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# Extension Note

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## Comparing Clearcutting and Alternatives in a High-elevation Forest: Early Results from Sicamous Creek

### Abstract

The Sicamous Creek Silvicultural Systems project examines clearcutting and silvicultural alternatives to clearcutting in high-elevation Engelmann spruce – subalpine fir (ESSF) forests, motivated by concerns about the effects of forestry practices on regeneration, hydrology, and biological diversity. Treatments include: 10-ha clearcuts, arrays of 1-ha openings, arrays of 0.1-ha patch cuts, individual tree selection (ITS), and uncut controls. The replicated experimental treatments at an operational scale have attracted many researchers to the site. We summarize the results of studies that have looked at harvest treatment effects and the effects of different opening sizes on 50 different resource values and ecosystem components, including: harvest economics and the residual stand, microclimate and snow, soil ecology, conifer regeneration, and biodiversity. All harvest treatments were successfully implemented under winter conditions. Harvest cost was somewhat less for 10-ha clearcuts than for the other treatments. Physical conditions for regeneration were generally better with 1- and 10-ha openings, but 0.1-ha openings or individual tree selection harvesting favoured many soil processes, natural regeneration, and components of biological diversity. Across all studies, most variables showed similar responses to the 1-ha openings and the 10-ha openings, but different responses to the 0.1-ha openings or individual tree selection. Openings of 1 ha or more could therefore be considered ecologically similar to larger clearcuts, implying that recent increased use of 3- to 5-ha openings operationally may not represent much ecological change from previous 20- to 40-ha clearcuts. Harvesting with 0.1-ha patch cuts was more often preferred for study variables than harvesting with uniform selection cuts. We recommend more operational trials with small patch cuts or patchy group selection, varying the amount of timber removed and size of gaps, as a way of increasing the ecological diversity of harvesting practices in the ESSF, and to help meet the growing list of objectives for high-elevation forestry.

### Introduction

High-elevation forests are a major source of forest products in the southern British Columbia Interior. Currently, about 25% of the timber supply in the area comes from these Engelmann spruce – subalpine fir

(ESSF) forests, and this percentage is expected to increase in the future. However, concern about the sustainability of standard harvesting in high-elevation forests—using clearcuts or modified clearcuts with wildlife tree patches—is also increasing. Public concern originally focussed on the effects of harvesting on water supply, particularly the persistent snowpack that supplies summer water to many Interior communities (Vyse 1999). Foresters also became concerned about poor regeneration success seen in many larger clearcuts at upper elevations. Short growing seasons, cold wet soils, summer frost and drought, insect damage, nutrient loss, and windthrow in the severe climate all threaten long-term silvicultural productivity. More recently, concern has broadened to include the diversity of animal and plant species uniquely adapted to high-elevation forests. Combined with a general public aversion to clearcuts, these pressures encourage forest managers to consider alternatives to traditional or modified clearcuts.

We have limited experience in British Columbia with alternatives to clearcuts. Partial cutting was used in the ESSF in the early 1970s, but mostly using a diameter-limit system, which removed most of the spruce and the subalpine fir over a certain diameter. Lack of regeneration and extensive windthrow discouraged use of this harvest system. However, this old form of "high-grading" tells us little about other uneven-aged management systems that could be used in the ESSF. Only one small trial of other silvicultural systems was documented in the ESSF prior to the 1990s (Vyse 1999). Operational harvesting of ESSF forests in British Columbia currently uses 90% clearcuts or clearcuts with wildlife tree patches, providing few opportunities to learn about alternatives. Experimental sites established as part of the B.C. Forest Service's Silvicultural Systems research program in the 1990s are therefore of particular importance for informing management decisions in the ESSF. This role will become even more important as British Columbia moves towards results-based forestry. Professional foresters will be increasingly responsible for basing their day-to-day decisions on the best available information about how their decisions affect many resource values. These experimental sites are also critical for developing local indicators of sustainability for forest productivity and biodiversity, as required by forest certification processes.

