand.
- Partial cutting alters the microclimate in the crowns of the trees in a way that favours the growth of *Bryoria* rather than *Alectoria.*
- The amount of lichen that disperses onto a regenerating area increases with proximity to mature lichen-bearing trees.
- Lichen abundance in partial cuts is limited by the lower numbers of old trees compared with unmanaged stands.
- Managers can help perpetuate forage lichens in partial cuts by:
  - keeping openings small (<1 ha) in both the ICH and the ESSF;
  - managing for a clumped stand structure in ESSF stands; and
  - primarily in the ESSF, managing for early development of an inner defoliated zone.

Partial cutting also affects the distance between old trees and young trees, raising the question of lichen dispersal as a limiting factor. In the ESSF, *Bryoria* is capable of dispersing at least 2 km over an open snow surface (T. Goward, unpubl. data). Even large stands of young trees are eventually colonized by *Bryoria*. However, studies of *Bryoria* and *Alectoria* dispersal from a mature timber edge into a clearcut or stand of young trees in the Coastal Western Hemlock zone (Stevenson 1988), the Swedish boreal forest (Dettki 1998), and the ICH (Quesnel and Waters 2000) have consistently shown that

- lichen dispersal is much lower in openings than under the forest canopy;
- dispersing lichen is more abundant close to mature timber than far from it; and
- *Bryoria* disperses over greater distances than *Alectoria*.

Most lichen establishment was within 100 m of mature timber. In the ICH, lichen dispersal within openings of 1.0 to 1.8 ha was approximately uniform, presumably as a result of the overlap of dispersal curves from the mature timber on all sides of the opening (Quesnel and Waters 2000). Dispersal was higher adjacent to residual trees or wildlife tree patches. These studies suggest that rapid re-establishment of lichens on regeneration can be encouraged by keeping openings small or narrow.

Because of the younger age structure in a partially cut stand, a higher proportion of the surfaces available for lichen establishment and growth will be young. Young branches on trees in old partial cuts in Sweden supported less *Alectoria* and *Bryoria* than old branches, even allowing for the effect of branch size (Esseen et al. 1996). In the ICH, *Alectoria* and *Bryoria* biomass on 100-year-old hemlocks in natural canopy gaps was only about half that on adjacent old-growth trees (D.S. Coxson and S.K. Stevenson, unpubl. data). Given the growth rates of *Alectoria* and *Bryoria* (Figure 17), it is unlikely that these patterns occur because the lichens have had insufficient time to grow. A more important factor may be insufficient time for the younger trees to develop an extensive inner defoliated zone, or "cone of defoliation," that supports abundant *Bryoria* (Goward 1998). Silvicultural regimes that encourage the development of this inner defoliated zone will likely encourage earlier development of abundant *Bryoria*.

Information so far suggests that light-entry partial cutting can maintain a suitable microclimate and stand structure for the growth of forage lichens on residual trees. There is likely to be a shift in genus composition toward *Bryoria*. Because there will be a smaller proportion of older trees, overall lichen abundance will be lower in partial cuts than in unmanaged stands. More work is needed to project whether the development of lichen abundance on regenerating trees in partial cuts will be rapid enough to maintain adequate forage for caribou after several entries.

**Biodiversity – Key Results**

- Selection harvesting prescriptions with smaller openings are generally more effective in maintaining habitat for mature-forest wildlife species than prescriptions with larger openings.
- Habitat for some mature-forest species can be retained by protecting dying and dead trees, coarse woody debris, and an intact forest floor during harvest and silvicultural activities.
- Single-tree selection would be improved for many animals by greater heterogeneity — patchy removal and retained wildlife tree patches
- Because no one harvest prescription is best for all mature-forest species, using a variety or a mixture of small openings is better than applying a single prescription uniformly over the landscape.

### 5.2.3 Biodiversity

Forests that are important to Mountain Caribou are also important to a myriad other organisms, some of which are specifically associated with old, structurally diverse stands. Because partial cutting is likely to be practiced extensively in Mountain Caribou range, it is important to understand how it affects other species. Management practices that emulate natural disturbance regimes are expected to maintain native biodiversity better than ones that do not (B.C. Ministry of Forests and Ministry of Environment 1995). Silvicultural systems that create small openings have the potential to maintain many of the native species and processes characteristic of old wet-belt forests. It is important to know how well selection harvesting maintains biodiversity and whether prescriptions can be improved to maintain habitat for other old-forest species as well as caribou. Most of the information available so far pertains to vertebrates, but studies of other organisms, including ectomycorrhizal fungi, terrestrial arthropods, soil micro-arthropods, and lichens, are ongoing (Coates et al. 1997; Hollstedt and Vyse 1997).

Selection harvesting with low-volume removal seems generally to maintain habitat for the assemblages of wildlife species associated with mature and old-growth forests. At Date Creek, a 30% removal partial cut had minimal detrimental effects on the abundance of mature-forest–dwelling birds and small mammals. A 60% removal partial cut retained substantial numbers of most species associated with uncut forest, but was also used by some species more typical of clearcuts (Steventon et al. 1998). At the ESSF study area in the Quesnel Highland, removal of 30% of the timber volume in openings of 0.03, 0.13, or 1.0 ha had no overall effect on the abundance or diversity of small mammals or breeding birds (B.C Ministry of Forests 1997a). However, some individual species preferred one treatment to others.

No one spatial pattern of selection harvesting is best for all mature-forest–dwelling species. The effects of various harvest patterns were studied at Sicamous Creek, where 33% of the timber volume was removed in a replicated set of single-tree selection units, arrays of 0.1-ha openings, arrays of 1-ha openings, and 10-ha clearcuts in 30-ha treatment areas (Hollstedt and Vyse 1997). Pine marten strongly avoided openings of 10 ha and 1 ha, but used the 0.1-ha openings. Use of all harvested treatments was reduced in winter, but the arrays of 0.1-ha openings had the least negative effect. Masked shrews declined 40% in large openings, but showed little change in the single-tree selection areas or 0.1-ha arrays. Red-backed voles declined sharply in the 1-ha and 10-ha openings, less in the 0.1-ha openings, and little in the single-tree selection units. The occurrence of spruce grouse in harvested treatments was reduced in proportion to the level of volume removal except in the single-tree selection area, where the reduction was much greater (Huggard and Klenner 1999).

