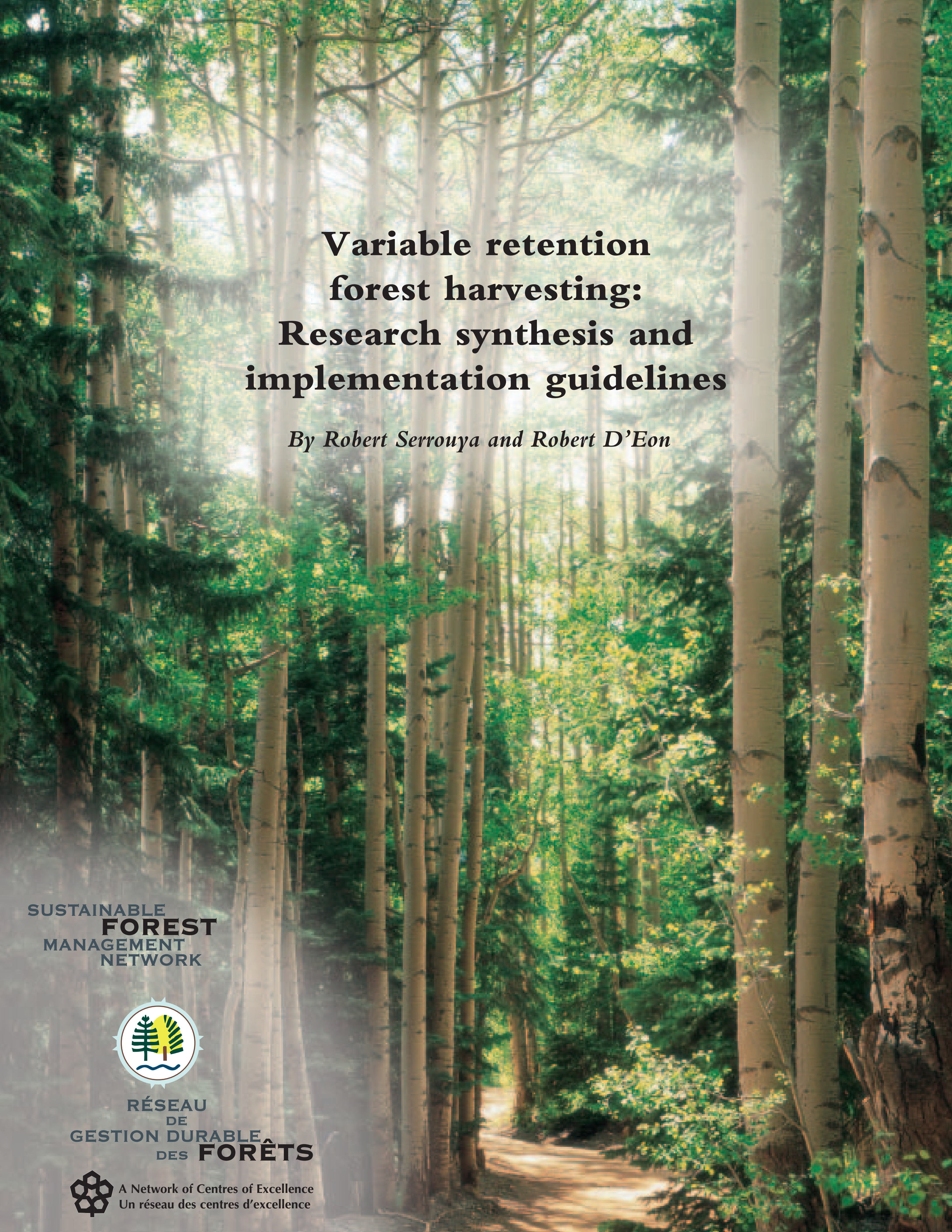

Variable retention forest harvesting: Research synthesis and implementation guidelines

By Robert Serrouya and Robert D'Eon

SUSTAINABLE FOREST MANAGEMENT NETWORK

RÉSEAU DE GESTION DURABLE DES FORÊTS

A Network of Centres of Excellence
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THE SUSTAINABLE FOREST MANAGEMENT NETWORK

Established in 1995, the Sustainable Forest Management Network (SFM Network) is an incorporated, non-profit research organization based at the University of Alberta in Edmonton, Alberta, Canada.

The SFM Network's mission is to:
- Deliver an internationally-recognized, interdisciplinary program that undertakes relevant university-based research;
- Develop networks of researchers, industry, government, Aboriginal, and non-government organization partners;
- Offer innovative approaches to knowledge transfer; and
- Train scientists and advanced practitioners to meet the challenges of natural resource management.

The SFM Network receives about 60% of its $7 million annual budget from the Networks of Centres of Excellence (NCE) Program, a Canadian initiative sponsored by the NSERC, SSHRC, and CIHR research granting councils. Other funding partners include the University of Alberta, governments, forest industries, Aboriginal groups, non-governmental organizations, and the BIOCAP Canada Foundation (through the Sustainable Forest Management Network/BIOCAP Canada Foundation Joint Venture Agreement).

KNOWLEDGE EXCHANGE AND TECHNOLOGY EXTENSION PROGRAM

The SFM Network completed approximately 270 research projects from 1995 – 2003. These projects enhanced the knowledge and understanding of many aspects of the boreal forest ecosystem, provided unique training opportunities for both graduate and undergraduate students and established a network of partnerships across Canada between researchers, government, forest companies and Aboriginal communities.

The SFM Network's research program was designed to contribute to the transition of the forestry sector from sustained yield forestry to sustainable forest management. Two key elements in this transition include:
- Development of strategies and tools to promote ecological, economic and social sustainability, and
- Transfer of knowledge and technology to inform policy makers and affect forest management practices.

