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MARCH 2005

The Opax Mountain Silvicultural Systems Project: Preliminary Results for Managing Complex, Dry Interior Douglas-fir Forests

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Abstract

The Opax Mountain Silvicultural Systems project explores management options for some of the issues facing managers of complex forests in the dry Interior Douglas-fir (IDF) biogeoclimatic zone. The project includes two study areas: one in the IDFxh2 variant and one in the IDFdk2. Each area has six operational-scale harvest treatments: uncut control; 20% removal of merchantable volume using individual tree selection (ITS); 50% ITS; 50% ITS with uncut reserves; 20% removal using a mixture of patch cuts of 0.1, 0.4, and 1.6 ha; and 50% removal with patch cuts of a similar nature as the 20% removal. The project includes studies of:

- fire history and other natural disturbance agents;
- regeneration in openings and under partial canopy;
- edge effects on microclimate, snowmelt, and soils;
- effects of canopy density, gap sizes, site preparation, and edges on planted seedlings, natural regeneration, and vegetation (including cover layers, individual species, and groups such as forage plants, weeds, soil seedbanks, and ectomycorrhizal hosts); and
- harvest treatment effects and habitat relationships of wildlife groups, including terrestrial invertebrates, arboreal beetles, small mammals, songbirds, woodpeckers, and ungulates.

We summarize results for many of the individual studies at Opax Mountain, dealing with the important management issues of natural disturbance regimes, regeneration, management of vegetation resources, and conservation of biological diversity in managed dry IDF stands. Natural disturbances at the site cover a wide spectrum of sizes, frequencies, severities, and effects on stand structure. Responses of the many study variables show that no one management treatment will maintain all valued components in the IDF forest. Together, these results support the use of a range of management practices broader than the current uneven-aged management widely practiced throughout the dry IDF biogeoclimatic zone. In particular, patch-cut systems with openings >0.1 ha, or extended rotations to permit the development of large live trees, snags, and coarse woody debris would complement individual tree selection systems.

BRITISH COLUMBIA

Ministry of Forests Forest Science Program

Introduction

Variability and Management of the Interior Douglas-fir (IDF) Zone

Forests of the dry Interior Douglas-fir (IDF) biogeoclimatic zone (Lloyd et al. 1990) of British Columbia are among the most variable in the province. Although often dominated by a single tree species (Douglas-fir), the forests show great regional and fine-scale variation. Regionally, IDF forests are denser and more productive in the central Interior, and more open and patchy, and slower-growing, in the drier southern Interior. The structure and composition of IDF forests also varies with elevation, from upper-elevation IDF stands that grade into dense lodgepole pine stands of the Montane Spruce (MS) biogeoclimatic zone, to open stands adjacent to the low-elevation open Ponderosa Pine (PP) or Bunchgrass (BG) biogeoclimatic zones. At upper elevations and in northern areas of the IDF zone, spring frosts play an important limiting role for Douglas-fir, while summer drought is a key factor at lower elevations.

Structures of IDF stands are often complex and can include large, widely spaced trees with open understories, dense thickets of small trees, or variable mixes of patchy overstory and understory trees (Figure 1). Slope, aspect, drainage, soil depth, and underlying geology all affect stand structure. In addition, a wide range of natural disturbances affect these stands, including: lightning; stand-replacing, moderate-severity, and light understory fires; endemic and periodic outbreaks of western spruce budworm, Douglas-fir tussock-moth, Douglas-fir bark beetle, and mountain pine beetles; and other disturbance agents, such as root rots and windthrow. Periodic harvesting and annual livestock use over the past century have also shaped stand structure.

Despite this natural variability, drier IDF forests throughout the southern Interior have traditionally been managed using uniform partial cutting. When regulated harvesting was first introduced 50 years ago, low-volume removals were prescribed and stems were marked to ensure that a healthy residual stand was retained. As the demand for timber increased, economic pressures changed harvesting to a diameter-limit system. This was easier to administer but often resulted in poor-quality retained trees and concern about long-term recruitment. More recently, stem marking has returned in an attempt to retain or create a desired size distribution of trees. With increased scrutiny of forestry practices, ever more complex guidelines have been introduced to regulate harvesting and regeneration of partially cut IDF stands with the intent of creating a multi-aged stand (Klenner and Vyse 1998). Recent drivers for harvest include large- and small-scale salvage following wildfire and mountain pine beetle outbreaks.

FIGURE 1 *Stand structure in the IDFxh2 varies greatly.*

This approach to managing IDF forests has created two problems. First, the regulations are cumbersome, and not conducive to results-based forestry. More importantly, no single approach is likely to successfully meet the wide range of objectives foresters are now responsible for: harvest economics, regeneration, forest health, biological diversity, water quality, and other forest resources. Specific management issues in the IDF zone have highlighted problems with widespread use of uniform partial cutting:

- Lack of regeneration in some par-

tially cut stands is an operational concern. While shading by retained trees should reduce dry conditions that threaten regenerating trees, root competition for water by residual trees may be a more important challenge to regeneration.

- At the same time, there is unease about some very dense stands with poor growth, low understory productivity, and high fuel loading.
- Planting is used to remedy regeneration problems, but grass competition for moisture (Heineman et al. 2003) and frost damage have led to many plantation failures. Site preparation can be used to reduce competition and frost, but it is expensive and difficult to apply following partial cutting.
- Multi-layer stands are susceptible to attack by western spruce budworm. This contributes to a widespread perception of an ongoing "decline" in forest health in the IDF zone.
- Production of forage for cattle is another responsibility of forest management throughout the IDF zone, which may not be best addressed with uneven-aged systems.
- Many species in the IDF zone also rely on forest features difficult to maintain with uniform partial cutting, such as large snags or interspersed openings and dense patches.
- The multi-layered stand structure created by uniform partial cutting represents only a small part of the range of conditions that would have arisen historically through natural disturbances.

The Opax Mountain Silvicultural Systems Project

Motivated by these concerns, researchers established the Opax Mountain project to examine partial cutting and alternative ways to manage dry IDF forests. The project is one of several silvicultural systems projects in British Columbia. All share the idea that the most reliable way of providing practitioners with the information they need to make responsible decisions is by comparing treatments with a replicated experimental design at an operational scale. Research at the silvicultural systems sites is multi-disciplinary to address the many responsibilities faced by applied users. The Opax site also developed as a response to a direct conflict between foresters, who viewed the area as an easily accessible timber source, and public groups concerned with environmental values. The large-scale research site helped resolve the conflict by allowing some timber harvesting, while providing information to improve management in the long term and fostering communication. This Extension Note presents an overview of the project, initial results, and preliminary interpretations for practitioners and the interested public.

Study Site

The Opax Mountain site is located 20 km northwest of Kamloops, B.C. The site contains two adjacent study areas of about 150 ha each: one at 900–1100 m elevation in the IDFxh2 variant (Mud Lake) and the other at 1200–1370 m in the IDFdk2 variant (Opax Mountain). Both sites have highly varied topography, creating ecosystems that range from numerous small wetlands and a wide variety of forest types, to dry rocky outcrops associated with old volcanic flows. The IDFdk2 study area has about one-third lodgepole pine mixed with Douglas-fir, while lodgepole pine is rare and localized in the IDFxh2 site, which borders on grasslands. Aspen occurs in scattered patches and spruce grows in some wetter areas (Bealle-Statland 1998). Selective logging took place at lower elevations during a short period of homestead settlement from 1900 to 1920. Much of the study area was again logged in 1956–1957 when most of the larger and better-formed stems were removed and milled on site.

The two study areas at Opax Mountain were each divided into six experimental treatment units of about 25 ha, with the following treatments applied in a randomized-block design (Figure 2):

1. Uncut control (D & I)
2. 20% merchantable volume removal using uniform partial cutting (F & L)
3. 20% area removal using small patch cuts of 0.1, 0.4, and 1.4 ha (C & K)
4. 50% uniform removal (B & G)
5. 50% removal with patch cuts (E & J)
6. 50% uniform removal over 70% of the block, with the remaining 30% as uncut reserves (A & H).