For some species, aspects of harvesting other than timber removal may be more important than the harvesting itself. Red-backed voles and shrews, for example, may be more affected by site preparation that alters coarse woody debris, shrub cover, and duff than by removal of the overstory (Huggard and Klenner 1999). The response of species that are strongly dependent on certain types of wildlife trees may depend on whether trees with the critical features were retained during logging. For example, cavity-nesting birds were not negatively affected by either 30% or 60% volume removal in two study areas in which suitable nest trees were retained during partial cutting (Steventon et al. 1998; Steeger et al. 1999).

The attributes that make a tree valuable as wildlife habitat are often associated with damage or decay that could make that tree dangerous to workers. According to Workers' Compensation Board regulations, if a worker may be exposed to a dangerous tree, then that tree must be removed.

In a single-tree selection block, harvesting can potentially take place throughout the unit, and a high proportion of the dead and dying trees are subject to removal. In a group selection block, worker activity is concentrated in the harvest openings, and fewer of the potentially dangerous trees are likely to affect work areas. At Pinkerton Mountain, the occurrence of trees with wildlife habitat attributes was reduced only slightly more in the single- tree selection unit than in the group selection unit (Stevenson and Keisker 2001). In this case, retention of trees with wildlife habitat attributes in the single-tree selection unit was probably enhanced because there were areas where no logging took place, either because of topographic constraints or because initial basal area was low and no trees had been marked for cutting.

Selection harvesting prescriptions with small openings appear to be most effective in maintaining the vertebrate species associated with old growth. Single tree selection would be improved for many animals by greater heterogeneity — patchy removal and retained wildlife tree patches (Huggard and Klenner 1999) — as was done at Pinkerton Mountain. Using a variety of opening sizes at the smaller end of the scale (<0.5 ha), including very small openings (≤0.1 ha), will probably maintain old-forest species better than applying a single prescription uniformly across the landscape.

The research results described here were obtained within the first few years after the first partial cut in previously unmanaged stands. With successive entries, there will be fewer large old trees, either living, dead, or fallen. The decline in abundance of these trees is likely to affect a variety of organisms that depend on the habitat attributes they provide. Prescriptions that retain a component of large old trees at all times are likely to maintain more of the biodiversity associated with natural wet-belt forests than those that do not.

## 6.0 QUESTIONS AND ANSWERS

*Harvesting one-third of the trees in a stand will reduce the lichen available to caribou by at least one-third. Will caribou habitat be maintained after the second and third entries?*

This management approach is not without risks to caribou. Currently, initial evidence suggests that caribou continue to use stands after they are harvested with the recommended selection system. More caribou-use data will be gathered on a large adaptive management project involving over 1000 ha of development. Future entries will be 80 years apart but will still have further impacts on lichen biomass. Caribou may still regard stands with these biomass levels as acceptable habitat provided a suitable proportion of trees within the stands have acceptable lichen loading. Stands managed in this way are expected to have approximately one- to two-thirds as much lichen as unharvested stands, depending on the time since the most recent entry. From best current knowledge, this integrated management approach still incurs a moderate risk to maintaining caribou habitat.

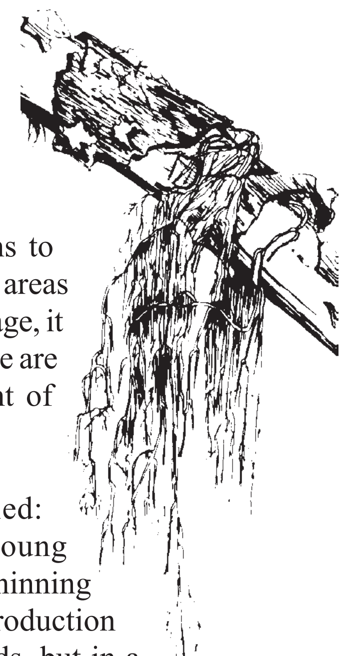
*Is management for caribou detrimental to other species?*

Any set of forest management practices will result in better habitat for some species and worse habitat for others. In general, the species that seem to respond most favourably to the management recommended for caribou habitat are those that are generally associated with old forests, although a few species respond negatively even to the relatively low impact of light-entry partial cutting. Habitat for some old-forest species can be protected by retaining large dying and dead trees, coarse woody debris, and an intact forest floor in portions of the block during harvesting and silvicultural activities.

Most of the species that are characteristically abundant for some years after clearcutting are unlikely to become as abundant after light-entry selection harvesting. The habitat needs of early successional species are better met in areas where caribou habitat management is not a priority. Habitat for Moose, deer, and Elk should not be enhanced in caribou range, because increased numbers of other ungulates and their predators is likely to be detrimental to caribou.

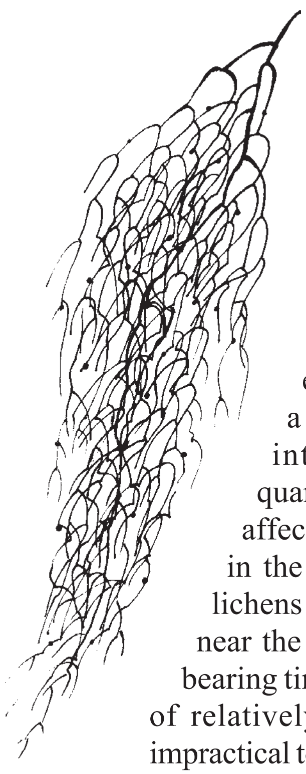
*Can arboreal lichens be enhanced in young stands?*

Because Mountain Caribou are adapted to an environment in which most forests are old and large disturbances are infrequent, a management strategy that aims to maintain suitable habitat conditions for caribou is preferable to one that makes the habitat unsuitable and then aims to recreate it. However, where large areas currently exist in an early seral stage, it is appropriate to ask whether there are ways to hasten the development of arboreal forage lichens.