In order to accomplish this transfer of knowledge, the research completed by the Network must be provided to the Network Partners in a variety of forms. The KETE Program is developing a series of tools to facilitate knowledge transfer to their Partners. The Partners' needs are highly variable, ranging from differences in institutional arrangements or corporate philosophies to the capacity to interpret and implement highly technical information. An assortment of strategies and tools is required to facilitate the exchange of information across scales and to a variety of audiences.

The preliminary KETE documents represent one element of the knowledge transfer process, and attempt to synthesize research results, from research conducted by the Network and elsewhere in Canada, into a SFM systems approach to assist foresters, planners and biologists with the development of alternative approaches to forest management planning and operational practices.

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Variable retention forest harvesting:

Research synthesis and implementation guidelines

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Executive Summary

The long-term consequences of multiple short-rotation clear-cut harvesting are feared to be forested landscapes devoid of structural attributes such as large live trees, snags, and dead down wood - structures common in older unmanaged forests. These structural attributes are believed to be important to the persistence of many species dependant upon them. Variable retention (VR) harvesting has been proposed as a way of curtailing this situation by providing long-term structural legacies in managed forests. While a relatively new phenomenon, VR has been implemented to varying degrees across Canada and elsewhere. This document is primarily a synthesis of experimental research on biotic responses to VR in different ecosystems in Canada. We also offer recommendations and guidance to managers seeking to implement VR.

One of the most central topics related to VR is post-fire residual patterns, since post-fire residuals have been espoused as a promising template to base green-tree retention strategies. A review of six major pieces of work on post-fire residuals yielded the following mean residual areas (i.e., proportion of total burned polygon left as unburned green-tree residuals): 9.4% in boreal Alberta, 7% in sub-boreal B.C., 13% in spruce/fir forests in B.C., 5% in boreal Ontario, 8.4% in boreal Quebec, and 1% in another study in boreal Quebec. While a somewhat over-simplification of a very complex phenomenon, these values provide useful starting points for managers wishing to implement VR.

In a review of wildlife response to post-harvest residual treatments, we summarize the results of three broad-scale replicated experiments in the Canadian literature: EMEND, the Sicamous Creek silvicultural experiment, and the Opax Mountain project. The EMEND (ecosystem management by emulating natural disturbance) project is a replicated experiment in northern Alberta designed to test the effects of clearcutting alternatives on biodiversity and other forest variables among a variety of retention levels. Responses among species and across treatments were diverse. Groups such as carabid beetles and aerial foraging birds declined sharply even with low levels of wood removal. In contrast, bark foraging and cavity nesting bird abundances showed strong increases with low levels of retention. The Sicamous project was designed to test the effectiveness of clearcutting alternatives by holding the removed volume constant, but applying four different harvest pattern treatments. While responses were again diverse, an important finding from Sicamous is that 73% of the 51 resource variables measured had similar responses between the 10 ha and 1 ha clearcut treatments. Whereas, the 10 ha treatments yielded similar results as the 0.1 ha treatments in only 33% of the variables, and 33% of cases when compared to the ITS treatment. This suggests that 1 ha could represent an important threshold where openings must be less than 1 ha in order to be perceived as anything less than a clearcut. The Opax Mountain project is a replicated and randomized-block design used to investigate the relative effects of volume removal and cut pattern on a wide variety of organisms, specifically focussing on individual tree selection and patch cutting. Again despite diverse responses, threshold effects were detected in several species of small mammals where, generally, a rather strong perturbation (e.g., 50%) was required to change small mammal abundance.

At this time, the most universally applicable recommendation in response to the diversity of biotic responses to VR is: there is no one universally best VR prescription, therefore, provide a variety of retention levels and patterns across the landscape. However, we offer and discuss several specific implications regarding threshold responses related to harvest patch size and species response.

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Introduction

Changing social values have led to more diverse forestry practices

Changing social values have led forestry practitioners to consider and implement alternatives to clearcut harvest methods. The growing recognition that traditional multiple-pass clearcut systems can lead to lower stand and landscape-level complexity (Delong and Tanner 1996; Bergeron et al. 2002) has helped initiate this change. Reduced complexity can pose greater risks to native flora and fauna, and has been linked to species loss or reduced wildlife populations in both Europe (Berg et al. 1994) and North America (Robbins et al. 1989).

In North America, most forest biodiversity research has focussed on short-term responses to harvesting (e.g., Sullivan et al. 2000; Tittler and Hannon 2000; Tittler et al. 2001; but see Schieck and Hobson 2000). Because of older harvest histories in Europe, researchers there have been able to shed insight into the longer-term consequences of intensive forestry (i.e., multiple-rotation plantation-silvilculture forestry) that have eluded other studies (Berg et al. 1994). For example, many studies in the pacific-northwest of North America failed to reveal consistent relationships between vertebrate abundance and structural attributes such as downed wood (Bunnell et al. 1999). In contrast, Berg et al. (1994) have linked many species declines and losses to the lack of downed wood, probably because Europe has a much longer history of intensive forestry over many rotations. Therefore, certain ecological thresholds have likely been surpassed in Europe, which could be why we have not seen similar patterns in North American studies (Bunnell et al. 1999).

Variable retention (VR) focuses on leaving a wide-range of structure behind

The recognition of short and especially long-term consequences of present day actions has helped focus thinking on what can be done to mitigate some of the negative effects of intensive fibre-oriented management. So-called “new forestry”(Franklin et al. 1997), which has been proposed as a means of addressing some of the short and long-term effects of forestry, is based on taking a broader view of the forest resource. Correspondingly, retaining forest structure (i.e., leaving portions or components of forests unharvested at the stand or landscape scale) using a wide array of retention levels is being investigated as a means of mitigating some of the effects of large-scale clearcutting (e.g., Tittler et al. 2001; Herbers and Maxcy 2002). A term used to describe this broad-range of retention is commonly referred to as “variable retention” (SPS 1995; Franklin et al. 1997; Bunnell et al. 1998; Sullivan and Sullivan 2001; Sullivan et al. 2001a).