The area was harvested in winter 1993–1994 with the co-operation of the Ministry of Forests Small Business Program. The uniform partial cuts were not implemented with the standard operational prescription of equal removal across the diameter distribution. Instead, a diameter-limit approach was used to remove larger trees. As well as allowing comparisons of uniform versus patch removal, the intent was to test the effects of removing particular stand structures such as large stems and snags. Comparisons of pre- and post-harvest permanent sample plots showed that all treatments removed the intended volume, except that 61.5% of the volume was removed in the 50% uniform treatments (Bealle-Statland 1998). The discrepancy was due to low precision in the initial cruise plots that were used to establish the diameter limits.

To remove the confounding influence of livestock grazing on vegetation succession and regeneration, cattle were excluded from the area with the help of professional horse riders during the first eight years of the study, and thereafter by a barbed wire fence that was installed around the study area.

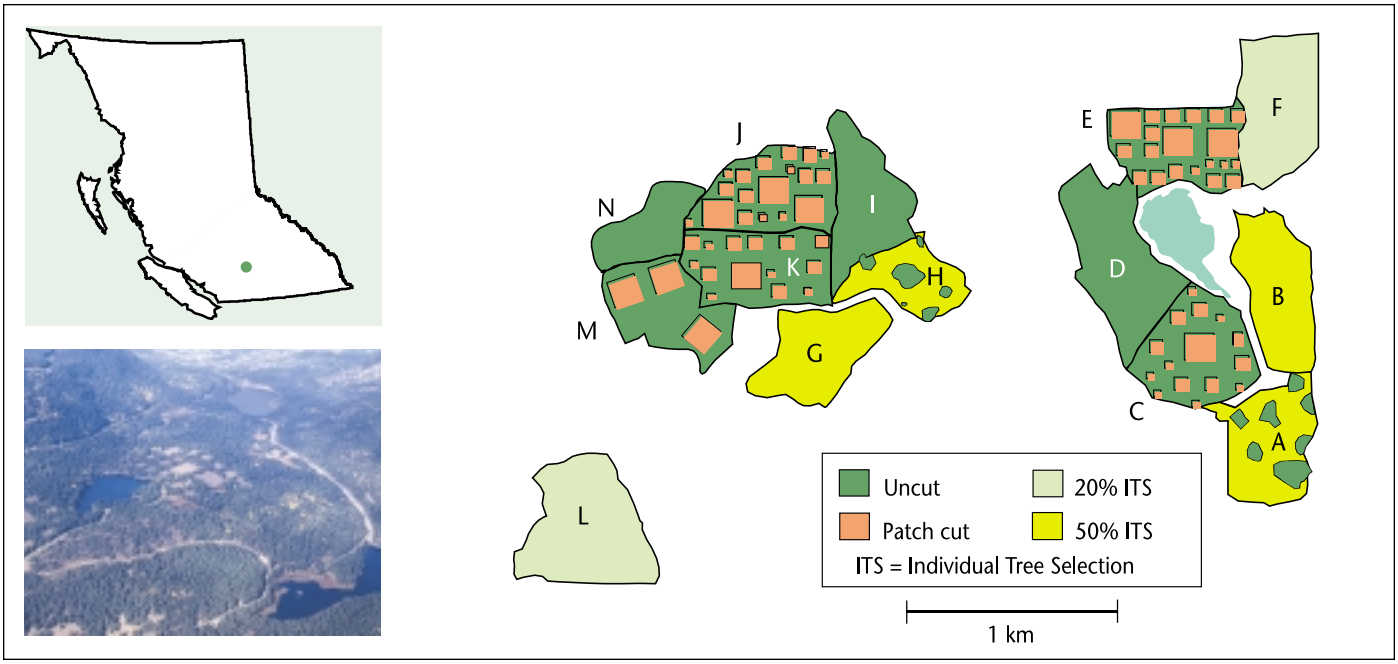


FIGURE 2 *Site overview of the Opax Mountain Silvicultural Systems project.*

The Isobel project, a complement ary study that integrates livestock grazing into the monitoring design, was implemented in 2002 (Klenner 2003) in an adjacent area.

Two experimental ground disturbance treatments (mechanical scarification and prescribed burn) were applied to subplots within the main harvesting treatments to examine vegetation and regeneration response.

In unharvested forest and in the large patch-cut openings (1.6 ha), three levels of downed wood were created experimentally to examine the habitat relationships between downed wood and small mammals. To achieve these levels, downed wood (>6 cm in diameter) levels were manipulated to create high, moderate, and low downed wood conditions (Craig 2002) in randomly chosen areas of residual forest and the 1.6-ha patch cuts. Two additional treatment units were added to the original design to ensure that three replicates were available for this study (M & N).

The multi-disciplinary work at Opax Mountain examines natural disturbances, stand structure, microclimate, soils, tree regeneration, vegetation, and wildlife species. Researchers have taken three general approaches to dealing with the natural variability of IDF stands and the effects of the harvest treatments:

1. *Natural disturbances and stand structure:* Studies of fire, insects, and other disturbances examined how the variable structure of IDF forests arose. The "ecosystem management" approach contends that forest management should "mimic natural disturbances." While it would be very difficult and costly to mimic all aspects of natural disturbances in the IDF zone, we can learn from natural disturbances to help develop management objectives for many values. How natural disturbances interact with management actions is also critical for understanding the long-term structure and condition of managed IDF stands.

2. *Canopy closure, gaps, and edges:* For many resource values, the patchy IDF forest is best seen as a continuum of canopy closure and canopy gaps of different sizes. This approach is especially well suited to studies of regeneration and vegetation that are closely tied to light, water availability, and soil conditions. Harvesting can create new

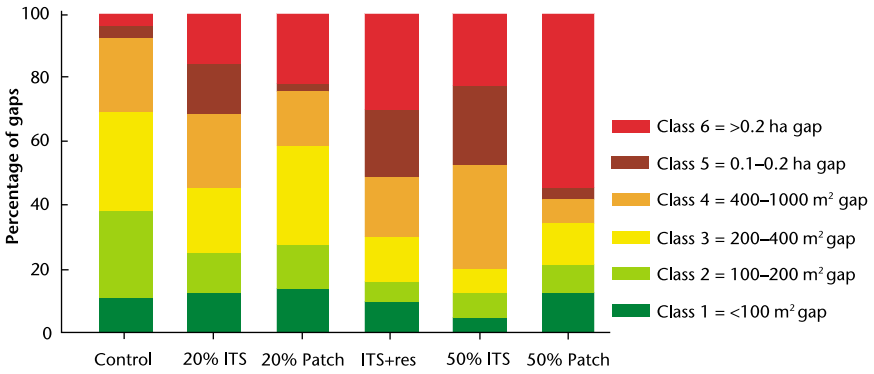


FIGURE 3 *Composition of treatments by "gap classes".*

gaps, enlarge others, or reduce canopy closure. From this perspective, patch cuts are just larger gaps. Larger openings also create edge effects into the opening or into forest.

The patchy uncut forest at the Opax site includes about 10% dense canopy, 30% moderate canopy, 30% open canopy or small gaps, 20% gaps of about 200 m^2, and 10% large natural or historical openings (Miège et al. 2002). Light partial cutting changes this distribution by substantially increasing the area in the two larger gap sizes. Heavier partial cutting increases the number of these large gaps (Figure 3) and reduces the amount of denser canopy closure. Patch cuts produce large gaps, while having less effect on small gaps and denser canopy closure.

3. *Overall silvicultural systems treatments:* Studies of mobile wildlife species examined the effects of the overall silvicultural systems treatments on the abundance, demography, or behaviour of selected indicator species. Additional work linked some species to the habitat elements that harvesting affects.

Results

Natural Disturbance Agents

Studies of fire, insects, and other disturbances seek to understand how the variable structure of IDF forests arose, and to provide information to help guide management. Windthrow is an additional direct post-harvest concern.

Fire: Our initial fire history results at Opax suggest that low-, moderate-, and high-severity fires have occurred in a complex pattern across the local landscape over the last 300 years. For example, the mean fire return interval varied between 9 and >60 years (Arsenault and Klenner 2004). The IDFxh2 site has experienced more frequent fires than the IDFdk2 site, but examples of all three types of fire severity are present at both sites.