Two approaches have been tried: thinning and inoculation of young stands with arboreal lichens. Thinning might be expected to enhance production of *Bryoria* in dense young stands, but in a 25- to 30-year-old stand in the SBSvk subzone, juvenile spacing had no detectable impact on the abundance of forage lichens after 3 years, and adversely affected growth of the forage lichens, especially *Alectoria sarmentosa* (Stevenson 1995). However, thinning may be beneficial in wetter subzones, especially if the importance of an inner defoliated zone to *Bryoria* production is considered. It may be helpful to delay thinning until the defoliated zone has developed, and to manage for clumped rather than uniformly distributed trees.

Lichen inoculation was tried in the same stand by using a modified leaf-blower to apply clumps of lichen to the upper crowns of the young trees, a technique developed by Enns (1998). Four years later, colonies of apparently healthy lichens were established in the inoculated trees, but there was no evidence of increased lichen abundance in adjacent uninoculated trees. For lichen inoculation to be an effective method of habitat enhancement, inoculated trees would have to function as centres of dispersal, and that had not occurred.



Although it is possible that some dispersal from the inoculated trees may be observed in the future, it seems unlikely that there is much to be gained from lichen inoculation. *Bryoria* fragments readily and is well adapted to dispersal by wind. Young trees are colonized by small pieces of *Bryoria* even at considerable distances from a stand of mature timber. The introduction of small additional quantities of lichen will probably not affect the overall development of lichens in the stand. The abundance of arboreal lichens that can be observed on young trees near the edge of a stand of mature, lichen-bearing timber results from an ongoing influx of relatively large fragments that would be impractical to duplicate artificially.

### *If we don't cut these old decadent stands soon, aren't they going to all die and fall over and be of no use for caribou or timber?*

No. It is sometimes suggested that many old spruce–subalpine fir and cedar–hemlock stands are "decadent" and in a state of decline that will end in collapse. This perception is usually based on observations of weakened, dying, or dead trees, often shortly after pest outbreaks or storms, when the damage is most obvious. However, with very few exceptions, wet-belt stands recover from such mortality within a few years or decades.

In most wet-belt stands, species composition is relatively diverse, and stands are composed of a mixture of age and size classes of trees. Disturbances generally kill or injure certain size classes and species of trees in small patches, and are seldom catastrophic over an entire stand. Dead or dying trees are replaced by adjacent surviving trees, advance regeneration, and new natural regeneration that establishes in created gaps. Studies to date have indicated that over time, such ingrowth balances losses from mortality, and that dramatic changes in species composition are rare.

The damaged, dead, and fallen trees that result from small disturbances are important habitat features that contribute to the structural and biological diversity of the stand.

### *Does partial cutting result in increased blowdown?*

Many types of forest harvesting can increase windthrow risk to trees left behind. On some sites, diameter-limit and other types of old "selective logging" methods in the wet-belt ESSF and ICH have resulted in significant windthrow. Generally, the occurrence of windthrow or wind damage has been relatively higher where:

- basal area or volume removal has been heavy (e.g., $\geq$50%);
- openings have exceeded two tree heights in width;
- dominant and strong codominant trees have been removed throughout the stand, exposing weaker codominant and intermediate trees; and
- no pre-harvest windthrow hazard assessments (Section 4.2) have been considered in the prescription.

This scenario is not confined to partial-cut systems; clearcut systems are also at risk when stand edges are exposed to high winds after harvesting. The question is, If we want to partial-cut to maintain caribou habitat, how can we avoid unacceptable levels of windthrow losses in the residual stand and adjacent areas? Pre-harvest windthrow assessments are an important tool available to help resource professionals consider these risks.

In general, the types of partial-cutting recommended for Mountain Caribou habitat — low rates of basal area or volume removal not exceeding 30% and harvest of single-trees or small groups of trees on a long cutting cycle — have relatively low risk of windthrow loss compared with historical diameter-limit and similar methods. In more recent ESSF and ICH partial-cuts incorporating these principles, wind damage has been low and comparable to rates found in uncut stands. Heavier rates of wind damage have been observed in partial-cuts with heavy volume removals (e.g., ~50% or more); these rates are similar to rates of damage found along the windward edges of moderately large clearcuts.

A manager must consider the following: Does an operational plan or prescription quantify an acceptable or unacceptable level of windthrow? What is the likely consequence of a given level of windthrow loss? Minor windthrow is unlikely to have significant management consequence in caribou habitat, and may benefit caribou. Heavy windthrow is undesirable. Prescribing and approving professionals who deal with windthrow risk must consider the likelihood and cost of salvage, and the benefits and consequences to forest health, wildlife habitat, scenic, and other objectives. For example, Coates (1997) suggests a "management threshold" of 8% windthrow in partial-cuts before action is likely to be taken. Similarly, Vernon Forest District typically anticipates 10% windthrow in partial-cuts as a precautionary measure, although actual windthrow losses have generally been much lower.

### *Will it be more difficult to meet silviculture obligations in partial cuts?*

Frequently, when foresters are developing silviculture prescriptions and other operational plans that include a mix of timber and non-timber objectives, they may recommend species mixes and stand structures that may not have been previously anticipated or included in standardized guidebooks and manuals. In these cases, the forester may need to modify conventional silvicultural standards, survey procedures, or definitions of target stand conditions to set realistic and achievable silvicultural goals. For example, it would likely be unrealistic and unreasonable to expect the same silvicultural performance and standards of seedlings planted under a single-tree selection prescription than those planted under a clearcut prescription.

In preparing such prescriptions, however, an important step should be to provide a clear, concise rationale that justifies the modified silvicultural standards, in the context of management objectives and target stand structures.

### *These prescriptions may maintain caribou habitat, but will they produce as much timber?*

Silvicultural systems trials that could examine these questions are only 5 to10 years old; answers will take many more years of data gathering. However, initial survival and growth results are promising (See Sections 5.1.4 and 5.1.5 for more information and references). Projected growth rates could be modelled; however, without good growth and yield data the quality of modelling efforts is debatable.

Partial cutting does not automatically mean lower timber yield than clearcutting. However, in this case, since longer cutting cycles are being prescribed, some reduction in long-term yield is likely. Land-use plans in some regions have lowered timber yield expectations for areas zoned as modified harvest for caribou in recognition of the possibility that lower yields may be the price for practicing integrated management that will maintain caribou habitat.