Potential short-term benefits include lower impacts on forest-dwelling species and long term benefits include earlier recolonization of some species

The potential ecological benefits of maintaining stand-level structural diversity (mainly large live trees, snags, and downed wood) on cutover areas are two-fold. In the short term, leaving this structure may mitigate some effects of logging on forest-dwelling species resulting in smaller initial impacts (Lehmkuhl et al. 1999). Over the long-term, pre-harvest characteristics (such as large snags and CWD) may result at an earlier age in regenerating forests, increasing habitat complexity as compared to clearcut methods.

How VR is implemented depends entirely on goals of practitioners

The main purpose of this document is to provide guidance for managers seeking to implement variable retention forest harvesting. However, implementing variable retention depends entirely upon the goals that are developed by managers and practitioners in a given jurisdiction. For this reason, this document will present different rationales for the use of variable retention, and discuss how this context will influence implementation. The second objective is to summarize some of the biotic responses to variable retention in different ecosystems across Canada. Results are presented separately for boreal, temperate interior, and western coastal ecosystems. However, this is not intended as a broad literature review, but rather a synthesis of experimental research. For the boreal forest, a broad review has already been completed with practical implementation guidelines (Song 2002). Here, supplemental information will be included when appropriate, particularly for ecosystems outside the boreal forest.

Work funded by the Sustainable Forest Management Network (SFMN) will be highlighted in **bold** print. Several SFMN extension and implementation documents are a result of research activities initiated by the Knowledge Exchange and Technology Extension (KETE) sub-committee. Those references will be bolded and *italicized*.

Why use variable retention?

VR can be used to increase complexity, mimic fire-residual patterns, or to benefit specific species

Three dominant rationales for using variable retention will be presented. Others likely exist, but have not been clearly articulated and are not prominent in the literature. The first is the goal to increase structural complexity relative to clearcuts and to represent a proportion of each ecosystem in a relatively unmanaged state (Bunnell et al. 2003). The second is the natural disturbance model that is being examined in boreal forests around the world. The third rationale is to retain attributes primarily to manage for individual species, in absence of a coarser-filter approach.

Although variable retention is a stand level tool, setting a context at a landscape level is critical for implementation. It is impossible to judge what is required at the stand level without understanding processes and perspectives at broad scales. For example, a landscape dominated by non-harvestable forests can be different from one where forest harvesting has become the main disturbance type. Discussions of the natural disturbance model and the complexity/representation approach begin with landscape-level contexts. These approaches share several concepts. For example, pursuing a natural disturbance model will, by definition, increase complexity relative to multiple-pass harvest systems, which is a shared goal of the representation/complexity approach.

1. Complexity and representation

Groups in Coastal BC simply wanted to increase structural complexity relative to clearcuts

Faced with world-wide environmental scrutiny, workers involved with Weyerhaeuser British Columbia (BC)'s coastal tenure (formerly MacMillan Bloedel Ltd.) were among the first to formally develop a rationale for implementing variable retention, and to apply it on a large scale (Bunnell et al. 1998). The first objective of their variable retention program was simply to increase structural complexity relative to clearcuts. This objective stemmed from the strong ecological evidence that higher stand-level complexity increases the availability of different ecological niches; hence, species richness and abundance are also increased (MacArthur and MacArthur 1961; Wilson 1974). This basic ecological principle is also the main reason that researchers in northwestern United States and Canada began to investigate variable retention (Franklin et al. 1997), not in an explicit attempt to mimic natural disturbance patterns per se. Albeit, most researchers realize that examining natural disturbance patterns furthers our understanding of how organisms are adapted to different disturbance regimes and the ecosystems they shape (Bunnell 1995).

They also wanted focus retention in ecosystems that were the least represented in "unmanaged" areas

Weyerhaeuser's second objective for using variable retention was to increase the representation of defined ecosystems in a condition that is relatively unmanaged[1]. In other words, stand-level retention is focussed in ecosystems that are under-represented in an unmanaged state (the level of unmanaged area is assessed at a landscape scale). Representing ecosystems in an unmanaged state is referred to as ecological representation (Huggard 2000b). There are four main benefits to pursuing this coarse-filter strategy:

Unmanaged areas are a coarse filter, helping to protect thousands of poorly-known species

1) Unmanaged areas help to account for the thousands of organisms that are too poorly known or difficult to manage on an individual basis;

2) They provide a buffer against risks, which are higher on the managed portion of the landbase, regardless of what harvesting paradigm is followed;

3) They provide the opportunity for natural disturbances and succession to occur, without the threat of salvage logging or other interventions. These processes are important to many species, and may not be replicated, even with well-informed management practices. In other words, it is a mechanism to attempt to account for unknown processes; and

4) Larger unmanaged areas can provide benchmarks to compare the effects of management on the harvestable portion of the landbase (Arcese and Sinclair 1997).

To assess representation, a landscape-level analysis is conducted to evaluate the proportion of each ecosystem that occurs in areas that are constrained from harvesting. Constrained areas could include parks, ecological reserves, economically inoperable sites, species-specific constraints (e.g, caribou

[1] By relatively unmanaged, we mean unmanaged for fibre production. These areas may be managed for other values (Huggard 2000b).

management zones), and riparian reserve zones. This analysis serves to highlight ecosystems that are under-represented at a landscape scale. The intent is not to try and achieve an arbitrary target of unmanaged area, but rather to draw attention to weaknesses and identify areas where improvements to representation can be made (WAMWG 2003). It also serves as the landscape-level context to addressing the question of how much should be retained at a stand-level. For example, if an ecosystem has 50% representation in unmanaged areas, whereas another has only 2%, clearly consideration should be given to placing stand-level retention in the latter case. Given a limited amount of area that can be allocated to non-timber values, the concept of identifying landscape-level weakness is critical, because the misguided allocation of resources can be difficult to reverse. As part of another SFMN extension document, ***Huggard (2003)*** provides a detailed description of how to implement an ecological representation program, and how such an analysis is relevant to forest management.