The Sicamous Creek project is the largest study of silvicultural systems in British Columbia, comparing clearcuts and alternatives in ESSF forest. The project uses large harvesting treatments, at a scale directly relevant to forest operations. Replication and random allocation of the treatments help ensure that results are scientifically valid. Simplification of the operational treatments, such as equal levels of timber removal and regularly spaced, square openings, remove some of the confounding effects of operational harvesting and should produce clearer results for a few critical questions. Many researchers have been attracted to the Sicamous Creek site by this combination of operational relevance and scientific rigour. The list of studies at the site closely parallels the long list of issues with which foresters are concerned (Table 1). The purpose of this extension note is to summarize some of the basic results of these studies, to provide links to detailed study results, and to find the common patterns shared by many studies. We focus on two related sets of questions:

1) How do clearcuts and alternative silvicultural systems affect the many resource values and ecosystem components studied at Sicamous Creek? Is there a best way to manage ESSF forests, or an optimal mix of options, or are there options that should be used more often than they are currently? What are the expected costs and benefits when a forester decides to use a particular harvest system?

2) How are the resources and ecosystem components affected by different-sized openings? What will be the effects of the recent operational change in the region from >20-ha clearcuts to more openings of 3–5 ha? Also, specifically, when does an opening become small enough to differ ecologically from a clearcut?

Other extension notes will summarize edge effects into and out of different-sized openings, the effects of different site preparation options, and the silviculture of subalpine fir and Engelmann spruce at Sicamous Creek.

## Study Site

The Sicamous Creek Silvicultural Systems site is located in the ESSF wet cold northern Monashee variant (ESSFwc2), 15 km southeast of Sicamous, B.C. Elevations range from 1550 m to 1850 m, with moderate slopes facing mainly north to northwest. A snowpack reaching 1.5–3 m depth is present for at least 7 months, with a brief, wet and cool summer. Subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) dominate the open canopy of the 350-year-old stand (Parish et al. 1999). White-flowered rhododendron (*Rhododendon albiflorum*) and false azalea (*Menziesia ferruginea*) are dominant shrubs, with a herb layer of five-leaved bramble (*Rubus pedatus*), Sitka valerian (*Valeriana sitchensis*), and oak fern (*Gymnocarpium dryopteris*), and a well-developed moss layer. Snags are abundant, reflecting endemic populations of balsam bark beetle (*Dryocetes confusus*). Tree damage from wind and snow is common.

Five harvest treatments were applied to three 30-ha replicate units at the

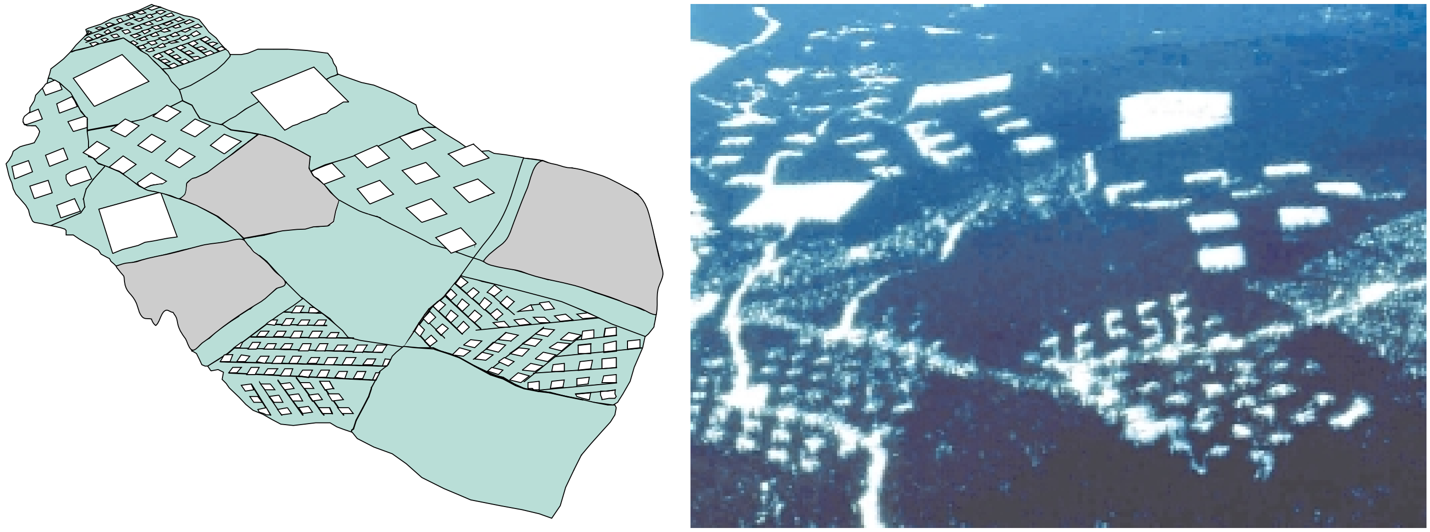

FIGURE 1 *Oblique-view map and aerial photograph of the Sicamous Creek Silvicultural Systems site. White squares on map are openings of 0.1, 1, or 10 ha; light gray areas are units with individual tree selection.*