In the short term, some increase in timber availability may occur because the caribou harvest prescriptions may free areas for harvest that are subject to other constraints. For example, some visual objectives can still be met under the prescription for maintaining caribou habitat.

### *To partial cut, will new and expensive harvesting equipment have to be acquired?*

Most partial cutting can be done with conventional equipment. For example, group selection has been effectively implemented using conventional feller-bunchers and grapple skidders. If single-tree selection is chosen, we recommend using zero-tailswing feller-bunchers, which are becoming increasingly popular.

For steep ground, several different cable systems are capable of performing the preferred group selection system and all are capable of applying the strip-selection system.

### *If the forest industry is going to make large sacrifices to maintain caribou habitat, what is government doing to ensure that winter recreation such as snowmobiling, heli or cat skiing, and ski-touring, do not eliminate caribou through harassment and displacement?*

Without a doubt, the positive efforts being made to maintain habitat through modified timber harvesting approaches will fail to maintain caribou if access issues, including winter recreation, are not adequately addressed. We recommend careful zoning of high-elevation forest and alpine to include: 1) areas of no motorized access, 2) areas of carefully controlled access to minimize impacts on caribou, and 3) areas of unrestricted access. Several sub-regional planning tables are currently attempting to do this. Good results can be achieved when land managers work together with local clubs and commercial operators to manage human behaviour in caribou habitat. Some recreation clubs and tourism operators have already modified their activities to accommodate the needs of caribou.

### *Do caribou use partial cuts?*

Caribou use has been recorded on several partially cut blocks in the Cariboo and Prince George regions. Observations have included caribou feeding on lichens on felled trees during logging as well as caribou using partial cuts years after logging was completed. More detailed information on caribou response to partial cutting will be gathered on the Mount Tom adaptive management trial in the Quesnel Forest District, where approximately 1000 ha of development is planned.

### *Won't partial cutting lead to more fragmentation and more roads?*

Unlike clearcutting, partial cutting does not cause fragmentation since, if properly implemented, it maintains caribou habitat. Large cutblocks are recommended along with concentrated harvesting over significant parts of drainages in short time periods. These recommendations will serve to minimize access concerns. The impact of roads can also be managed through aggressive road deactivation. Properly designed, the road situation would not be significantly different in clearcutting versus partial cutting in caribou habitat, whereas the benefits of partial cutting are enormous.

## 7.0 INFORMATION NEEDS AND THE FUTURE

The challenge of integrating forest management for timber production with management for Mountain Caribou and overall biodiversity is complex. This report synthesizes the best information available on caribou/forestry management for the use of resource managers involved in decision-making at the stand and landscape levels.

Since the publication of *Mountain Caribou in managed forests: Preliminary recommendations for managers* in 1994, new information has been gained from a series of operational trials. This program of applied research is based on the concept of adaptive management – the potentials of natural systems may be learned not only through basic research or development of ecological theory, but also through management experience. Successful adaptive management requires explicit statement of assumptions, careful monitoring, and a willingness to alter management if results indicate the need to do so.

Significant advances have been made since 1994 in understanding the short-term effects of various silvicultural systems on:

- abundance and growth rates of arboreal forage lichens;
- survival and initial growth of seedlings;
- success of natural regeneration; and
- windfirmness of the residual stand.

Although those studies continue to yield information, current or planned silvicultural systems studies will soon improve knowledge about:

- physiological responses of arboreal lichens to altered stand structure;
- logging productivity;
- use of partial cuts by caribou after the first harvest entry; and
- short-term post-harvest dynamics of the residual stand.

Many other topics may remain incompletely understood for decades because of their long-term nature or the difficulty of investigation. Better information on these topics would improve management:

- Impact of various silvicultural systems on:
  - establishment of lichens on regeneration
  - long-term productivity of lichens
  - use by caribou at various stages of development of regeneration
  - long-term windfirmness
  - long-term growth and yield
  - long-term site productivity
  - timber supply
- Relationships between site characteristics and the response of lichens to various silvicultural systems.
- Landscape-level impacts of the overall management strategy on population dynamics of caribou, including:
  - predator–prey dynamics
  - effects of increased access
  - response of caribou to second-growth development

Many of the special resource values of the Interior Wetbelt are associated with old stands in which small-gap disturbances are common and stand-destroying disturbances are rare. The uneven-aged forest management strategy proposed for caribou habitat has the potential of maintaining some of these resource values better than even-aged management. Some information is available on the effects of various silvicultural systems on biodiversity, but much more is needed.

*Caribou habitat management should be carried out within the context of an overall biodiversity strategy.*

Caribou habitat management should be carried out within the context of an overall biodiversity strategy.

Resolving the challenge of integrated resource management within portions of Mountain Caribou habitat will be a long-term process. In the short term, silvicultural prescriptions and forestry development should follow a conservative and adaptive management strategy. Monitoring of the treatments and their effects on the overall resource is essential to the continuous improvement of the management strategy.

## 8.0 REFERENCES CITED


Alexander, R.R. 1987. Ecology, silviculture, and management of the Engelmann spruce-subalpine fir type in the central and southern Rocky Mountains. U.S. Dep. Agric., For. Serv., Rocky Mt. For. Range Exp. Stn., Agric. Handb. 659.

Alexander, R.R., and C.B. Edminster. 1977. Regulation and control of cut under uneven-aged management. U.S. Dep. Agric., For. Serv., Rocky Mtn. For. Range Exp. Stn., Fort Collins, Co. Res. Pap. RM-182.

Alexander, R.R., and O. Engelby. 1983. Engelmann spruce-subalpine fir. Pages 59-64 *in* R.M. Burns, tech. comp. Silvicultural systems for major forest types of the United States. U.S. Dep. Agric., For. Serv., Agric. Handb. 445. Washington, DC.

Antifeau, T.D. 1987. The significance of snow and arboreal lichen in the winter ecology of Mountain Caribou (*Rangifer tarandus caribou*) in the north Thompson watershed of British Columbia. M.Sc. Thesis, Univ. B.C., Vancouver, BC.