Insects: We detected seven spruce budworm outbreaks over the last 300 years (Campbell et al. 2004). Again, these outbreaks varied in space and time. We are currently examining the relationship between fire events, spruce budworm, and climate over the last 300 years. Mountain pine beetle outbreaks have also affected the upper part of the study area, and the whole site has likely experienced Douglas-fir bark beetle mortality and the effects of several species of root disease.

Windthrow: Post-harvest windthrow was high in the uncut control and 50% ITS units in the IDFdk study area due to their exposure (Miller and Maclauchlan 1998; A. Vyse, unpublished data). Lodgepole pine had slightly higher windthrow rates than Douglas-fir where the species occurred together, and the windthrown pine tended to be larger (Miller and Maclauchlan 1998). Windthrow was 2–3 times greater within 10 m of the edges of 0.4- and 1.6-ha openings, but not affected by 0.1-ha patch cuts. However, this edge effect did not amount to higher overall windthrow rates in the patch-cut treatments compared with ITS.

Windthrown trees were used by both primary (tree-killing) and secondary bark beetles, with 64% of down lodgepole pine attacked and 30% of Douglas-fir (Miller and Maclauchlan 1998). However, this did not appear to contribute to attacks on live trees, as small endemic patches of Douglas-fir beetle were not associated with windthrow (Miller and Maclauchlan 1998). Windthrow and endemic bark beetles at the site have moderate, patchy effects on stand structure. A recent outbreak of mountain pine beetle is killing lodgepole pine in the IDFdk site, but the net effect on the stand has yet to be evaluated.

Natural disturbance agents – summary: The wide variation in historical disturbances does not support the creation or maintenance of a multi-layered stand across extensive areas in the IDF zone. The application of a uniform, all-aged management system will not reflect the range of variability in structure and pattern of the forest created by historic natural disturbances. Nor is it likely to be the best management option in the face of expected natural disturbances such as fire, western spruce budworm outbreaks, or root disease. The variety of disturbances also makes it very difficult to predict how well any silvicultural system in the IDF zone will perform in the long term. Some issues associated with this uncertainty will be addressed by long-term operational trials like the Opax study.

Microclimate and Soils

Measurements of snow, soil temperature, moisture, and nutrients help in understanding what conditions are needed for tree growth, as well as how suitable managed stands are for other vegetation and wildlife.

Snowmelt: Snowmelt showed a pronounced but short edge effect associated with harvested openings. Mid-winter snow depths were typically 20 cm deeper across openings than in the forest. In late winter, snow depths dropped 20 cm within 5 m of the northern (south-facing) edge. They remained about 10 cm deeper up to 15 m into the opening on the shaded north-facing side (Figure 5) (Huggard et al. 1998). These differences in exposure lead to an average snow-free date nearly a month earlier along the northern edge than on the southern edge of openings. Earlier bare ground may lengthen the growing season for trees and other vegetation, but may also lead to drought later in the summer.

Soil temperature: In the summer, soil temperatures showed a similar edge effect, with temperatures at 10 cm depth 4°C higher than the average on the northern edge of openings, and 3°C lower on the southern edge (Figure 5) (Bissonnette and Lloyd 1999). Both edge effects disappeared by 20 m into the opening.

TABLE 1 *Study variables, approaches, and methods at the Opax Mountain Silvicultural Systems site*

Study variable	Approach	Method
Growth and yield	Treatments	Periodic measurements in permanent sample plots
Stand development	Treatments	Age and growth reconstructed from tree rings and stem analysis, projections using computer models
Fire regime[1]	Across site	Reconstructed from tree rings using fire scars and tree age as indicators
Douglas-fir defoliators[2]	Across site	Reconstructed from tree rings, corrected for annual climate effects
Bark beetles	Treatments	Species and abundance of arboreal beetles recorded using multiple funnel traps, bark- and wood-boring beetles associated with blowdown
Windthrow	Treatments, edges	Transect surveys 3 years after harvest
Soil temperatures	Edges	Thermocouples across edges
Soil moisture[3]	Edges	Moisture blocks across edges
Snow depth and duration	Treatments, edges	Mid-winter and spring snow depth transects
Soil chemistry, N[4]	Treatments, edges	Chemical and N availability measures on forest floor and mineral soil samples
Decomposition	Treatments, edges	Mass loss of litter bags
Advanced regeneration	Treatments	Periodic measurements of abundance and height growth of seedlings established before harvest
Seedfall	Treatments, edges	Abundance of tree seeds recorded by species in traps along transects
Planted Fd, Pl, and Py seedlings	Openings, under canopy	Periodic measurements of survival and growth using operational surveys
Seedlings and planted seeds	Gap size, edge, site prep	Germination, survival, and growth of planted seedlings and seeds (some protected with mesh)
Natural regeneration	Treatments, gap size	Ingress in vegetation and site prep regeneration plots
Seedling bank age structure[5]	Patches of seedlings	Age and radial growth reconstructed from tree rings, height growth measured by internode length
Vascular plants[6]	Gap size, edge, site prep	Species, % cover, and height recorded in plots on transects, gap classes, site prep trials
Lichens and bryophytes	Gap size, edge, site prep	% cover of selected species and groups
Soil seedbanks[7]	Patch cuts, leave strips	Vegetation plots, soil samples, and species of germinants from soil samples in greenhouse trials
Ectomycorrhizal fungi	Host associations	Root samples of tree and shrub species
Habitat elements	Treatments	5.6 m radius plots, CWD intercept transects
Woodpeckers[8]	Treatment, edge, habitat	Transect counts, nest, and foraging observations using radio-telemetry
Song birds	Treatment	Abundance and species recorded using point count surveys
Winter use by mammals	Treatment, edge, habitat	Snow-track surveys
Squirrels, mice, and voles[9]	Treatment, edge, habitat	Live trapping, habitat plots, radio-telemetry, and CWD manipulation experiments.
Long-toed salamanders	Treatments	Pitfall trapping and pond surveys
Shrews and terrestrial invertebrates	Treatment, edge, habitat	Pitfall traps, habitat plots
Arboreal beetles	Treatments	Funnel traps
Stand dynamics simulations	Treatments	Computer modelling of stand structure using different management scenarios

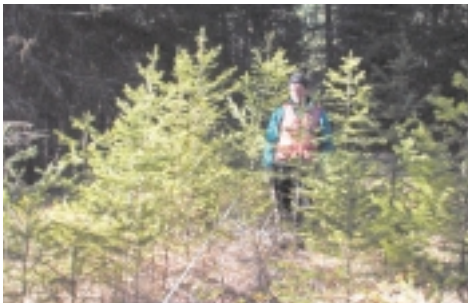
[1]Superscript numbers are related to the following study photos.

[1]*Fire regime*

[2]*Douglas-fir defoliators*

[3]*Soil moisture*

[4]*Soil chemistry, N*



[5]*Seedling bank age structure*

[6]*Vascular plants*

[7]*Soil seedbanks*

[8]*Woodpeckers*

[9]*Squirrels, mice, and voles*

FIGURE 4 *Illustrations of the range of studies being conducted at the Opax site. Numbers relate to superscripts in Table 1.*