Landscape context is essential, and helps focus where stand-level retention should occur

Zonation of different harvest intensities is another landscape-level context that is relevant to variable retention. Coastal Weyerhaeuser BC established 3 zones of contrasting harvest intensity to help spread the risk associated with forest management on biological diversity (Bunnell et al. 2003). Based on decreasing levels of harvest intensity, these zones are the timber, habitat, and old-growth zones. Different levels of within and between-stand retention occur in each of the three zones. These zones are broadly analogous to TRIAD (Seymour and Hunter 1999) approaches that are being used by other forest companies in Canada (e.g., Bunnell et al. 2003)

Zonation, or the TRIAD approach of different harvest intensities in different zones is relevant to variable retention

Using the Coastal Weyerhaeuser BC example, in the timber zone, where the highest degree of harvesting occurs, the minimum level of retention is 5% for dispersed retention (e.g. single tree) or 10% for aggregated retention (e.g., patch retention). This zone covers 65% of the tenure, and 80% of the stands in this zone are available for harvest. In the habitat zone, where multiple values are integrated, at least 15% of the stand is retained using aggregated, dispersed, or mixed retention. This zone covers 25% of the tenure, and 70 percent of stands may be harvested, whereas the remaining 30% cannot. The remaining 10% of the tenure is the old-growth zone, where at least 20% of the stand is retained. Only 1/3 of the stands in the old-growth zone can be harvested. Attempts were made to place old growth zones with the landscape context in mind; in other words, they were skewed towards areas that were the least represented in an unmanaged state, based on prior landscape-level representation analyses.

Retention-patches in all three zones are permanent, and the zones are spread throughout the tenure, among the 15 distinct ecosystems that have been identified. The harvesting intensities outlined above, particularly at landscape (i.e., zone) scales, should be sufficiently disparate to identify meaningful differences in species' response. This can provide key insight towards understanding how organisms respond to stand and landscape-level harvest intensities, and how much forest retention is required to maintain biological richness.

It is important to note however, that Coastal Weyerhaeuser BC's implementation of this approach is recent and is being performed in an adaptive management context, and is therefore continuously undergoing evaluation.

2. Natural disturbance template

The natural disturbance template assumes that species benefit from harvesting patterns that resemble natural disturbance patterns

The recent emergence of ecosystem management led researchers to focus attention on understanding how natural disturbances affect ecosystems and the adaptations of organisms within them (Bunnell 1995). The rationale behind the natural disturbance template of forest management suggests that organisms are more likely to persist if forest harvesting approximates patterns and structures resulting from natural disturbances **(Bergeron et al. 2002)**. The principle can be applied at scales of landscapes or stands. Age class distributions, harvest intervals, and spatial configuration are aspects that operate at landscape scales and can be manipulated by managers to resemble natural disturbance regimes.

VR under this template is based on green-tree retention that resembles residual structure left by fires

At the stand level, the natural disturbance template focuses on leaving behind similar amounts of green trees to those that are spared by fires (Vanha-Majamaa and Jalonen 2001). Important parameters include: (1) the amount of residuals (the term residual refers to live trees left unburned by fires) by fire size and cover types, (2) the frequency distribution of residual patch sizes, and (3) within-stand spatial arrangement. These aspects are directly relevant to the implementation of variable retention based on a natural disturbance template. Studies that attempt to quantify these parameters are in their infancy, and will be summarized in a subsequent section.

Several authors have attempted to determine relationships between fire size and the residual areas spared by fires. Some reported an increasing relationship between fire size and residual area, to an upper asymptote (Eberhart and Woodard 1987; Lee et al. 2002), while others have not observed any patterns (Stuart-Smith and Hendry 1998). Although the reasoning is sound, the consequences of applying variable retention in patterns that resemble fires, across very large areas, are almost completely unknown (Vanha-Majamaa and Jalonen 2001; **Bergeron *et al.* 2002**; Lee *et al.* 2002).

One limitation of this approach is that many snags remain after a fire, but are not present after harvesting

Most authors acknowledge that the rationale of basing harvesting on natural disturbance has limitations (**Bergeron *et al.* 2002**; Lee et al. 2002). First, social values tend to limit harvesting vast contiguous areas in short time periods, which is a characteristic of some fires. More striking, however, is the substantial divergence in snag densities between post-fire and post-harvested landscapes (Schieck and Song 2002). The ecological consequences of this difference are most pronounced 15-30 years after the disturbance (Schieck and Song 2002). For example, bark beetles, which commonly erupt following fires because of high snag densities, attract large numbers of black-backed and three toed woodpeckers. It is unlikely that this phenomenon can be replicated by leaving green trees following harvesting. For example, Schieck and Hobson (2000) found that 2 years after fire, cavity nesters were only about 17% as abundant in sites that had been burned compared to logged sites. Similarly, in a study in Saskatchewan, black-backed and three-toed woodpeckers were only found in burned treatments (Morissette et al. 2002). Whether these stand-level responses are important to woodpecker persistence at larger scales is unknown, especially in the context of widespread salvage logging and fire suppression. It is likely, however, that species associated with post-fire snags will be a concern if management emphasis is placed solely on leaving green trees as the primary retention strategy (Hutto 1995). If harvesting replaces fire as the dominant disturbance in the boreal forest, these differences in snag densities will be magnified across large areas, and may have consequences for organisms that require dead and decaying wood.