Aplet, G.H., R.D. Laven, and F.W. Smith. 1988. Patterns of community dynamics in Colorado Engelmann spruce-subalpine fir forests. Ecology 69:312-319.

Apps, C.D., and T.A. Kinley. 1998. Assessment of a habitat suitability model for Mountain Caribou in southeastern British Columbia. Rangifer Spec. Issue No. 10:61-72.

—. 2000. Multi-scale habitat associations of Mountain Caribou in the southern Purcell Mountains, British Columbia. Unpubl. Rep. Available at www.env.gov.bc.ca/kor/wld/final.html.

Apps, C.D., B.N. McLellan, T.A. Kinley, and J. Flaa. 2001. Scale-dependent habitat selection by Mountain Caribou, Columbia Mountains, British Columbia. J. Wildl. Manage. 65:65-77.

Armleder, H.M., and S.K. Stevenson. 1996. Using alternative silvicultural systems to integrate Mountain Caribou and timber management in British Columbia. Rangifer Spec. Issue No. 9:141-149.

Armleder, H.M., S.K. Stevenson, and S.D. Walker. 1992. Estimating the abundance of arboreal forage lichens. B.C. Min. For., Land Manage. Handb. Field Guide Insert 7. Victoria, BC.

Arsenault, A. 1998. Disturbance ecology in forests of the Interior Cedar-Hemlock Zone. Pages 16-17 *in* M. Jull, D. Coxson, S. Stevenson, D. Lousier, and M. Walters, comp. Ecosystem dynamics and silvicultural systems in Interior wet-belt ESSF and ICH forests. Workshop Proc., June 1997, Prince George, BC. UNBC Press, Prince George, BC. 71pp.

Arseneau, M.J., L. Sirois, and J.P. Ouellet. 1997. Effects of altitude and tree height on the distribution and biomass of fruticose arboreal lichens in an old growth balsam fir forest. Ecoscience 4:206-213.

Benskin, H. J. 1975. Preliminary study of windthrow losses in the white spruce-subalpine fir forests of the Prince George Forest District. Unpubl. Rep., E. P. 755. B.C. For. Serv. Res. Branch. Victoria, BC.

Bergerud, A.T. 1978. The status and management of caribou in British Columbia. B.C. Fish and Wildl. Branch Rep., Victoria, BC. 150pp.

—. 1980. A review of the population dynamics of caribou and wild reindeer in North America. Pages 556-581 *in* E. Reimers, E. Gaare and S. Skjennebeg, eds. Proc. 2nd Int. Reindeer/Caribou Symp., September 1979, Roros, Norway.

Bergerud, A.T, H.E. Butler, and D.R. Miller. 1984. Antipredator tactics of calving caribou: Dispersion in mountains. Can. J. Zool. 62:1566-1575.

Bergstrom, B.W. 1983. Growth response and stand management of the advance subalpine fir on diameter-limit cut stands in the Adams Lake area of the Kamloops Forest Region. B.S.F. Thesis, Univ. B.C., Vancouver, BC. 93pp.

British Columbia Ministry of Environment, Lands and Parks. 1998. Environmental trends in British Columbia 1998. Victoria, BC. 43pp.

British Columbia Ministry of Forests. 1997a. Progress report on group selection systems for high elevation forests in the Cariboo Forest Region. Cariboo For. Reg., Williams Lake, BC. 8pp.

—. 1997b. Site index estimates for coniferous tree species in British Columbia. Victoria, BC.

—. 1998a. Windthrow field card reference Page A and B: FS712-1 (HFP 98/05). Forest Practices Branch, Victoria, BC.

—. 1998b. Windthrow field assessment form: FS712-2 (HFP 98/05). Forest Practices Branch, Victoria, BC.

—. 1998c. Windthrow field card prescription page: FS712-3 (HFP 98/05). Forest Practices Branch, Victoria, BC.

—. 2000. Windthrow assessment summary card: FS712-4 (HFP 00/03). Forest Practices Branch, Victoria, BC.

British Columbia Ministry of Forests and Ministry of Environment, Lands and Parks. 1995. Biodiversity Guidebook. Forest Practices Code of British Columbia. Victoria, BC. 99pp.

Campbell, J. 1998. Canopy research in north-central British Columbia: An exploration of lichen communities. M.Sc. Thesis, Univ. North. B.C., Prince George, BC. 132pp.

Campbell, J., and D.S. Coxson. 2001. Canopy microclimate and arboreal lichen loading in a subalpine spruce-fir forest. Can. J. Bot. In press.

Cariboo-Chilcotin Land-Use Plan (CCLUP) Caribou Strategy Committee. 2000. Mountain Caribou Strategy. Cariboo-Chilcotin Land Use Plan. Cariboo Mid-Coast Interagency Management Committee. Williams Lake, B.C.

Coates, K.D. 1997. Wind damage two years after partial-cutting of the Date Creek silvicultural systems study in the Interior cedar-hemlock forests of northwestern British Columbia. Can. J. For. Res. 27:1695-1701.

Coates, K.D., A. Banner, J.D. Steventon, P. LePage, and P. Bartemucci. 1997. The Date Creek silvicultural systems study in the interior cedar-hemlock forests of northwestern British Columbia: Overview and treatment summaries. B.C. Min. For. Land Manage. Handb. 38. Victoria, BC. 129pp.

Coates, K.D., and P.J. Burton. 1999. Growth of planted tree seedlings in response to ambient light levels in northwestern interior cedar-hemlock forests of British Columbia. Can. J. For. Res. 29:1374-1382.

Coates, K.D., S. Haeussler, S. Lindeburgh, R. Pojar, and A.J. Stock. 1994. Ecology and silviculture of interior spruce in British Columbia. FRDA Report 220. B.C. Min. For./ Can. For. Serv. 182pp.

Common, R.S., and I.M. Brodo. 1995. *Bryoria* sect. *Subdivergentes* recognized as the new genus *Nodobryoria* (lichenized Ascomycotina). The Bryologist 98:189-206.

Coupe, R.C., A.C. Stewart, and B.M. Wikeem. 1991. Engelmann Spruce-Subalpine Fir zone. Pages 223-236 *in* Ecosystems of British Columbia. B.C. Min. For. Spec. Rep. No. 6.