Sicamous Creek site (Figure 1): 1) 10-ha clearcut with 20 ha of leave strips, 2) nine 1-ha openings with 100-m leave strips, 3) sixty-five 0.1-ha patch cuts with 30-m leave strips, 4) uniform individual tree selection (ITS) removing 20% of the trees across the size distribution, plus skid trails, and 5) uncut controls. Including skid trails, each of the four harvest treatments removed approximately one-third of the trees, representing the first pass of a three-pass system. All harvesting used feller-bunchers, except two of the ITS replicates that were hand-felled. Harvesting occurred in winter 1994–1995. Harvested areas were mounded with an excavator and planted. Some areas in each replicate unit were reserved for experimental comparisons of different site preparation options.

## Studies of Harvest Treatments and Opening Sizes

Studies of harvest treatments and opening sizes at Sicamous Creek fall into five broad categories: 1) Harvest economics and damage in the residual stand, 2) Microclimate and snow, 3) Soil moisture, nutrients and biological components, 4) Tree regeneration, and

TABLE 1 *Studies of harvest treatments and opening sizes at Sicamous Creek*

| Study | Method |
|---|---|
| *Harvest economics and residual stand* | |
| Logging cost | Worker and machine monitoring, scaling records |
| Residual damage | Post-harvest surveys |
| Wind and snow damage | Transect surveys 1997, 1999 |
| Bark beetle | 70-mm aerial photography surveys 2001 |
| *Microclimate and snow* | |
| Air and soil temperature | Continuous monitoring along transects 1998 |
| Snow depth and duration | Extensive depth surveys in winter 1996-1997 |
| *Soil moisture, nutrients, biology* | |
| Soil moisture | Gravimetric samples on transects, mounds |
| Soil nutrients | Chemical analysis of forest floor and mineral soil |
| Decomposition | Mesh bags of standardized litter types |
| Litterfall | Collected in large seed traps |
| Fine roots | Sieving and handsorting of soil cores |
| Soil organisms | Handsorting or extraction from soil cores |
| Ectomycorrhizal fungi | Sorting of soil cores and planted sterile seedlings |
| Truffles | Sorted forest floor plots |
| *Regeneration* | |
| Advanced regeneration | Plots surveyed in 1995 and 2000 |
| Seed fall | Seed traps |
| Natural regeneration | Surveys on and off site preparation mounds |
| Planted seedling performance | Yearly measurements of planted trees |
| Planted seedling foliage | Chemical analysis of seedling samples |
| *Biological diversity* | |
| Habitat (snags, logs, covers) | Standardized habitat plots and transects |
| Plant species | Vegetation quadrats |
| Pine marten | Winter track surveys |
| Three-toed woodpeckers | Observations of radio-tagged birds |
| Spruce grouse | Spring sign surveys |
| Song birds | Annual point count surveys |
| Small mammals, invertebrates | Pitfall sampling |

5) Biodiversity, including habitat structures, plants, and animals. Most studies examined all harvest treatments, except microclimate studies and some soils studies that did not sample in the ITS treatments. Biodiversity studies sampled entire treatment units, including the leave strips around the harvested openings, while studies of regeneration and soils concentrated on the harvested parts of treatments. Within openings, most studies sampled throughout the opening, generally by stratifying sampling by distance from the edge of the opening.

## Summary of Results—Harvest Treatments and Opening Sizes

Treatment results from the different studies are summarized in tables in the following sections. Treatments coded with green are the best or close to the best for the subject of the study—for example, lowest levels of damaging agents, best conditions for regeneration, and highest numbers of a sensitive biodiversity component. Yellow indicates a minor decline compared to the best option, orange a moderate decline, and red a more serious drop. Blue indicates an increase in a harvest treatment for some biodiversity components.[1] Changes coded with yellow may not always be "significant" in terms of traditional statistics, but they indicate a substantial likelihood of a biologically meaningful change.