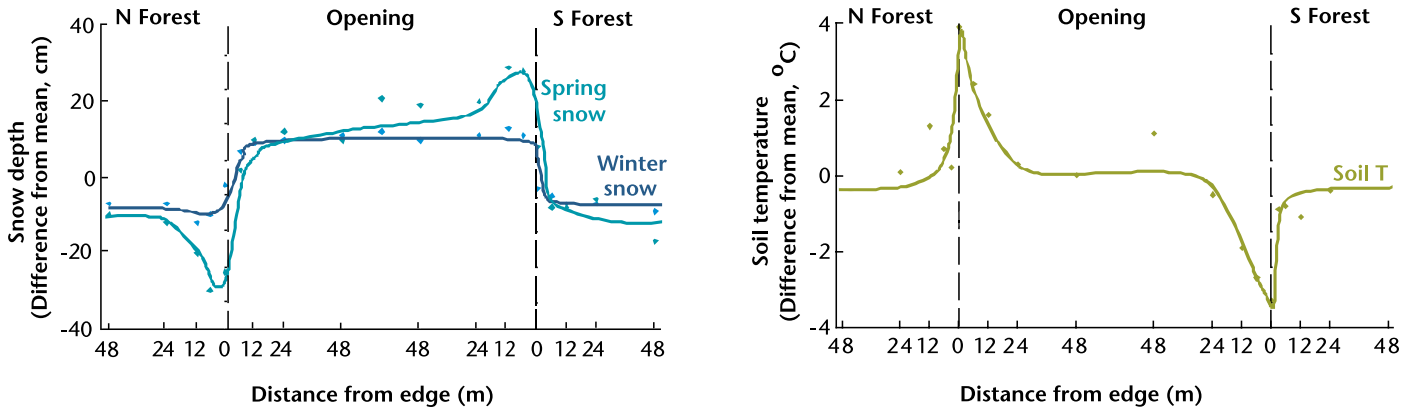


FIGURE 5 *Edge effects in snow depth (left) and summer soil temperatures (right), from forest on the north side (south-facing edge) through 1.6-ha openings into the south forest (north-facing edge). Values are differences from the overall mean value of the variable. Curves have been fitted to show the researchers' interpretation of the original data (shown by symbols).*

Microclimate and soils – summary:
Soil moisture: Potential drought stress for plants, measured by soil water potential, was very high in openings at the northern edge, and was also high at the southern edge (Orchansky 2002). However, soil water potential 24 m into the opening was only slightly greater than values in the uncut forest. The high drought stress at all locations in late summer, except in wet microsites, indicates that moisture may limit productivity.
Nitrogen: Mineralized nitrogen was increased by both partial and patch cuts, primarily in the form of nitrate (NO_3) (Figure 6) (Hope et al. 2003). The nitrification effect was apparent within 10 m into the opening. The increase in nitrate was not due to increased litter decomposition, which remained constant across the opening and into the forest (Figure 6) (Hope et al. 2003). Altered microbial activity due to carbon changes and reduced uptake of nitrate by trees are possible explanations for the increase in NO_3. Increased availability of nitrogen in the openings could promote seedling growth during the first year, but would likely be sequestered by grasses in subsequent years. Other nutrients showed minor or no changes in the harvested areas (Hope and Prescott 2001).

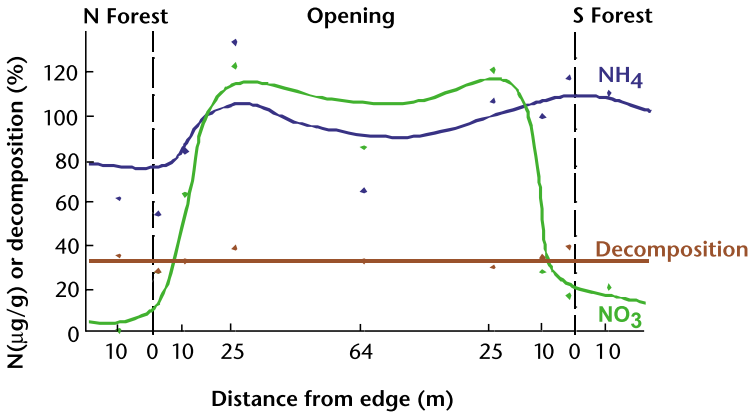


FIGURE 6 *Edge effects in two forms of mineralized nitrogen (µg/g), and in litter decomposition (% of standard litter samples remaining after 3 years).*

Natural Regeneration

Studies of seedfall, germination, natural ingress, and growth and survival of advanced regeneration assess the contribution of natural regeneration to silvicultural objectives as well as increase our understanding of IDF forest dynamics.

Seedfall: Douglas-fir seedfall occurred frequently but irregularly. Over 8 years, it was abundant in 2 years and nearly absent in 3 years. About 2.5 times more seed fell at the IDFxh2 site (Arsenault and Vyse 2001). The amount of seedfall was not affected by the uniform selective cutting, suggesting that the crowns of retained trees expanded and produced more seed. Low amounts of pine seedfall every year suggest that the cones are mostly serotinous.

Seedfall declined rapidly across the edges of the patch-cut treatments. Over the first 5 years of seedfall monitoring, seedfall was 17.9 viable seeds per square metre per year in the uncut forest, 9.7 at the edge of openings, 4.5 at 15 m into openings, and 2.2 at over 30 m into openings.

In addition, a sowing experiment using Douglas-fir seeds showed very high rates of seed consumption (>95%). Even seeds protected with

small mesh grid from vertebrates (small mammals and birds) were consumed at high rates (75–100%) (Doney and Lloyd 2001).

Natural regeneration: Post-harvest natural regeneration was extremely irregular. Only 18% of plots had new seedlings 7 years after harvesting, suggesting that suitable conditions for regeneration are infrequent and depend on particular combinations of weather and seedfall. After the high seedfall in the IDFxh2 site in the fall of 2002, many germinants were observed on the forest floor on a variety of seedbeds in the control and uniform cover treatments. However, very few survived the subsequent hot dry summer.

In a comparison of natural ingress in screefed, lightly burned, and undisturbed experimental plots, screefed sites had 1300 natural seedlings per hectare, while burned and undisturbed plots had less than 200 per hectare (Doney and Lloyd 2001). Survival of these natural seedlings after 3 years was low (60% in screefs, 44% in burns).

Advanced regeneration: Advanced regeneration was abundant in the IDFdk study area and moderately abundant in the IDFxh zone.

- Mean density was highest in the control and decreased in the ITS treatments with increasing harvest levels (Table 2) (Kaipainen et al. 1998).
- The occurrence of regeneration was very patchy. At the IDFxh2 site, almost one third of regeneration plots had no regeneration, and 5% had more than five seedlings per 10-m^2 plot. The proportion of empty plots was lower in the IDFdk2 site (19%) and the proportion of plots with more than five seedlings was much higher (38%).
- Height growth of advanced regeneration over 7 post-harvest years was greatest in the 50% ITS units and in the controls (Table 2) (P. Puttonen, unpublished data).

Natural regeneration – summary: Current management practices in the IDF zone assume that natural regeneration will be rapid and well distributed, but we found the reverse. Pre-harvesting advanced regeneration can occur in high densities and responds well after logging, but was very patchy, and was destroyed in the larger openings. Natural regeneration after harvesting was absent in the larger openings, but, even in the ITS treatments, ingress was slow because seedfall was erratic, seed consumption was high, and germination was poor after hot dry summers. Exposure of mineral soil increased germination but small seedlings did not tolerate drought.

TABLE 2 *Density and growth of advanced regeneration and natural regeneration ingress in six silvicultural systems treatments, and in IDFdk versus IDFxh*

Treatment	Control	ITS 20%	20% patch	ITS+res	ITS 50%	50% patch	dk/xh
Advanced regen (/ha)	4149	3522	657	2371	1972	709	4.3
Ht. growth (%, 4 yr)	64	44	40	40	84	44	2.1
Nat. regen (/ha, 4 yr)	2450	650	500	950	1125	475	0.4

Note: green = best option(s), yellow = somewhat worse, orange = poor.

Planted Seedlings

Planting is widely used to enhance and ensure regeneration of large openings. Survival and growth were tracked for three species of conifer seedlings planted in openings and under different canopy conditions in partial cuts.

Seedlings in openings: Three species of seedlings—Douglas-fir, ponderosa pine, and lodgepole pine—were planted in mechanically prepared screefs in openings.

- Within a species, survival rates were the same, but growth was slightly better in 1.6-ha openings than in smaller patch cuts (Table 3) (A. Vyse, unpublished data).
- Lodgepole pine had substantially higher survival and growth at both study areas than Douglas-fir and ponderosa pine.
- Growth of all species was moderately higher at the IDFxh2 study area.
- By far the fastest-growing trees at the Opax Mountain site are aspen where these have resprouted naturally. They have already become a major structural feature in some openings.