Coxson, D.S., D.D. McIntyre, and H.J. Vogel. 1992. Pulse release of sugars and polyols from canopy bryophytes in tropical montane rain forest (Guadeloupe, French West Indies). Biotropica 24: 121-133.

Coxson, D.S., M.R. Webber, and K.A. Kershaw. 1984. The thermal operating environment of corticolous and pendulous tree lichens. The Bryologist 87:197-202.

DeGrace, L.A. 1950. Selective logging of spruce in subalpine Alberta. Can. Dep. Resour. and Dev. For. Branch., For. Res. Div., Silvicultural Res. Note No. 96.

DeLong, C. 1998. Natural disturbance rate and patch size distribution of forests in northern British Columbia: Implications for forest management. NW Science 72:35-48.

DeLong, D.L. 1997. A retrospective investigation of advanced western redcedar regeneration in the ICHwk1, ICHmw2, and ICHmw1 of the Nelson Forest Region. B.C. Min. For. Res. Branch. Work. Pap. 25.

Dettki, H. 1998. Dispersal of fragments of two pendulous lichen species. Sauteria 9:123-132.

Dobbs, R.C. 1976. White spruce seed dispersal in central British Columbia. For. Chron. 52:225-228.

Eastham, A., and M.J. Jull. 1999. Factors affecting natural regeneration of *Abies lasiocarpa* and *Picea engelmannii* in a subalpine silvicultural systems trial. Can. J. For. Res. 29:1847-1855.

Enns, K.A. 1988. Transplants of *Alectoria sarmentosa* in the Mount Cain second-growth winter range. Unpubl. rep. prep. for Can. Forest Products, Ltd. and B.C. Min For., Res. Branch, Victoria, B.C.

Esseen, P.-A., K. Renhorn, and R.B. Pettersson. 1996. Epiphytic lichen biomass in managed and old-growth boreal forests: Effect of branch quality. Ecol. Appl. 61:228-238.

Farnden, C.F. 1994. Forest regeneration in the ESSF zone of north-central British Columbia. Can. For. Serv., Pac. and Yukon Reg. Info. Rep. BC-X-351.

Feller, M. 1997. Regeneration of Engelmann spruce and subalpine fir from seed in ESSFwc2 forests. Pages 154-169 *in* C. Hollstedt, and A. Vyse, eds. Sicamous Creek Silvicultural Systems Project: Workshop proceedings. April 1996. Kamloops, BC. B.C. Min. For., Res. Branch. Work. Pap. 24.

Fiedler, C.E., W.W. McCaughey, and W.C. Schmidt. 1985. Natural regeneration in intermountain spruce-fir forests: A gradual process. U.S. Dep. Agric. For. Serv. Intermountain For. and Range Res. Stn., Ogden, UT. Res. Pap. INT-34.

Flaa, J.P., and B.N. McLellan. 2001. A summary of the population characteristics of Lake Revelstoke caribou. Proc. Biology and Management of Species at Risk conference. B.C. Min. Environ., Lands and Parks, Victoria, BC. In press.

Glew, D.R. 1963. The results of stand treatment in the white spruce-subalpine fir type of the northern interior of British Columbia. Dep. Lands, For., and Water Resour., B.C. For. Serv., Victoria, BC. For. Manage. Note 1.

Goward, T. 1994. Notes on oldgrowth-dependent epiphytic macrolichens in inland British Columbia, Canada. Acta Bot. Fennica 150:31-38.

—. 1998. Observations on the ecology of the lichen genus *Bryoria* in high elevation conifer forests. Can. Field-Nat. 112:496-501.

Guildin, J.M. 1991. Uneven-aged BDq regulation of Sierra-Nevada mixed conifers. J. For. 6:27-32.

Hamilton, D., 1999. Central Selkirk caribou project annual report April 1998 to March 1999. B.C. Min. Environ., Lands and Parks. Nelson, BC.

Harris, A.S. 1989. Wind in the forests of southeast Alaska and guides for reducing damage. U.S. Dept. Agric., For. Serv. Gen. Tech. Rep. PNW-GTR-244. 63pp.

Hatter, I., D. Hebert, T. Kinley, S. McNay, B. Nyberg, D. Seip, R. Thompson, G. Woods, and J. Youds. 2000. Recovery plan for the Mountain Caribou *(Rangifer tarandus caribou)* in British Columbia. Draft rep. prep. for Mountain Caribou Technical Advisory Committee.

Hawkes, B., W. Vasbinder, and C. DeLong. 1997. Retrospective fire study: Fire regimes in the SBSvk and ESSFwk2/wc3 biogeoclimatic units of northeastern British Columbia. Final rep. for McGregor Model Forest Association. PO Box 9000, Prince George, BC.

Heard, D.C. and K.L. Vagt. 1998. Caribou in British Columbia: A 1996 status report. Rangifer, Spec. Issue No. 10:117-123.

Herring, L.J. 1977. Studies of advance subalpine fir in the Kamloops Forest District. B.C. Min. For., Victoria, B.C. Res. Rep. No. 80.

Hollstedt, C., and A. Vyse, eds. 1997. Sicamous Creek Silvicultural Systems Project: Workshop proceedings, April 1996. Kamloops, BC. B.C. Min. For., Work. Pap. 24. Victoria, BC. 283pp.

Huggard, D.J., and W. Klenner. 1999. Silvicultural systems for wildlife in the ESSF: Research at Sicamous Creek. SISCO (Southern Interior Silviculture Committee): Proc. Ann. Meeting, Penticton, BC.

Huggard, D.J., W. Klenner, and A. Vyse. 1999. Windthrow following four harvest treatments in an Engelmann spruce-subalpine fir forest in southern interior British Columbia, Canada. Can. J. For. Res. 29:1547-1556.

Johnstone, W.D. 1978. Growth of fir and spruce advance growth and logging residuals following logging in west-central Alberta. Can. For. Serv., Northern For. Res. Cent., Inf. Rep. NOR-X-203.

James, A.R.C., and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. J. Wildl. Manage. 64:154-159.