Symbols beside each value indicate whether it applies to only the centre of the opening (†), to the average across the opening (‡), or to the whole treatment including leave strips (no symbol). The following summaries are all extremely abbreviated. Please see the references cited in the summary tables for full details and interpretations.

TABLE 2 *Logging costs and the residual stand*

| Variable | 10 ha | 1 ha | 0.1 ha | ITS | Control | Ref. |
|---|---|---|---|---|---|---|
| Logging costs ($/m$^3$) | 11.07 | 15.79 | 13.65 | 14–31 | | 21 |
| Residual damage (%) | low | low | low | 4–25 | | 21 |
| Windthrow (% basal area/year) | 1.4 | 1.3 | 0.8 | 1.8 | 0.6 | 10 |
| Snow damage (% basal area) | 4.4 | 4.6 | 3 | 3.7 | 5.9 | 11 |
| Balsam bark beetle (trees/ha post-harvest) | 3.5 | 7.4 | 5.2 | 2.6 | 4.5 | 17 |

### Harvest operations, economics, and damage to residual stand

The first conclusion of the Sicamous Creek project was simply that alternatives to large clearcuts were feasible in the ESSF, even under winter harvesting conditions. With little recent experience, some operational foresters had been doubtful. However, all treatment units ended up being implemented as planned, with few problems. The hand-felled individual tree selection (ITS) units were a partial exception, with a more patchy result than intended due to falling difficulties. The feller-buncher did not have problems with uniform individual tree removal.

Logging costs (from layout to truck-loading) were higher in the 1-ha and 0.1-ha treatments than in the 10-ha clearcut, due to higher layout costs and longer skidding distances. Costs in the mechanically felled ITS unit were similar to costs for the 1-ha and 0.1-ha treatments. The hand-felled ITS units were much more expensive, due mainly to far greater skidding costs. The extra manoeuvring of logs in the hand-felled ITS units resulted in the only substantial damage to residual trees. Extra skidding costs in patch-cut arrays could be reduced in operational blocks by locating the landing in the middle of the patch-cut array. This was not done at Sicamous Creek, particularly in the 1-ha arrays, to avoid disrupting the pattern of these experimental blocks. The high layout costs for the patch-cut treatments ($4.78/m$^3$) reflect the precise, square openings of the research design. Layout could be simplified in normal operational patch cuts.

ITS units had high windthrow rates, probably due to the reduced crown contact between remaining trees. However, leave strips around 1-ha and 10-ha openings also had large amounts of blowdown. The arrays of 0.1-ha patch cuts had lower windthrow, with crown contact maintained between residual trees, and reduced wind exposure beside small openings. The heavy snow in winter 1998–1999 caused extensive damage to subalpine fir, particularly in the uncut controls. Snow damage was slightly less for the residual trees in the ITS and 0.1-ha treatments than in the leave strips beside 1- and 10-ha openings. Spruce showed the same patterns, but with about one-third the wind and snow damage of subalpine fir.

Balsam bark beetle activity was low across the site after harvesting. Rates were lowest in the ITS units and highest in the leave strips of the 1-ha treatments, but this may reflect chance occurrences, given the low observed attack rates.

1 This coding is definitely a simplification, as the "best" treatment for even a single variable is not always a clear concept. For example, fewer bark beetles may be considered better for tree growth and yield, but woodpeckers and other animals rely on bark beetles for food and to create snags. Similarly, increased mineral nitrogen may help plant growth, but lead to leaching and long-term nutrient deficits.

TABLE 3 *Microclimate and snow*

| Variable | 10 ha | 1 ha | 0.1 ha | ITS | Control | Ref. |
|---|---|---|---|---|---|---|
| Air temperature – daily mean (ºC) | 10.9‡ | 11.3‡ | 10.3‡ | | | 22 |
| Air temperature – daily max. (ºC) | 16.7‡ | 16.2‡ | 15.3‡ | | | 22 |
| Air temperature – daily min. (ºC) | 5.3‡ | 6.9‡ | 6.3‡ | | | 22 |
| Soil temperature – mean (7 cm, ºC) | 9.5‡ | 9‡ | 8.6‡ | | | 22 |
| Snow – January depth (cm) | 154 | 160 | 162 | 170 | 155 | 8 |
| Snow – spring depth (cm) | 89 | 96 | 75 | 79 | 91 | 8 |
| Snowmelt (50% bare, date in June)[a] | 9 | 10 | 3 | 6 | 10 | 8 |
| Snowmelt (50% bare, date in June)[a] | 2‡ | 11‡ | 8‡ | | | 8 |

[a] Note that the first snowmelt result is averaged across the whole block (for water supply), while the second is for the opening only (for seedling snow-free date).