Seedlings in partial cuts: Seedlings were planted in small mechanically screefed spots in the 50% uniform residual stand at the IDHxh2 site 3 years after harvesting. The patchy canopy of the residual stand provided an opportunity to study the performance of three species of planted seedlings under a full range of canopy closure. Survival of Douglas-fir, lodgepole pine, and ponderosa pine was relatively high except under nearly complete canopy closure (Table 4) (Vyse et al. 2001). All three species

TABLE 3 *Performance of operationally planted seedlings in screefed sites in three opening sizes, and in IDFdk versus IDFxh*

Species	Measure	0.1 and 0.4 ha	1.6 ha	dk/xh[a]
Fd and Py	Survival (%, 4 yr)	74	74	1.1
	Diameter (mm, 5 yr)	28	33	0.7
	Height (cm, 5 yr)	121	124	0.7
Pl	Survival (%, 4 yr)	92	92	1.0
	Diameter (mm, 5 yr)	36	48	0.8
	Height (cm, 5 yr)	192	230	0.8

Note: green = best option(s), yellow = somewhat worse, orange = poor.
[a]Value in IDFdk/value in IDFxh.

showed declining growth rates as canopy closure increased, with substantial declines even under 20–40% closure (Table 4). The reduced performance may be due to shading, but tree performance could also be strongly affected by root competition for limited soil moisture with retained trees and with pinegrass.

Planted seedlings – summary: With screefing to reduce vegetation competition, all three conifer species are likely to meet regeneration objectives in both variants. Lodgepole pine performed better (survival and growth) in both variants, but it should not be relied on exclusively for regeneration of openings in the IDF zone, for several reasons:

1. It is nearly absent naturally in the IDFxh study area, suggesting that it may not do well in the longer term in that variant.

2. The structural variation produced in stands dominated by Douglas-fir is an important ecological characteristic of the IDF zone.

3. A recent mountain pine beetle outbreak in the Opax area suggests that widespread promotion of lodgepole pine–dominated second-growth stands may be a risky strategy.

Planted seedlings can be grown under canopy where required to meet stocking standards, and, in these lower-light situations, Douglas-fir does as well as lodgepole pine. Growing-season frost is rare at the site; our results may not apply to parts of the IDF zone where frost is an issue.

TABLE 4 *Performance of three species of seedlings planted under different levels of canopy closure*

	Canopy closure (%)				
	0–20	**20–40**	**40–60**	**60–80**	**80–100**
Fd+Py survival (%, 4 yr)	85.0	81.2	82.5	86.0	71.2
Pl survival (%, 4 yr)	92.2	93.0	77.2	80.1	73.8
Fd height (cm, 4 yr)	42.4	28.8	23.6	16.0	11.2
Py height (cm, 4 yr)	59.2	38.0	28.0	22.0	22.8
Pl height (cm, 4 yr)	88.0	59.2	49.2	34.0	25.6

Note: green = best option(s), yellow = somewhat worse, orange = poor.

TABLE 5 *Cover of vegetation layers, functional groups, and species in six canopy closure and gap classes, and in IDFdk versus IDFxh (5 years after logging)*

	Canopy closure/gap class[a]						
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**dk/xh**
Shrub cover (%)	5.4	9.3	12.3	11.4	9.9	8.7	0.8
Herb cover (%)	17.3	31.5	41.4	44.3	38.0	35.0	0.9
Bryophyte cover (%)	7.4	10.9	8.0	4.9	3.7	3.1	0.9
Lichen cover (%)	0.4	1.3	0.9	1.0	0.5	0.1	2.3
Forage cover (%)	21.2	33.8	46.6	48.5	42.3	41.0	0.7
Weed cover (%)	0.4	0.9	2.8	4.1	5.4	5.1	0.2
N-fixer cover (%)	1.7	3.5	4.6	5.7	4.8	2.3	0.9
EMR fungi hosts (index)	10.0	6.9	4.4	2.1	1.2	0.8	0.8
Rose (%)	1.0	1.0	2.0	3.0	1.9	2.3	0.3
Spirea (%)	0.9	2.3	3.1	2.0	3.3	2.5	0.8
Pinegrass (%)	8.5	11.0	18.5	17.9	15.8	16.2	1.0
Rattlesnake plantain (%)	0.2	0.2	0.1	0.1	0.0	0.0	0.7
Pleurozium (%)	2.4	4.3	2.9	0.7	0.2	0.0	0.7
Peltigera (%)	0.3	0.4	0.4	0.4	0.2	0.1	0.8
Species richness (species/16 m^2)	28.3	31.1	29.6	29.0	29.7	27.9	0.8

Note: green = best option(s), yellow = somewhat worse, orange = poor, red = serious concern.
[a]See legend in Miège et al. (2002) for definition of canopy closure/gap classes (1 = most dense/dark, 6 = very open/bright).

Vegetation

Individual plant and lichen species are a major component of biodiversity, and vegetation offers habitat for wildlife, potential competition for conifer regeneration, cattle forage, hosts for mycorrhizal fungi, and a source of weed species. Vegetation studies examined effects of canopy closure and gap size, small site preparation treatments, and changes across the edges of openings.

Vegetation response to gap classes: Vegetation cover layers and species groups showed various responses to gap classes:

- Shrub and herb cover, and lichens to a lesser extent, were most abundant under open canopy and in small gaps, and were sparse under dense canopy (Table 5) (Miège et al. 2001). Rose was most common in gaps of any size. *Spirea* was common in all treatments except under dense canopy closure. Rattlesnake plantain was one of only a few vascular plant species closely associated with dense or moderate canopy closure.
- The percentage cover of the lichen *Peltigera* declined in large gaps and patch cuts.
- Bryophytes, including the dominant *Pleurozium*, were also most abundant under moderate canopy closure, and were least abundant in openings of any size. Mosses declined mainly where substrates were disturbed in openings.
- Cover of forage plants was slightly greater in small and moderate openings, but was also high in large openings and patch cuts, with pinegrass the dominant forage species.
- Occurrence rates of ectomycorrhizal fungi on tree and shrub species measured at the site (Durrall and Gillespie 1998; Hagerman et al. 2001) were combined with cover of these species (Miège et al. 2001) to index ectomycorhizzal

TABLE 6 *Cover of vegetation layers, functional groups, and species in three site preparation treatments (3 years after site preparation), averaged across all crown closure/gap classes*

Variable	Control	Burn	Screef
Shrub cover (%)	10.7	10.8	7.0
Herb cover (%)	41.3	41.9	20.6
Bryophyte cover (%)	10.6	2.4	5.9
Lichen cover (%)	2.1	0.0	0.1
Forage cover (%)	45.7	45.5	25.5
N-fixer cover (%)	5.3	3.2	2.7
EMR fungi hosts (index)	5.2	5.0	3.6
Rose (%)	2.4	2.1	1.4
Spirea (%)	2.2	2.7	2.3
Pinegrass (%)	16.0	18.8	10.0
Rattlesnake plantain (%)	0.2	0.1	0.0
Pleurozium (%)	4.6	0.8	0.5
Peltigera (%)	0.6	0.1	0.2
Species richness (species/16 m^2)	33.3	26.4	28.1

Note: green = best option(s), yellow = somewhat worse, orange = poor, red = serious concern.

host potential (Table 5). These host species decreased in burned areas, and showed a strong negative trend in abundance with increasing openness or gap size (Table 5).

- The abundance of introduced weedy plants increased with increasing gap size. Weeds (introduced species) were more abundant in the IDFxh. Overall, small gaps provided the best mix of vegetation cover, including cattle forage, with fewer weeds than larger openings.

Vegetation – site preparation effects: As expected, all vegetation cover layers were reduced in the short term by burning and screefing, even though these experimental treatments were at very low intensities. Vegetation condition in the different treatments recovered at different rates (Table 6) (Miège et al. 2001). On the burn plots, the overall cover of shrubs, herbs, and forage plants recovered to control levels by year 3, but the screefed plots remained at lower levels. Most common vascular species followed the same pattern, as did rarer species (such as rattlesnake plantain) that are mostly associated with forest cover. The cover of bryophytes, lichens, and nitrogen-fixing plants did not recover substantially following either the burn or screef treatment.