Jull, M., D. Coxson, S. Stevenson, D. Lousier, and M. Walters, comp. 1998. Ecosystem dynamics and silvicultural systems in interior wet-belt ESSF and ICH forests. Workshop Proceedings, June 1997. Prince George, BC. UNBC Press, Prince George, BC. 71pp.

Jull, M., S. Stevenson, and B. Sagar. 1999. Group selection in old cedar-hemlock forests: Five-year results of the Fleet Creek partial-cutting trial. B.C. Min. For., Prince George For. Reg., Prince George, BC. For. Res. Note # PG-20.

Ketcheson, M.V., T.F. Braumandl, D. Meidinger, G. Utzig, D.A DeMarchi, and B.M. Wikeem. 1991. Interior Cedar-Hemlock zone. Pages 167-182 *in* Ecosystems of British Columbia. B.C. Min. For. Spec. Rep. No. 6.

Klinka, K., Q. Wang, R.E. Carter, and H.Y.H. Chen. 1996. Height growth-elevation relationships in subalpine forests of interior British Columbia. For. Chron. 72:193-198

Lajzerowicz, C. 1999. How does overstory retention affect above- and below-ground resource availability and seedling performance? Implications for silvicultural systems choice in the ESSF. M.Sc. Thesis, Univ. North. B.C. Prince George, BC. 7pp

Lewis, K.J., and B.S. Lindgren. 1999. Influence of decay fungi on species composition and size class structure in mature *Picea glauca X engelmannii* and *Abies lasiocarpa* in sub-boreal forests of central British Columbia. For. Ecol. Manage. 123:135-143.

McCaughey, W.W., and W.C. Schmidt. 1982. Understory tree release following harvest cutting in spruce-fir forests of the Intermountain West. U.S. Dep. Agric., For. Serv. Intermountain For. and Range Exp. Stn., Ogden, UT. Res. Pap. INT-285.

Miller, J., D. DeLong, B. McLellan, and E. Terry. 1999. Partial cutting prescriptions for Mountain Caribou in the ESSF of southeastern BC: A retrospective investigation. Unpubl. FRBC rep. KB 97 194.

Mitchell, J.L. 1996. Trial of alternative silvicultural systems in southern British Columbia: Summary of harvesting operations. For. Eng. Res. Inst. Can. (FERIC). Rep. No. TN-240.

Newsome, T.A., M.J. Waterhouse, H.M. Armleder and O.A. Steen. 2000. We're harvesting timber and maintaining caribou habitat: What about silviculture and other concerns? Pages 49-53 *in* C. Hollstedt, K. Sutherland, and T. Innes, eds. From science to management and back: A science forum for southern interior ecosystems in British Columbia. Proc. Southern Inter. For. Ext. and Res. Partnership, Res. Info. Rep. No 1.

Nyberg, J.B. 1998. Statistics and the practice of adaptive management. Pages 1-8 *in* Statistical methods for adaptive management studies. B.C. Min. For. Res. Branch. Victoria, BC. Land Manage. Handb. 42.

Oosting, H.J., and J.F. Reed. 1952. Virgin spruce-fir of the Medicine Bow Mountains, Wyoming. Ecol. Monogr. 22:69-91.

Parish, R. 1997. Age and size structure of the forest at Sicamous Creek., 1997. Pages 16-31 *in* C. Hollstedt, and A. Vyse, eds. Sicamous Creek Silvicultural Systems Project: Workshop proc., April 1996, Kamloops, BC. B.C. Min. For., Res. Branch. Work. Pap. 24.

Parish, R., J.A. Antos, and M.-J. Fortin. 1999. Stand development in an old-growth subalpine forest in southern interior British Columbia. Can. J. For. Res. 29:1347-1356.

Pavel, M. 1999. Analysis of skyline partial cutting operation in interior cedar-hemlock biogeoclimatic zone. For. Eng. Res. Inst. Can. (FERIC). Rep. No. TR-125.

Quesnel, H.J. and L. Waters. 1999. Integrating Mountain Caribou requirements and forest management in the interior wet-belt near Revelstoke: Windthrow. Unpubl. rep. prep. for B.C. Min. For., Res. Branch, Victoria, BC.

—. 2000. Integrating Mountain Caribou requirements and forest management in the interior cedar hemlock: Lichen retrospective and dispersal study. Final rep. prep. for B.C. Min. For., Res. Branch, Victoria, BC.

Reynolds, R.R. 1997. Climatic data summary for the biogeoclimatic zones of British Columbia. B.C. Min. For., Res. Branch. Victoria BC.

Rogers, B., and M. Jull. 2000. Fleet Creek ICH Group Selection Research Project: Planted regeneration trial 1995-1999. Unpubl. rep.

Rominger, E.M., L. Allen-Johnson, and J.L. Oldemeyer. 1994. Arboreal lichen in uncut and partially cut subalpine fir stands in woodland caribou habitat, northern Idaho and southeastern British Columbia. For. Ecol. Manage. 70:195-202.

Rominger, E.M., and J.L. Oldemeyer. 1989. Early-winter habitat of woodland caribou, Selkirk Mountains, British Columbia. J. Wildl. Manage. 53:238-243.

Rominger, E.M., C.T. Robbins, and M.A. Evans. 1996. Winter foraging ecology of woodland caribou in northeastern Washington. J. Wildl. Manage. 60:719-728.

Rominger, E.M., C.T. Robbins, M.A. Evans, and D.J. Pierce. 2000. Autumn foraging dynamics of woodland caribou in experimentally manipulated habitats, northeastern Washington, USA. J. Wildl. Manage. 64:160-167.

Seip, D.R. 1990. Ecology of woodland caribou in Wells Gray Provincial Park. B.C. Min. Environ. and Parks. Wildl. Bull. No. B-68. 43pp.

—. 1992. Factors limiting woodland caribou populations and their interrelationships with wolves and Moose in southeastern British Columbia. Can. J. Zool. 70:1494-1503.

Servheen, G. and J.L. Lyon. 1989. Habitat use by woodland caribou in the Selkirk Mountains. J. Wildl. Manage. 53:230-237.

Shea, K.L. 1985. Demographic aspects of coexistence in Engelmann spruce and subalpine fir. Am. J. Bot. 72:1823-1833.