## Microclimate and snow

Mean and maximum air temperatures were about 1° higher in the 1- and 10-ha openings than in the 0.1-ha openings. Soil temperatures increased slightly with opening size. These September air and soil measurements may indicate longer potential growing seasons in the 1- and 10-ha openings. However, the minimum overnight temperature was lower in the 10-ha opening, indicating that frost may occur earlier in these large openings. Additionally, the warmer temperatures in the 1- and 10-ha openings may worsen occasional periods of summer drought.

Maximum snow depth in the 1 year of measurement was somewhat greater in ITS than in other treatments (which retain denser patches of canopy). Deeper snow may damage seedlings and hinder access to prey by pine martens. Spring snow depths were lower in ITS units, and ground exposure occurred earlier, reflecting the more dispersed trees retained in ITS units. Similar results in the 0.1-ha patch-cut treatment may be due to narrower leave strips, or may be an artefact of aspect differences in two replicates of this treatment. In the openings themselves, snowmelt was earliest in the 10-ha clearcuts, which is probably beneficial for extending the growing season for seedlings. Overall, though, the differences between treatments in the 1 year of measurement were not large.

## Soil moisture, nutrients, and biology

Under typical conditions, soil moisture near the surface tends to be slightly lower in 1- and 10-ha openings than in other treatments. During the strong drought in August 1998, surface soil moisture was substantially lower in the 1- and 10-ha openings, and slightly lower in the 0.1-ha openings than in the ITS units or uncut controls. The surface drying in the larger openings is probably caused by a shallow litter layer and only partial vegetation cover, allowing more heating and increased direct evaporation from the soil surface, despite reduced evapotranspiration by trees. Low soil moisture could affect regeneration, but this is probably a minor issue with the wet climate at Sicamous Creek. One set of measurements under non-drought conditions showed lower soil moisture on site preparation mounds in the 10-ha openings compared to mounds in the other harvested treatments.

Nitrogen mineralization, which promotes both nitrogen availability and loss through leaching, was elevated for at least 6 years post-harvest in the three sizes of openings. ITS increased nitrogen mineralization slightly. Other nutrients did not show differences between treatments. Increased mineral nitrogen was not due to faster decomposition in openings, as rates were actually slightly lower in all opening sizes. Nutrient input through litterfall was greatly reduced in 1- and 10-ha openings, and substantially reduced in 0.1-ha patches. This simply reflects the very short distance that litter typically falls from retained trees. Litterfall in ITS units was reduced about one-third with the one-third reduction in trees.

Fine root production was much lower in the openings, with the loss of large trees, except at the edge of the openings. Fungi, nematodes, and microarthropods (mites, etc.) in the centres of 1- and 10-ha openings were reduced to about 40% of their levels in uncut forest, reflecting the reduction of root production and changed microclimates. Soil bacteria, however, increased in the openings. Most ectomycorrhizal fungal species were eliminated from soil cores in openings after 3 years, except where roots of retained trees spread in from the edge. Average diversity is slightly higher in 0.1-ha openings than in 1- and 10-ha openings, because the narrow root zone is a greater proportion of the small openings. Reflecting this, sterile seedlings picked up more ectomycorrhizal fungi in 0.1-ha openings than in the larger openings. However, operationally planted nursery seedlings maintained the same diversity of ectomycorrhizal fungi in the three sizes of openings. Nursery seedlings experimentally planted in the controls lost some of their fungal species. Truffles completely disappeared from all opening sizes after harvesting.