Vegetation cover and species – edge effects: Vegetation measurements across edges generally differed between openings and forest, usually with a sharp change. Only a few variables show edge effects that extend more than 10 m into either the opening or the forest (Brand and Lloyd 2001):

- Tree cover 6 years after harvest was slightly elevated in both screefed and undisturbed sites for a few metres into the opening, and reduced slightly into the forest (Figure 7) (Brand and Lloyd 2001). This finding reflects seedfall into the opening, and some windthrow disturbance of the forest edge.
- Moss cover recovered slightly from screefing along the shaded part of the opening, but did not recover in openings more than 10 m from the edge.

The most notable edge effect on vegetation species was an increase in pinegrass in hand-screefed plots, and a corresponding increase in forage production, 5–10 m into the opening (Figure 8) (Brand and Lloyd 2001). This increase in pinegrass in screefs after 4 years is probably still insufficient to cause competition problems for seedlings planted shortly after harvest. The peak on the northern edge is unique to the the site preparation treatment and requires further investigation. Reduced vegetation cover was also noted in openings within 5 m of some edges (e.g., early seral species) (Figure 8), probably due to root competition for water with the adjacent retained trees. This root competition at edges could reduce planted seedling performance, but this effect is not apparent in the operational planting.

During the 4-year post-harvest period, the percentage cover of weeds did not increase in forest adjacent to patch cuts (Brand and Lloyd 2001). Species associated with older forest retained forest abundances at 6 m into the opening, but then mostly disappeared at greater distances (Figure 8). Other vegetation species showed

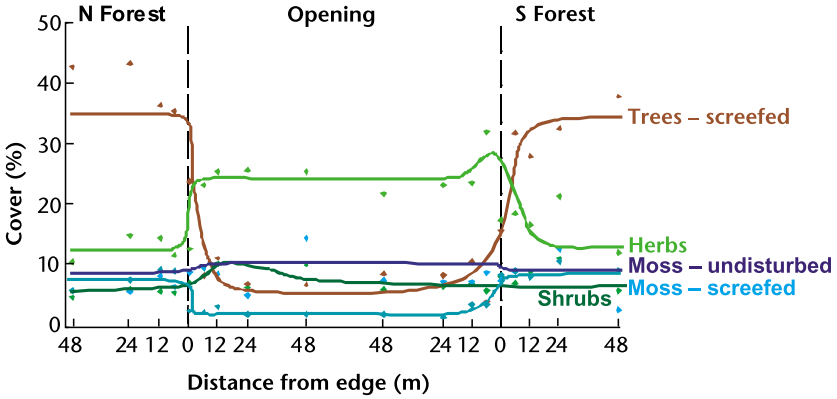


FIGURE 7 *Response by vegetation cover layers to edges of harvested 1.6-ha openings.*

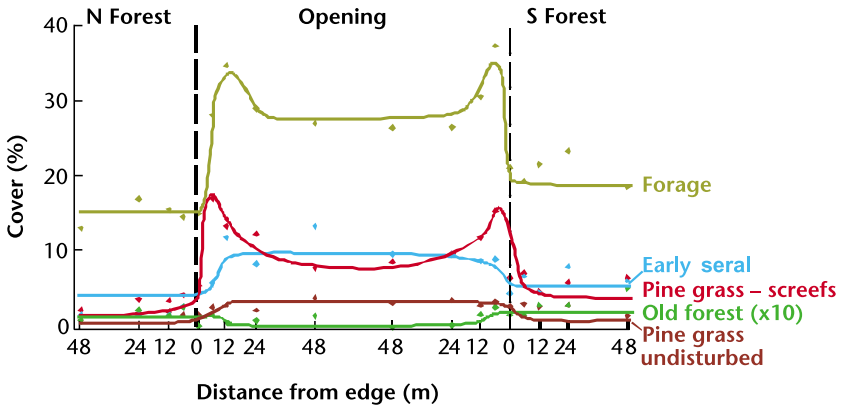


FIGURE 8 *Edge effects on pinegrass (screefed and undisturbed sites) and three functional groups. Cover of old forest–associated species has been multiplied by 10 for visibility.*

either no effect of edge distance (e.g., *Peltigera*), or no effect of the opening at all (e.g., rose).

Vegetation – summary: Vegetation that tolerates open conditions did equally well in any opening size, but species associated with canopy cover rapidly declined as openings increased beyond 200 m^2. Small gaps, therefore, maintained a greater diversity of plant groups, with fewer weeds than large openings. The results suggest that small openings caused by variable partial cutting in these stands can be used to ensure regeneration success while minimizing adverse effects on vegetation.

Most plant or lichen species or groups of species were reduced by burning and screefing. Shrubs and herbs, including ungulate forage, recovered quickly in burns, but more slowly in screefs, while bryophytes and lichens had not recovered in either type of disturbed site after 3 years.

Wildlife

Wildlife studies examined effects of the harvest treatments and edges of openings on a range of species to represent the wide diversity of animal species—from terrestrial invertebrates and small mammals and songbirds, to larger carnivores and ungulates.

Habitat features: Habitat features used by many wildlife species (e.g., large live trees, snags) were reduced in most harvest treatments, particularly those with 50% removal (Table 7). However, changes were often minor compared with existing variation in these elements in IDF stands. Snags were reduced in the 50% removal treatments, because almost all snags in these treatments were felled to meet safety regulations. Coarse woody debris (CWD) volumes were substantially increased by logging slash in the treatments with 50% patch cuts, while the 50% uniform treatments caused a

TABLE 7 *Harvest treatment effects on wildlife habitat elements and animals. All values are percentages of the highest abundance of the variable.*

Variable	Uncut	20% ITS	20% patch	ITS+res	50%ITS	50% patch
Canopy cover	83	100	60	47	75	67
Moss cover	80	100	71	33	60	46
Shrub cover	100	31	100	54	59	68
Snags	100	67	53	64	44	23
Coarse woody debris	35	33	29	46	51	100
Mule deer (winter)	100	71	58	50	31	4
Moose (winter)	100	57	49	0	10	47
Snowshoe hare (winter)	100	6	4	0	4	44
Grouse (winter)	100	98	29	100	41	59
Hairy Woodpecker (winter)	67	21	30	100	56	33
Yellow-rumped Warbler	74	100	65	72	74	100
Dark-eyed Junco	72	59	85	100	98	91
Golden-crowned Kinglet	100	50	75	33	25	52
Red squirrel	100	70	70	64	54	54
Flying squirrel	100	52	40	35	26	23
Yellow-pine chipmunk	13	21	34	61	51	100
Deer mouse	21	21	34	15	24	100
Meadow vole	18	29	43	23	31	100
Masked shrew	93	83	71	82	100	84
Montane shrew	48	61	57	68	100	75
Spiders	40	81	98	93	100	95
Centipedes	50	65	81	92	82	100
Ants	69	89	99	100	76	90
True bugs	100	51	61	40	30	48
Rove beetles	100	88	85	63	78	63
False darkling-beetle	82	14	46	37	100	20
Douglas-fir bark beetle	55	75	42	75	59	100
Secondary bark beetles	61	84	71	39	47	100

Note: green = best option(s), yellow = somewhat worse, orange = poor, red = serious concern.

minor increase. In the long term, these treatments will probably have lower recruitment of new CWD after the logging debris has decayed.

Winter tracking: Winter use by ungulates declined in the 20% removal units, and dropped substantially with 50% removal (Table 7) (Huggard and Klenner 1998a). These results correspond to increased snow depths in the harvested areas, reaching depths (e.g., >40 cm) that likely impede movements (Huggard and Klenner 1998a). These critical depths were reached even at the IDFxh2 study area in moderate- and deep-snow winters. The narrow 10–30 m leave strips in the 50% patch-cut treatments were apparently not wide enough to maintain deer use. Snowshoe hares are closely associated with dense patches of small trees, which were nearly eliminated by the uniform partial cuts (Table 7). Leave strips around patch cuts retained some of this habitat for the hares. Winter occurrence of Ruffed Grouse and Sharp-tailed Grouse was associated with patchy deciduous trees and denser areas of forest.