3. Species-specific approaches to variable retention

For the purposes of this document, we refer to species-specific approaches to variable retention as attempts to manage for individual species using structural retention. Some jurisdictions have explicitly based retention levels on apparent needs of some “key” species. The rationale behind the species-specific approach is that if a given “key” species is maintained, other species will be “taken care of”. “Umbrella” and “keystone” species fall under this category. Umbrella species are those whose ranges encompass the ranges of many other species. The assumption being that if the umbrella species is doing well, most species within its range will also be accommodated. Similarly, keystone species are those that create habitats for other species (e.g., beavers creating fish habitat), thus ensuring the well being of keystone species is assumed to account for a suite of other organisms. These species-centered management approaches have recently come under criticism (Simberloff 1998; Lindenmayer *et al*. 2000; ***Hannon and McCallum 2002***) because of unproven efficacy at meeting the previous assumptions (See ***Hannon and McCallum [2002]*** for review). For example, the abundance of umbrella species failed to reflect declines in other species that were within their range (Oliver et al. 1998; Lindenmayer et al. 2000). Some studies have shown that randomly selected species performed just as well as those chosen using formally defined criteria to indicate population trends in groups of other species (Niemi et al. 1997; Hutto 1998; Oliver et al. 1998). Another concern is that umbrella or keystone species are often selected for social reasons to the exclusion of biological ones. Finally, management of focal species tend to be highly specific and prescriptive, which ultimately leads to a reduction in variability (***Hannon and McCallum 2002***).

Species-centered approaches are based on retaining structure for the needs of individual species. These species often include "umbrella" or "keystone" species – those that help account for other species. Relying on these focal species approaches, on their own, has come under criticism.

In the end, however, individual species need to be monitored to act as a feedback mechanism of how well coarse-scale approaches (i.e., the natural disturbance template, or representation/complexity approach) are working towards meeting their objectives. The selection process of these suites of indicators should include consideration of sessile and motile organisms, slow and fast dispersers with small to large home ranges, and those that occupy a variety of habitats.

However, monitoring individual species for the purpose of testing the efficacy of coarser-scale approaches is a very different goal than managing or monitoring solely for individual species (i.e., species-specific approaches). The latter has been implemented with questionable success in the absence of coarser-level approaches, which attempt to encompass a broader range of ecological processes (Lindenmayer et al. 2000).

Biotic response

Canadian Boreal forests
Post-fire residuals

There is limited information upon which to base harvesting patterns using post-fire residuals

Post-fire residuals are trees that survive fire, and can occur singly or in groups. Given that post fire residuals have been espoused as a promising template upon which to base green-tree retention strategies, there is a surprising lack of research in Canada on this topic (Perron 2003). Notable exceptions include Eberhart and Woodard (1987), Delong and Tanner (1996), **Smyth (1999)**, Kafka et al. (2001), Lee et al. 2002, and Perron (2003). This section consolidates information that has been collected on post-fire residuals in Canada. The original intent was to perform meta-analyses stratified by different ecosystems across Canada (i.e., Eastern black-spruce-dominated boreal, western white spruce and mixed boreal, and the BC interior temperate forests). However, there were not enough data from each region to warrant such an approach. Instead, parameters for each study were summarized descriptively and compared among studies. The data sets included two from Northern Alberta (mixed-boreal), one from the southern interior of BC (spruce/pine/fir), one from the central interior of BC (sub-boreal), two from Quebec (boreal) and one from Ontario (boreal). Data were either taken directly from existing reports or, when the desired information was not present, authors were contacted to provide raw data.

2 pieces of information are important: the frequency of residual patch sizes and the relationship between fire size and residual area

Two relationships were explored that are relevant to variable retention and stand-level implementation (within a landscape-level context): 1) The composition of different residual size patches by area; and 2) The relationship between fire size and amount of residual forest structure. This information also allowed the calculation of overall proportion of residuals for a given study area, if it was not explicitly reported in the published documents. Unless stated, all summaries pertain to islands of unburned trees that were completely surrounded by burned area. Some authors analyse peninsular residuals separately: these are fingers of unburned area that extend into the burned area. Peninsulars will also be discussed if the information was presented. Other parameters such as fire frequency, age class distributions, or spatial arrangements of cutblocks have been summarized elsewhere and are not the focus of this report (e.g., **Bergeron *et al.* 2002**).

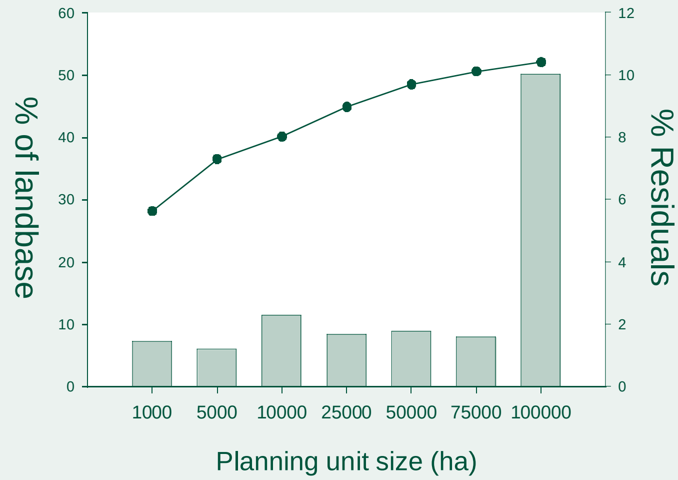

Figure 1. Amount of area that planning units of different size classes occupy on the landscape (bars) intended to match fire patterns, and percent of unburned residuals (line) that is expected to occur in a fire of similar size. Adapted from Lee et al. (2002).