## Regeneration

Most advanced regeneration was lost from the 10-ha openings during harvest, compared to about half from the 1- and 0.1-ha openings, possibly due to more random skidding across the snowpack in the 10-ha clearcut. The 10-ha openings were also logged first at the site, when lower snowpacks may have provided less ground

TABLE 4 *Soil moisture, nutrients, and organisms*

| Variable | 10 ha | 1 ha | 0.1 ha | ITS | Control | Ref. |
|---|---|---|---|---|---|---|
| Soil moisture (top 10 cm) – typical (%) | 41† | 43† | 47† | 49 | 50 | 24 |
| Soil moisture (top 10 cm) – drought (%) | 19† | 19† | 26† | 30 | 31 | 24 |
| Soil moisture on mounds (%) | 25† | 42† | 40† | 39 | | 19 |
| Mineral nitrogen (µg N/g soil) | 21† | 22† | 20† | 10 | 6 | 24 |
| Carbon, sulfur, pH | no substantial differences | | | | | 4 |
| Decomposition – needles (% loss/5 years) | 51† | 49† | 52† | 56 | 58 | 24 |
| Litterfall (kg/ha/year) | 36† | 34† | 85† | 415 | 689 | 24 |
| Fine roots (% of uncut) | 54† | 55† | 66† | | 100 | 3 |
| Soil organisms (% of uncut) | 44† | 38† | | | 100 | 3 |
| Soil bacteria (% of uncut) | 192† | 157† | | | 100 | 3 |
| Ectomycorrhizal fungi species (% of uncut) | 27‡ | 32‡ | 41‡ | | 100 | 2 |
| EMR fungi operational seedlings (spp/tree) | 2.7‡ | 2.8‡ | 2.9‡ | | 1.9 | 13 |
| Truffles (% of uncut) | 0‡ | 0‡ | 0‡ | | 100 | 12 |

protection. Growth of advanced regeneration after 5 years was greater in the 0.1-ha openings than in the other harvested treatments. Conifer seedfall was high in the uncut sites, reduced in the ITS units, and substantially lower in the openings. The greater proportion of the cutblock that is near the edge resulted in increased seedfall in the 0.1-ha openings compared to the 1- and 10-ha openings. Opportunities for natural regeneration are therefore greatest in the 0.1-ha and ITS treatments.

Planted Engelmann spruce and subalpine fir seedlings had highest survival in the 10-ha openings, reduced survival in the 1-ha openings, and lowest survival in the 0.1-ha patchcuts and ITS units. Reduced light probably caused the moderate reduction in survival. More natural regeneration compensated for the greater mortality of planted seedlings in small openings. Longer-term monitoring is needed to check that total stocking meets regeneration requirements. Height growth of planted seedlings was greatest in the 0.1-ha patchcuts, but this may be an artefact of more, warmer, northwestern aspects in two of the 0.1-ha units. Lower height growth occurred in the ITS units and in seedlings experimentally planted in the controls. Diameter growth showed the same pattern as height growth. Results were also similar for planted subalpine fir, except that overall survival and growth were lower. Foliar nitrogen in the seedlings differed little, but was highest in the 0.1-ha openings and lowest in the 1-ha openings. Effects of different site preparation treatments will be summarized in a future extension note.

## Biological diversity

The safety requirement to remove snags in harvested and adjacent areas nearly eliminated snags in the its and 0.1-ha treatments, and reduced them in the 1-ha treatments. Snag-falling, along with windthrow in harvested areas, reduced dense patches of canopy in all leave strips, especially narrower ones. Areas with canopy cover >30%, which are selected by pine marten and spruce grouse, were absent in the its units because of uniform removal, snag-falling, and windthrow. Coarse woody debris (cwd) volume did not differ in the 1- and 10-ha openings compared to controls 2 years after harvesting, but this was because decayed cwd was substantially reduced during harvest, while recent cwd was added as slash. Decayed cwd was not reduced in the 0.1-ha and its units, while logging slash and felled snags increased total volumes. Increased total cwd volume in harvested areas is beneficial in the short term to put off declines expected later in the rotation. Long-term cwd levels in harvested areas depend on growth and mortality of regenerating trees.

Shrub cover was reduced by logging activity in all harvested areas. Impact on shrubs was least in the 0.1-ha openings, where skidding followed well-defined trails. Recovery of damaged shrubs has been minor in the 6 years after harvest. Overall herb cover differed little between treatments immediately after harvest and 5 years later. However, species composition has changed. Heart-leaved twayblade (*Listera cordata*) is an example of a species that declined with harvesting, showing similar declines in all harvest treatments.