Woodpeckers: Eight species of woodpeckers used the site. Radio-tracked woodpeckers had home ranges extending well beyond the study area, encompassing a wide variety of forest types. Woodpeckers nested almost exclusively in aspens, generally near natural or harvested edges (Klenner and Huggard 1998). Other cavity-nesters, such as Red-breasted Nuthatches, preferred to nest near the tops of broken conifer and aspen snags. Trees selected for foraging in winter tended to be recently dead snags of moderate to large diameters (>30 cm dbh). However, differences in woodpecker use of treatments in winter did not correspond closely to observed changes in snag abundance, because of the highly patchy use of the site by the birds.

Songbirds: Several common songbirds, such as the Yellow-rumped Warbler, did not show pronounced effects of the harvesting, likely due to the highly variable nature of the forest. Birds associated with open conditions, such as Dark-eyed Juncos, showed only a modest increase in the more intensively harvested areas (Table 7) (T. Dickinson, unpublished data). Species more associated with canopy cover and larger trees, such as Golden-crowned Kinglets and Western Tanagers, declined with harvesting intensity, but with high variability (Table 7).

Squirrels: Density of red squirrels declined in proportion to the percentage removal of trees (Table 7) (Herbers 2001). In patch-cut areas, the squirrels adjusted their territories to conform to the leave strips, while in the uniform partial cuts, they expanded territory size to incorporate roughly the same number of trees. These territory changes did not appear to affect survival of the squirrels (Herbers 2001). Flying squirrels declined more rapidly than red squirrels, and northwestern chipmunks increased to 7 times their abundance in uncut forest in the patch cuts.

Shrews: Masked and pygmy shrews at the site showed no consistent response to treatments, while the abundances of montane and vagrant shrews increased in proportion to percentage removal in the harvest treatments (Table 7) (Huggard and Klenner 1998b). The abundance of shrews increased along the northern edge of openings in spring (Figure 9), probably because earlier snowmelt encouraged plant growth and insect production in these locations.

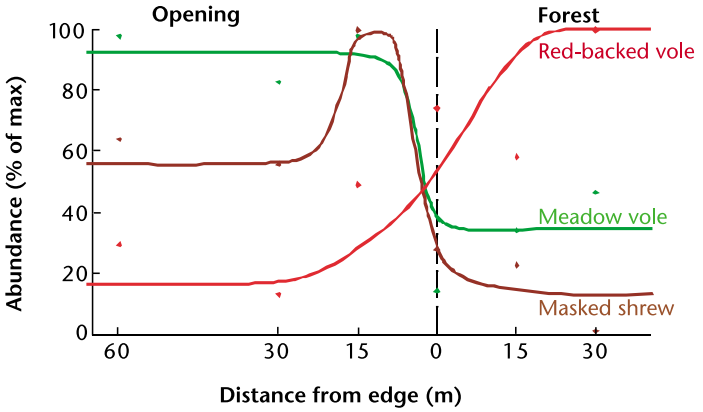


FIGURE 9 *Edge responses of three small mammal species nests.*

Salamanders: Long-toed salamanders were too patchily distributed across the site to assess treatment effects. In ponds, the effects of harvesting on reproductive success differed between the IDFxh and IDFdk study areas (Ferguson 2001). At lower elevations, ponds exposed by harvesting tended to dry out too early in the summer for successful production of young. At higher elevations, the extra heat in exposed ponds appeared to promote growth and the production of larger young.

Arthropods: The highly diverse arthropod community showed a variety of responses to the treatments. Groups that actively hunt on the ground, such as spiders and centipedes, increased with increasing percentage removal, probably in response to greater forest-floor temperatures (Table 7) (Huggard 2002). Ants, which eat seeds and can reduce other components of insect diversity, increased in the more open harvest treatments (Table 7). However, the increase in ants was not pronounced, likely because favourable warm, open conditions already occur throughout dry IDF forests. Insect species caught in aerial traps, especially bark beetles, were highly patchy, making comparisons of treatments

difficult (Table 7) (Miller and Maclauchlan 1998).

Wildlife – summary: Overall, treatments with 20% removal had less of an effect on wildlife species than 50% removal. However, harvesting the same amount of timber with 20% removal systems affects 2.5 times as much land as using a 50% system. For most organisms, the observed reduction in a 50% removal block was less than 2.5 times as much as in 20% removal treatments. Extensive light partial or patch cutting would therefore have greater overall negative impacts on many organisms than less extensive harvesting with greater percentage removal. This summary, however, could change as greater percentages of the harvestable land base are affected over a rotation. In addition, light partial cutting requires a more extensive system of active roads and more frequent re-entry intervals, issues that were not evaluated at the Opax site but may have detrimental effects on wildlife.

Comparing patch-cut and individual tree selection systems at a given percentage removal shows that each system favours roughly half the organisms studied. A mix of practices at the landscape level, combined with some unharvested areas or extended rotations, is recommended to maintain diversity. Practices that help conserve critical habitat elements reduced by harvesting—such as dense patches, snags, old trees and aspen—could have the greatest positive effects for wildlife diversity.

Summary

This note outlines some of the studies and the wide variety of responses to the treatments and stand structures created by harvesting at Opax Mountain. The project is 10 years old, so all results reflect only initial post-harvest responses. Results will change as trees regenerate and as succession, natural disturbances, and subsequent harvest entries affect the forest. Conclusive results will not be obtained for several generations. Managers should proceed with caution. However, even these preliminary results demonstrate the obvious—but often neglected—lesson that no single management approach will maintain the full range of values that are the professional responsibility of forest managers. This point should be made all the more strongly for the variable IDF zone. In particular, the standard silvicultural goal of maintaining an all-aged stem distribution within stands in the dry IDF zone cannot, by itself, meet all the management objectives for the zone.

Studies based on gap-size classes and the overall silvicultural systems treatments help define harvest types that produce different responses for a range of variables. The most common result from Opax Mountain, for many of the variables we examined, was that openings <0.1 ha produce different results compared with openings >0.1 ha. Small openings (<0.1 ha) are typically created by individual tree or small-group selection systems applied to the patchy natural IDF forest. The larger openings (>0.1 ha) require cutting defined areas and should also be included as one of the management tools for the IDF zone.

Studies of the natural disturbance regime at Opax Mountain, including both fire and other agents, show a vast range of variability in the size, severity, frequency, species-specificity, and effects on stand structure. This work strongly reinforces the need to use a wide variety of management techniques in the dry IDF zone. Widespread application of any single management strategy, or one particular stand structure goal, solely because it occurred under the natural disturbance regime, is not supported by the work at Opax. An operational trial, the Isobel project adjacent to the Opax Mountain project, is extending the range of treatments being studied.

In addition to these general messages, the work at Opax Mountain provides more specific information for particular management topics:

Regeneration: Harvested openings can be successfully regenerated with any of the three tree species examined, provided that planting occurs shortly after harvest and some screefing is used to remove competing vegetation. Lodgepole pine is likely to meet free-growing criteria faster than other species, but should not be used exclusively because it does not meet all ecological, economic, and forest-health objectives. Although planted lodgepole pine is currently performing well, we doubt its usefulness at lower elevations because the species is not widely distributed in these stands naturally. Advanced regeneration can supplement restocking requirements, particularly at higher elevations, but it is very patchy. Harvesting operations could target the release of such patches. Natural regeneration potential is moderately high, particularly in smaller openings, if mineral soil is exposed, but survival is very low during hot dry summers.

Vegetation: The range from open canopy to moderately small openings created by partial cutting maintains vegetation cover layers and accommodates many species, while also producing ungulate forage. Larger openings are more productive for some species, but also appear to promote weedy species, particularly when they are near grassland areas with many introduced plants. A few vascular plants, along with bryophytes and some lichens, are associated with denser canopy cover, and decline in uniform partial cutting. Hence, patches of uncut forest are needed for these groups. Short or negligible edge effects suggest that these uncut reserves need not be very large.

Wildlife: Uniform partial-cut harvesting is compatible with maintaining many animal species. However, larger

openings also have associated species, including those that respond positively to forest edges. Habitat features reduced by harvesting, such as dense canopy, large snags, CWD and aspen, should be a management focus, within a diverse range of harvest systems.