Simpson, K. 1987. The effects of snowmobiling on winter range use by Mountain Caribou. B.C. Min. Environ., Wildl. Work. Rep. WR-25.

Simpson, K., and E. Terry. 2000. Impacts of backcountry recreation activities on Mountain Caribou. B.C. Min. Environ., Lands and Parks. Wildl. Work. Rep. WR-99. 12pp.

Simpson, K., E. Terry, and D. Hamilton. 1997. Towards a Mountain Caribou management strategy for British Columbia: Habitat requirements and subpopulation status. B.C. Min. Environ., Lands and Parks. Wildl. Work. Rep. WR-90. 27pp.

Simpson, K., and G.P. Woods. 1985. Movements and habitats of caribou in the mountains of southern British Columbia. B.C. Min. Environ., Wildl. Bull. B-57. 41pp.

Smith, D.M. 1986. The practice of silviculture. 2nd ed. McGraw-Hill, New York, NY.

Stathers, R.J. 1999. Group selection systems for high-elevation ESSFwc3 forests to maintain caribou habitat in the Cariboo Forest Region: Microclimate studies. Unpubl. rep. prep. for Res. Section, B.C. Min. For., Cariboo Forest Region, Williams Lake, BC. 44pp.

Steeger, C., R. Holt, and J. Smith. 1999. Enhancing biodiversity through partial cutting. Rep. prep. for For. Practices Branch, B.C. Min. For. 52pp.

Stevenson, S.K. 1988. Dispersal and colonization of arboreal forage lichens in young forests. B.C. Min. Environ. and B.C. Min. For. IWIFR-38. Victoria, BC. 58pp.

—. 1995. Thinning and lichen inoculation at the Haggen Burn site: Final report. Unpubl. rep. prep. for B.C. Min. Environ., Lands and Parks, Prince George, BC. 51pp.

Stevenson, S.K., H.M. Armleder, M.J. Jull, D.G. King, E.L. Terry, G.S. Watts, B.N. McLellan, and K.N. Child. 1994. Mountain Caribou in managed forests: Preliminary recommendations for managers. B.C. Min. For. Res. Branch, Victoria, BC.

Stevenson, S.K., and D.H. Hatler. 1985. Woodland caribou and their habitat in southern and central British Columbia: Vol. 1. B.C. Min. For. Land Manage. Rep. 23. Victoria, BC. 355pp.

Stevenson, S.K., M.J. Jull, and R.M. Sagar. 1999. Selection silvicultural systems in Mountain Caribou habitat: Logging and learning at Pinkerton Mountain. B.C. Min. For., Prince George For. Reg., Prince George, B.C. For. Res. Note No. PG-19.

Stevenson, S.K., and D.G. Keisker. 2001. Evaluating the effects of partial cutting on wildlife trees and coarse woody debris. *In* Proc. Ecology and Management of Dead Wood in Western Forests, November 1999, Reno, NV. U.S. Dep. Agric., Gen. Tech. Rep. Submitted.

Stevenson, S.K., A.N. Lance, and H.M. Armleder. 1998. Estimating the abundance of arboreal forage lichens: User's guide. B.C. Min. For. Land Manage. Handb. 43. Victoria, BC. 35pp.

Steventon, J.D., K. MacKenzie and T. Mahon. 1998. Response of small mammals and birds to partial cutting and clearcutting in northwest British Columbia. For. Chronicle 74:703-713.

Sutherland, C., O. Steen, T. Newsome, J. Perry, P. Teti, B. Chapman, and H. Armleder. 1992. Group selection system for high elevation forests (ESSFwc3) to maintain caribou habitat in the Cariboo Forest Region: Working Plan. B.C. Min. For., Project E.P. 1104.02.

Terry, E.L, B.N. McLellan, and G. Watts. 2000. Winter habitat ecology of Mountain Caribou in relation to forest management. J. Appl. Ecol. 37:589-602.

Terry, E.L., B.N. McLellan, G. Watts, and J. Flaa. 1996. Early winter habitat use by Mountain Caribou in the North Cariboo and Columbia Mountains, British Columbia. Rangifer Spec. Issue 9:133-140.

Thibodeau, E.D., R.K. Krag, and I.B. Hedin. 1996. The Date Creek study: Productivity of ground-based harvesting methods in the Interior cedar-hemlock zone of British Columbia. For. Eng. Res. Inst. Can (FERIC). Report SR-114. 38pp.

Tysiaczny, M.Y., and K.A. Kershaw. 1979. Physiological environmental interactions in lichens. VII. The environmental control of glucose movement from alga to fungus in *Peltigera canina* var. *praetextata* Hue. New Phytol. 83:137-146.

Veblen, T.T. 1986. Treefalls and the coexistence of conifers in subalpine forests of the central Rockies. Ecology 67:644-649.

Veblen, T.T., K.S. Hadley, and M.S. Reid. 1991. Disturbance and stand development of a Colorado subalpine forest. J. Biogeog. 18: 707-721.

Waters, L. 1997. Case study: Patch cutting in old-growth to maintain early winter caribou habitat. B.C. Min. For., Nelson For. Reg. Ext. Note RS-029. 4pp.

Weetman, G.F. 1996. Are European silvicultural systems and precedents useful for British Columbia silviculture prescriptions? Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II. Can. For. Serv./B.C. Min. For. FRDA Rep 239. 31pp.

Wildlife Tree Committee of British Columbia. 1993. Wildlife tree management in British Columbia. Province of B.C., Victoria, B.C. 30 pp.

Workers' Compensation Board of British Columbia. 1998. Occupational health and safety regulation. B.C. Regulation 296/97. Vancouver, BC.

Young, J.A., and L.M. Roorda. 2000. Towards integrated management solutions: The Quesnel Highland Caribou Project. Radio-Telemetry Progress Report 1993-1999. Wildl. Branch, Cariboo Region, B.C. Min. Environ., Lands and Parks, Williams Lake, BC.

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R-26. S.K. Stevenson, H.M. Armleder, M.J. Jull, D.G. King, B.N. McLellan, D.S. Coxson. 2001. Mountain Caribou in Managed Forests: Recommendations for Managers. Second Edition. 58pp.