Pine marten in winter avoided the treatments with 1- and 10-ha openings, including their adjacent leave

TABLE 5 *Natural and planted regeneration*

| Variable | 10 ha | 1 ha | 0.1 ha | ITS | Control | Ref. |
|---|---|---|---|---|---|---|
| Advanced regeneration retention (/ha) | 120‡ | 1400‡ | 1400‡ | | 2700 | 25 |
| Advanced regeneration growth (%/year) | 8.4‡ | 6.7‡ | 12.9‡ | 6.8 | 11.3 | 26 |
| Seedfall (/m$^2$/yr) | 30‡ | 29‡ | 41‡ | 73 | 123 | 29 |
| Natural regeneration (seedlings/ha) | 500‡ | 200‡ | 2600‡ | 2400 | 900 | 26 |
| Total conifer stocking (1000s/ha) | 2 | 7 | 11 | 18 | 14 | 29 |
| Seedling survival (% over 4 years) | 88 | 81 | 77 | 75 | 59 | 29 |
| Seedling height growth (cm at 4 years) | 46 | 46 | 51 | 40 | 37 | 29 |
| Planted seedling foliar nitrogen (%) | 1.7† | 1.5† | 2† | 1.8 | | 18 |

strips. ITS units with reduced canopy cover were also avoided. Marten use was reduced least in the 0.1-ha units. Woodpecker foraging declined greatly in the ITS units after harvest, but did not drop in the 0.1-ha units despite loss of many snags. Spruce grouse did not use openings in the winter, but used all sizes of leave strip as much as uncut forest. ITS units had disproportionately low grouse use, probably due to the loss of favoured higher-density patches of canopy. Red-backed voles were reduced in openings, but used leave strips. The 0.1-ha treatments had less effect on this ecologically important species. Shrews generally benefited from harvesting, or showed some reduction in the 1- and 10-ha openings. Several songbirds associated with older forest declined after harvest, with greatest effects in the 10-ha and ITS treatments. Displaced birds may have been concentrated in the leave strips adjacent to the smaller openings.

The highly diverse invertebrates showed a diversity of responses. Several groups, such as millipedes and slugs, showed declines in the 1- and 10-ha openings, but less decline in the 0.1-ha arrays or the ITS units. Many of these groups dwell in moist forest floor or rotting wood. *Scaphinotus angusticollis*, a large beetle that eats snails, declined in the harvest openings, but persisted in all sizes of leave strips. However, its numbers dropped throughout ITS units. Ice crawlers, a large, rare insect active under snow, increased with small openings, but declined with 10-ha openings and ITS. Active hunters, such as spiders, typically increased in any harvested units, probably because of increased activity on warmer ground. Plant-feeding insects showed similar increases in openings. Ants and several pioneer species of beetles were absent at the site prior to harvesting, but became abundant in the openings. Colonization by ants is a concern, as they can eradicate other invertebrate species.

TABLE 6 *Components of biological diversity (abundances as a percent of abundance in controls)*

| Variable | 10 ha | 1 ha | 0.1 ha | ITS | Control | Ref. |
|---|---|---|---|---|---|---|
| Snag density | 51 | 22 | 7 | 3 | 100 | 6 |
| Dense canopy (>30% cover) | 50 | 39 | 25 | 0 | 100 | 6 |
| CWD volume | 103 | 103 | 159 | 152 | 100 | 6 |
| Well-decayed CWD | 54 | 67 | 96 | 134 | 100 | 6 |
| Shrub cover – year 5 | 49 | 64 | 75 | 56 | 100 | 6 |
| Herb cover – year 5 | 114 | 105 | 95 | 110 | 100 | 16 |
| Mosses and liverworts | 47 | 50 | 65 | 61 | 100 | 16 |
| Heart-leaved twayblade | 42 | 45 | 39 | 51 | 100 | 20 |
| Pine marten | 29 | 38 | 65 | 42 | 100 | 5 |
| Three-toed woodpeckers | 122 | 114 | 101 | 22 | 100 | 15 |
| Spruce grouse | 56 | 67 | 72 | 38 | 100 | 9 |
| Red-backed voles | 80 | 80 | 91 | 77 | 100 | 6 |
| Masked shrews | 80 | 80 | 131 | 106 | 100 | 6 |
| Dusky shrews | 141 | 138 | 100 | 141 | 100 | 6 |
| Hermit thrush | 68 | 82 | 84 | 64 | 100 | 1 |
| Golden-crowned kinglets | 41 | 78 | 55 | 43 | 100 | 1 |
| Millipedes | 62 | 80 | 99 | 76 | 100 | 7 |
| Slugs | 79 | 73 | 65 | 88 | 100 | 7 |
| Snail-eating ground-beetle | 81 | 84 | 88 | 54 | 100 | 7 |
| Ice crawlers | 77 | 145 | 309 | 41 | 100 | 7 |
| Spiders | 159 | 174 | 210 | 248 | 100 | 7 |
| Ants (and other "invaders") | 4810 | 3550 | 5700 | 2500 | 100 | 7 |