Boreal forests in Alberta

For their study of boreal forests in northern Alberta, Lee et al. (2002) created planning unit sizes to roughly match fire sizes, and suggested that the frequency of these planning units on the landbase match the frequency of occurrence of fire sizes (Fig. 1). The idea behind these planning units is that they should be harvested as quickly as possible (much like a fire operates), to diverge from the notion of multiple-pass forestry within a rotation. Each of these planning units should contain live residuals that match the amount of residuals that would occur in a fire of similar size. In two separate post-fire residual studies done in boreal Alberta, researchers found that as fire size increased, so did the amount of live residuals (Eberhart and Woodard 1987; **Smyth 1999**). This is probably because larger fires are more likely to encounter low fuel areas and topography that favours fire skips (Foster 1983; Delong and Tanner 1996). This pattern is reflected in the amount of residuals per planning unit size class recommended by Lee et al. (2002). They suggest that the percent of residuals range from 5.6% to 10.4% (Fig. 1), but because the larger planning units occupy the most area on the landscape, the overall proportion of green-tree residuals is closer to the upper limit of this range. A weighted average between the amount of area occupied by each planning unit and the percent of residuals per planning unit suggests that approximately 9.4% of a managed landscape should contain green-tree residuals. In boreal Alberta, this can be considered a broad target, if the objective is to follow a natural disturbance-harvesting template. Lee et al. (2002) point out that these residuals do not represent a permanent deletion from the landbase because they could be harvested at the end of the current rotation, or beginning of the next. However, the overall 9.4%, although not spatially static, likely would be a net permanent deletion from the landbase. This is because each time a planning unit is targeted for harvesting, 9.4% (on average) would have to be retained, even if the previous cohort of residuals was harvested.

Lee et al. (2002) found that as fires got bigger, so did the proportion of residual (unburned) area, up to a point

A weighted average revealed that 9.4% of the disturbed landscape contained green-tree residuals

Caution should be used when harvesting residuals because large pieces of deadwood may no longer be recruited into the system

Harvesting residuals deserves a cautionary note with respect to rare habitat attributes, such as large or well-decayed pieces of deadwood (i.e., snags or downed wood). To maximize timber production, rotation lengths are designed to harvest as many live trees as possible prior to canopy break-up or tree decay. This puts traditional rotation lengths in direct conflict with "managing for deadwood". Thus, if retained patches (i.e., patches left behind from previous harvesting) are harvested at the end of the current rotation or early in the next, levels of deadwood are likely to drop substantially (or in the case of rare types of deadwood, become virtually absent) relative to unmanaged systems. Retaining green trees to die is the most efficient means of maintaining deadwood in a system over the long term (Huggard 2000a). If retention patches are removed at the end of a rotation (or at the beginning of the next rotation), this recruitment is less likely to occur.

On the other hand, if natural disturbance rates are frequent enough such that large or well-decayed pieces of deadwood do not accumulate naturally in a given ecosystem, then harvesting residuals would not be a concern. However, **Cumming *et al.* (2000)** point to recent evidence of more frequent gap-dynamics systems in Alberta's boreal forest than what was previously thought. Their research focused on age-class distributions and "true" ages of aspen (Populus tremuloides) stands by drawing attention to the notion that standing age distributions may be a misleading indicator (i.e., an underestimate) of time-since-disturbance intervals. Although their work did not focus explicitly on deadwood, it follows that gap dynamic systems would accumulate deadwood (to a certain "equilibrium" offset by decay) at levels that would be much higher than forests harvested based on rotation lengths that maximize fibre production. Harvesting green-tree residuals may jeopardize their ability to contribute deadwood in intensively managed forests, which is an important role of green-tree retention strategies (Franklin et al. 1997). Simulation tools that project deadwood levels would help to quantify the magnitude of this potential problem (e.g., Huggard 2000a). Several parameters are required to project deadwood abundances through time. They include: baseline levels of deadwood (by size and decay class) in uncut forests, death rates of trees of different species, decay rates of snags, fall-down rates of snags and live trees, and decay rates of downed-wood. Lee (2002) calls for similar research to address this knowledge gap that has potentially serious consequences for deadwood levels over the long term.

From their synthesis of post-fire residual data, Lee et al. (2002) report that 25% of the residual area was in patches that were 1.1 to 5 ha (Fig. 2), which is the most abundant residual size class (by area). Specific guidelines for implementation of these residuals, in the context of different-sized planning units, are given in Tables 13.3 and 13.4 of Lee et al. (2002). However, the authors caution that the ecological consequences of implementing their natural disturbance-succession template are unknown. The appropriate approach would be to implement this model in an adaptive management framework. Large-scale, replicated management prescriptions should be applied that use the natural disturbance template over a range of planning unit sizes, and compare the ecological response to "status quo" or other forestry paradigms such as old-growth reserves with multiple-pass forestry in the surrounding matrix.

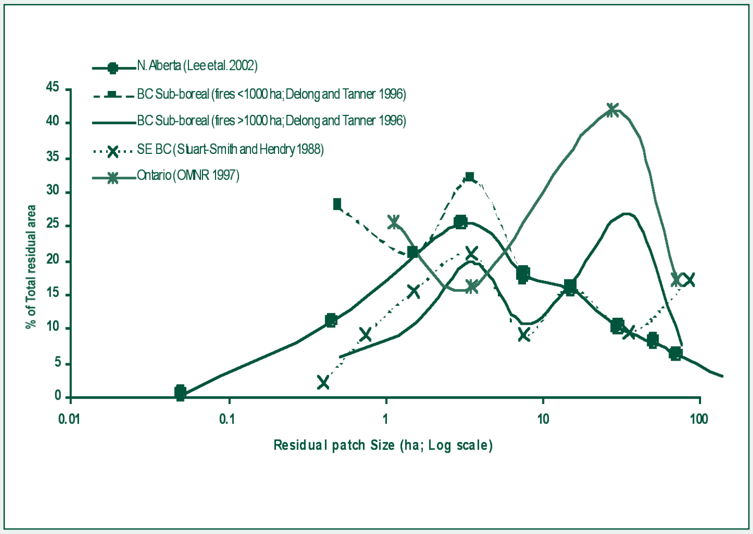

Figure 2. Proportion of total residuals that occurs in different size classes for four different studies across Canada.