Given the diversity of IDF ecosystems, it is difficult to know how broadly the results from Opax Mountain apply. Although the abundance of many variables differed between the IDFdk and IDFxh study areas, overall responses to harvest treatments, site preparation treatments, gap sizes, and edges were often similar. These results suggest some generality in the overall patterns reported here. However, Opax Mountain has only one study area in each of the variants. Confidence in the generality of the results—or knowledge of how much they vary—will come only from work across the zone, but, given the few initiatives, much of this knowledge will have to come from other large-scale research as well as monitoring IDF operational harvesting. Creating these opportunities to learn to improve management is another fundamental reason for encouraging more diverse practices in the IDF zone.

References

Arsenault, A. and W. Klenner. 2004. Fire regime in dry-belt forests of British Columbia: perspectives on historic disturbances and implications for management. Presented at an international conference on mixed severity fire regimes: ecology and management, Spokane, Wash., Nov. 17–19, 2004. Available from: http://www.emmps.wsu.edu/fire

Arsenault, A. and A. Vyse. 2001. Opax Mountain Silvicultural Systems study: project coordination, facilities and overall extension. Sci. Council B.C., Burnaby, B.C. Unpublished report.

Bealle-Statland, C. 1998. Stand structure and growth estimates for the Opax Mountain Silvicultural Systems trial. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Bissonnette, D. and D. Lloyd. 1999. Soil temperature response to cutblock edges at the Opax Silvicultural Systems research site. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Brand, N. and D. Lloyd. 2001. Vegetation response to clearcut edges in the IDF at the Opax Mountain Silvicultural research site. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Campbell, R., D.J. Smith, and A. Arsenault. [2004]. Multicentury history of western spruce budworm outbreaks in Interior Douglas-fir forests near Kamloops, British Columbia. Can. J. For. Res. Submitted.

Craig, V. 2002. Population and habitat use characteristics of forest-dwelling small mammals in relation to downed wood. PhD thesis. Univ. British Columbia, Vancouver, B.C.

Doney, M. and D. Lloyd. 2001. Natural and artificial regeneration in the IDFdk1 and IDFxh2 at the Opax Mountain Silvicultural Research site. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Durrall, D.M. and M. Gillespie. 1998. The potential for woody angiosperms and advanced regenerated Douglas-fir to provide refuge for ectomycorrhizal inoculum at Opax Mountain: preliminary results. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Ferguson, C.M. 2001. Effects on long-tailed salamanders (*Ambystoma macrodactylum*) of removing canopy cover adjacent to breeding sites and in terrestrial habitats. MSc thesis. Univ. British Columbia, Vancouver, B.C.

Hagerman, S.M., S. Sakakibara, and D.M. Durall. 2001. The potential for woody understory plants to provide refuge for ectomycorrhizal inoculum at an interior Douglas-fir forest after clear-cut logging. Can. J. For. Res. 3 (4):711–721.

Heineman, J.L., G.D. Hope, S.W. Simard, A. Vyse, D.L. Lloyd, and D.J. Miège. 2003. The effects of site preparation and harvesting practices on planted seedling productivity and microenvironment in southern interior dry, grassy IDF forests. B.C. Min. For., Victoria, B.C. Tech. Rep. 009.

Herbers, J.R. 2001. Red squirrel demography and behaviour in a managed Interior Douglas-fir forest of British Columbia. MSc. thesis. Univ. British Columbia, Vancouver, B.C.

Hope, G. and C. Prescott. 2001. Opax Mountain Silvicultural Systems Project: effect of silvicultural systems on soil productivity in the IDF zone: impacts on soil organic matter and soil nitrogen. Sci. Council B.C., Burnaby, B.C. Unpublished report.

Hope, G.D., C.E. Prescott, and L.L. Blevins. 2003. Responses of available soil nitrogen and litter decomposition to openings of different sizes in dry interior Douglas-fir forests in British Columbia. For. Ecol. Manage. 186:33–46.

Huggard, D. 2002. Treatment and edge effects for shrews and invertebrates at Opax: summary to contribute to overall project synthesis. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Huggard, D. and W. Klenner. 1998a. Winter use of the Opax Mountain Silvicultural Systems site by ungulates, squirrels, hares, and grouse. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

———. 1998b. Effects of harvest type and edges on shrews at the Opax-Mountain Silvicultural Systems Site.

In Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Huggard, D. R. Walton, and W. Klenner. 1998. Depth and duration of snow at the Opax Mountain Silvicultural Systems Site: *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Kaipainen, J., P. Puttonen, and A. Vyse. 1998. Advanced regeneration of Interior Douglas-fir forests following uniform partial cut and small patch-cut logging at Opax Mountain. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Klenner, W. 2003. Harvesting and site preparation treatments to develop and maintain open crown closure conditions in dry-belt Douglas-fir forests. B.C. Min. For., For. Serv., Southern Interior Forest Region, Kamloops, B.C. Unpublished report.

Klenner, W. and D. Huggard. 1998. Nesting and foraging habitat requirements of woodpeckers in relation to experimental harvesting treatments at Opax Mountain. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Klenner, W. and A. Vyse. 1998. The Opax Mountain Silvicultural Systems Project: evaluating alternative approaches to managing dry Douglas-fir forests. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Lloyd, D., K. Angove, G. Hope, and C. Thompson. 1990. A guide to site identification and interpretation for the Kamloops Forest Region. B.C. Min. For., Victoria, B.C. Land Manage. Handb. 23.

Miège, D., M. Doney, A. Arsenault, and D. Lloyd. 2004. Germination and early survival and growth of Douglas-fir following site-preparation treatments across a light gradient at Opax Mountain, British Columbia. Unpublished manuscript.

Miège, D., D. Lloyd, and A. Arsenault. 2002. Canopy gap characteristics of partial cutting in Douglas-fir forests of Interior British Columbia. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Miège, D., D. Lloyd, M. Doney, and N. Brand. 2001. Vegetation response to partial cutting and site preparation in Douglas-fir forests of Interior British Columbia. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Miller, D. and L. Maclauchlan. 1998. Assessment of forest insect conditions at Opax Mountain silviculture trial. *In* Managing the dry Douglas-fir forests of the southern Interior: workshop proc. A. Vyse, C. Hollstedt, and D. Huggard (editors). B.C. Min. For., Victoria, B.C. Work. Pap. 34/1998.*

Orchansky, A.L. 2002. The Ministry of Forests Opax Mountain Research Site: a summary of micrometeorological measurements in a forest-clearing. B.C. Min. For., Kamloops Region, Kamloops, B.C. Unpublished report.

Vyse, A., C. Ferguson, and P. Puttonen. 2001. Growth of underplanted Douglas-fir, lodgepole pine, and ponderosa pine seedlings in a recent partially-cut Interior Douglas-fir stand in south-central British Columbia. Unpublished report.

* Available from: www.for.gov.bc.ca/hfd/pubs/Docs/Wp/Wp34.htm

Acknowledgements

We wish to thank our colleagues from the Opax Mountain research team for sharing their insight and data, which made this Extension Note possible. In particular we would like to acknowledge the contributions of Catherine Bealle-Statland, Dan Bissonette, Nicole Brand, Rochelle Campbell, Vanessa Craig, Tom Dickinson, Mona Doney, Dan Durrall, Christine Ferguson, Michelle Gillespie, Shannon Hagerman, Graeme Hope, Jim Herbers, Janna Kaipainen, Dennis Lloyd, Lorraine Maclauchlan, David Miège, Dan Miller, Alberto Orchansky, Cindy Prescott, Pasi Puttonen, Dan Smith, and Russ Walton. We also wish to thank the rest of the Opax Mountain research team for their support, and the many dedicated field assistants who contributed to the project over the last decade. Catherine Bealle-Statland, Graeme Hope, Brent Olsen, Ken Soneff, and Russ Walton provided comments on an earlier version of this note. Funding for this project has been provided by Forest Renewal BC, Forest Innovation Investment, Forest Investment Account (Forest Science Program), and the B.C. Forest Service.

Citation

Huggard D.J., A. Arsenault, A. Vyse and W. Klenner. 2005. The Opax mountain silvicultural systems project: preliminary results for managing complex, dry Interior Douglas-fir forests. B.C. Min. For., Res. Br., Victoria, B.C. Exten. Note 72. <http://www.for.gov.bc.ca/hfd/pubs/Docs/En/En72.htm>

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