## Summary and Implications—Harvest treatments and opening sizes

The most obvious result of examining all the studies at Sicamous Creek is that no single harvest treatment is best—or, in some cases, "least worst"—for all variables studied. Because these study variables broadly parallel forest managers' responsibilities, there is no single ideal silvicultural system for the ESSF. The Sicamous Creek study is therefore an extensively documented proof of the saying "Don't do the same thing everywhere." However, results of the Sicamous Creek project can go beyond this basic principle.

First, the project demonstrated that alternatives to traditional clearcuts are possible and economically feasible in the ESSF. The site acts as a demonstration for these possibilities. It may encourage foresters to expand their practices beyond the clearcuts that are still dominant in high elevations.

Second, the numerous studies at Sicamous Creek help to define which resources and ecosystem components win and which lose in each silvicultural option. Some patterns are apparent in the summaries above. For example, physical variables associated with improved regeneration conditions tend to be better provided by the larger openings and their larger leave strips. However, aspects of soil ecology, natural regeneration, and many components of biodiversity showed better results in the arrays of 0.1-ha openings or the ITS units. Different systems may be favoured in areas where different resource values are emphasized. The studies also provide information for managing numerous specific resources that can be of direct concern for management in particular areas. These include successfully establishing conifer regeneration, maintaining a persistent snowpack, preserving long-term soil productivity, or managing for special species, such as pine marten. Results-based forest practices require that managers know how the variables for which they are responsible respond to management options.

Third, not doing the same thing everywhere means that we have to know which management options are really different ecologically. Using the simple colour-coding scheme for the 51 resource and ecological variables above, the 10-ha treatments were the same as the 1-ha treatments in 73% of the cases, the same as the 0.1-ha treatments in 34% of the cases, and the same as the ITS treatments in 33% of the cases. For most ecological variables, 10-ha clearcuts are not very different from 1-ha openings, but they are different from 0.1-ha patch-cut systems or ITS units. Ecologically, 1-ha openings might be considered as much "clearcuts" as 10-ha openings. The recent change from clearcuts of 20–40 ha in the local ESSF to 3–5 ha openings does represent a change in practices. However, for many ecological variables, this is still "doing the same thing everywhere." Results from the Sicamous Creek project support increased use of systems with openings <1 ha to truly enhance the ecological diversity of practices in the ESSF.

Finally, the various research studies at the site help to define some preferred features of truly alternative harvesting systems. In the studies where both 0.1-ha and ITS units were measured, 0.1-ha treatments were preferred for the variable 47% of the time, ITS was preferred 18% of the time, and the two were equal in 36% of cases. The patch-cut system would therefore be somewhat preferred overall compared to ITS. In several cases, the poorer results from ITS are due to its uniform thinning—for example, increased windthrow, greater mid-winter snow accumulation, and lower numbers of canopy-preferring species such as spruce grouse and marten. Group selection systems that retain dense patches of trees would probably have many of the same ecological benefits as the 0.1-ha patch-cut arrays, without requiring detailed layout.

These results from the first 6 years after harvest, in the first pass of the first rotation, clearly provide only initial guidance for long-term management of a >100-year rotation. Stand modelling and ongoing monitoring at the Sicamous Creek site are needed to update the results throughout the rotation. A second limitation of the study is that the Sicamous Creek site, though large and replicated, represents only one particular location. It is surrounded mainly by old forest. We do not know how generally these results apply throughout the ESSF, especially in more extensively managed landscapes. Co-ordination with two other high-elevation silvicultural systems research sites, at Lucille Mountain (Jull and Stevenson 2001) and Quesnel Highlands (Soneff and Waterhouse 1997), will help establish how broadly these results apply in British Columbia. However, more large-scale research installations are unlikely in the near future. Therefore, the best way to find out how general are the results from ESSF research sites is to try alternative silvicultural systems at operational sites in the ESSF, and to monitor their success.

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