In sub-boreal BC, Delong and Tanner (1996) also found that as fire size increased, so did the proportion of green-tree residuals

Sub-boreal forests in British Columbia

In BC's sub-boreal forests, Delong and Tanner (1996) studied the size class distribution of post fire residuals for nine fires, but they distinguished between fires greater and less than 1000 ha (Fig. 2). Fires less than 1,000 ha most often (32%) had residual patches that were 3.5 ha, very similar to Lee et al. (2002). In contrast, fires larger than 1,000 ha had the highest proportion (27%) of residuals in patches that were 35 ha. However, the second-most abundant (20%) residual patch size class was 3.5 ha, similar to the smaller fires and those reported by Lee et al. (2002). Delong and Tanner (1996) also reported the frequency of occurrence of fires in different size classes, and the amount of residuals for fires of different sizes (although class intervals were relatively large for this metric). Their results broadly corroborated the results found by others that the proportion of residuals increases with increasing fire size (Eberhart and Woodard 1987; Smyth 1999). Island remnants comprised 3-15% of the residual area for the nine fires they examined. Similar to what we did with Lee et al.'s (2002) data, we performed a weighted average to account for the proportion of fires of different size classes that occur in the landscape and the amount of residuals that occur in those fires. This calculation suggests that roughly 7% live residuals (by area) survive fires across the landscape, which is 2.4% less than what we obtained with Lee et al.'s (2002) data from Alberta (Table 1). Island remnants less than 0.2 ha were not included in any of Delong and Tanner's (1996) analyses, hence the 7% is probably an underestimate. We stress that these are rough calculations because of the broad size classes that were presented for post-fire residuals in different fire sizes (Fig. 6 in Delong and Tanner (1996)).

Spruce/Fir forests in British Columbia

In spruce/fir ecosystems researchers found an average area of 13% as green-tree residuals, and there was no relationship between fire size and residual area

In a study of 10 wildfires in spruce, pine, and fir forests of southeastern BC, Stuart-Smith and Hendry (1998) found that the mean percent of unburned areas was 13%. Unlike the previous studies reported here, they found no relationship between fire size and proportion of unburned area, but residual patch frequency increased with increasing fire size (Stuart-Smith and Hendry 1998). Similar to Lee et al. (2002), the highest proportion (21%) of residual patch size class was in the range of 3.5 ha, but the second-most abundant (17%) residual patch size class was relatively large - 85 ha (Fig. 2). Note that this patch size summary excludes peninsular areas (unburned areas that were not completely surrounded by burned areas; termed skips in their report).

Boreal forests in Ontario

The OMNR found that 5% of burned areas consisted of green-tree residuals, but that number increased to 24% when peninsulars were considered

The Ontario Ministry of Natural Resources (OMNR) conducted a detailed analysis of 42 fires in boreal forests of Northern Ontario. Similar to Stuart-Smith and Hendry (1998), they distinguished between peninsular and island (patches inside a fire and completely surrounded by burned area) residuals. This is an important distinction because the proportion of unburned areas are much larger when peninsulars are considered. For the 42 fires, the percent residual area ranged between 10 and 50%, and averaged 24%. However, most (80%) of the 24% was from peninsular areas, whereas the remainder was from island patches. Thus, considering only island residuals, an average of 5% of the burned landscape contained post-fire residuals (OMNR 2001). There appeared to be no relationship between fire size and the proportion of unburned areas, although the regression analysis they presented did not distinguish between peninsular and island residuals (OMNR 1997). The Ontario implementation guide suggests different levels of overall retention for different cover types, with the lowest level of retention for upland conifers and the highest retention for hardwoods, reflecting the different flammability of these species (OMNR 2001). The highest proportion of residual size class, by area, was in the 5-50 ha size class, which is similar to Delong and Tanner's (1996) results for fires greater than 1000 ha. However, the most frequently occurring patches were less than 5 ha, and there was a decreasing trend of patch frequency (per unit area) with increasing fire size (OMNR 1997). Table 3 in the OMNR guidebook provides useful guidance for implementing variable tree retention based on a natural disturbance template (OMNR 2001).

Boreal forests in Quebec

In an area of Quebec, residual size patches were much larger than previous studies, but different methods may explain this

In Quebec, two studies have summarized post-fire residuals. The first was in the boreal forest of western Quebec, where 16 fires were examined using aerial surveys (**Bergeron *et al.* 2002**; although the authors provided us with raw data for 13 of those fires, which is how we based our metrics). In these fires, residual size classes were much larger than other studies; 62% of the residual area were in patches that were >190 ha, followed by 10% of the area that were in 35-75 ha patches. The most frequently occurring size classes were in the 35-75 ha range (30%) followed by the 15-35 ha class (23%). Overall, 8.4 % of the area of the 16 fires remained as internal unburned areas (Table 1). There was no relationship between fire size and proportion of unburned area.

Using satellite imagery, Perron (2003) characterized post-fire residuals west of Lac-St-Jean, also in the boreal black spruce forests of Quebec. The median internal unburned area was 1% (range 0-8%, quartiles: 1-4%). Including peninsular areas, which were well described in this study, those values increase to 19% (range: 7-37%, quartiles 12-26%). Median internal residual size patches were less than 1 ha, but including peninsulars they were 1 ha (median; range: 0-3ha, quartiles 1 ha). Methodological difference probably accounted for the large discrepancy in patch sizes between the two Quebec studies, and may explain why the previous Quebec study had unburned patch sizes that were so large.

8.4% of burned areas consisted of green-tree residuals

In Quebec, Perron (2003) found that 1% (median value) of burned areas consisted of green trees

Table 1. Proportion of residual (green-tree) area for 5 different studies across Canada. N refers to the number of fires.

Ecosystem (province)	N	Mean residual area (%)	Reference
Boreal (Alberta)	7	9.4[a]	Lee et al. 2002
Sub-boreal (BC)	9	7.0[a]	Delong & Tanner 1996
Spruce/Fir (BC)	10	13	Stuart-Smith & Hendry 1998
Boreal (Ontario)	42	5[b]	OMNR 1997
Boreal (QC)	13	8.4[a]	Bergeron et al. 2003d
Boreal (QC)	35	1[c]	Perron 2003

a Calculated from a weighted average of the amount of area occupied by each fire and the percent of residual area in each of those fires.
b Value increases to 24% when peninsulars are considered
c Median value; increases to 19% when peninsulars are considered
d Raw data were provided

Both the OMNR guidebook (OMNR 2001) and Lee et al.'s (2002) work for boreal Alberta present usable direction for implementing variable retention based on natural disturbance templates in boreal forests. However, both documents stress the need to apply their recommendations in a framework of replicated management experiments. Although harvesting can approximate fire, certain key elements cannot be replicated, hence the application of a natural disturbance template should be compared to other policy options, on equally large scales.

In three of the cases summarized above (smaller fires in BC's sub-boreal, northern Alberta, and southeastern BC), most of the residual area was in patches that were 1-10 ha (Fig. 2), but data from boreal Ontario and larger fires in BC's sub-boreal suggested that dominant patches were in the 30ha range. Bergeron's study

Different mapping approaches made it difficult to compare among studies. Standards should be developed for mapping post-fire residuals so that information can be better consolidated

indicated that unburned areas were in even larger patches (>190 ha). Different methods or scales of mapping post-fire green-tree polygons (or estimating single trees) likely accounted for a substantial portion of these differences. For example, we suspect that post-fire polygons mapped in **Bergeron *et al.'s* (2002)** study were at a much coarser scale than ones using fine-scale aerial photography. They classified areas as "partially burned with dominance of live tree", but did not map the small remnants of live trees within those partially burned zones. Thus, smaller unburned patches would have been washed out, which could explain why the distribution of post-fire residual polygon areas was so large for this study.

Most of the studies used aerial photos, but Perron (2003) was the first to map post-fire residuals using satellite imagery. Satellite images provide the advantage of relatively inexpensive, up-to-date coverage, but do not provide the resolution of aerial photos. Aerial photos are more costly, which may reduce sampling intervals, but can provide excellent resolution, especially the 3-D computer mapping that is now possible with digital orthophotos. Given the importance of post-fire residual metrics for the natural disturbance harvesting template (and to allow for comparisons across ecosystems and studies), standards should be developed to guide mapping of minimum polygon sizes, methods of estimating individual tree densities, and how to distinguish peninsular areas, internal patches, and areas outside the fire's influence.

Wildlife response to residual trees

The previous section summarized the occurrence of post-fire residuals to provide information for managers interested in emulating these natural patterns using forest harvesting; ultimately, however, we are interested in how organisms themselves respond to post-fire residuals, or more specifically the attempt to mimic these patterns using forest harvesting. Hence, this section summarizes some of the research findings of experimental research into the effects of volume removal and harvest spatial patterns on organism response.

This summary focuses on 3 experimental studies that dominate the literature in this field: (1) The EMEND project in northern Alberta, which tested the effects of volume removal; (2) The Sicamous Creek Silvicultural Experiment in the interior of BC, which tested the effects of harvest spatial pattern by keeping volume removal constant; and (3) The Opax Mountain Project in southern BC which tested both volume and pattern responses.

1. Harvest intensity: early results from EMEND

The EMEND (ecosystem management by emulating natural disturbance) project is a replicated, multidisciplinary study that was designed to test the effects of clearcutting alternatives on biodiversity, forest regeneration, soil dynamics and microorganisms. The rationale behind the experimental design was to try and determine if various harvesting practices can approximate natural disturbances (primarily wildfire), gauged by how organisms respond to different harvesting treatments **(Spence and Volney 1999)**. Forest fires frequently leave behind live green trees, so species may benefit if harvesting practices can approximate natural patterns of green-tree retention. Although this harvesting paradigm has been proposed in several ecosystems (Delong and Tanner 1996; **Bergeron *et al.* 2002; *Lee and Boutin 2003***), testing the presumed ecological benefits has only recently begun (Norton and Hannon 1997; Schieck and Hobson 2000; Stuart-Smith 2001; Tittler et al. 2001).

Several researchers have highlighted the EMEND project as an opportunity to identify stand-level relationships between forest structure and various indicator organisms in the framework of a replicated, controlled experiment. They also suggest that EMEND provides the opportunity to test for threshold responses of various organisms by attempting to answer the question "how much retained structure is enough to maintain ecosystem function?" (***Hannon and McCallum 2002;* Harrison 2002**). EMEND provides a unique opportunity to test these factors because treatments are well distributed along the gradient of retention levels. Treatments were located in 10 ha units that were subject to 6 retention levels: 100%, 75%, 50%, 20%, 10%, and 0% (clearcuts). However, in an attempt to match fire skips that occur naturally, all harvested treatments, including the clearcuts, contained two uncut residual islands of green trees, each 0.2 and 0.46 ha. Each harvest treatment (except the 100% and 0% treatment) had leave strips separated by machine corridors. Leave strips had either no harvesting (i.e., in the 75% retention treatment, because the 25% removal came from the machine corridors) or varying degrees of harvesting (e.g., the 50 to 10% retention treatments).

Some studies at EMEND examined all 6 retention levels whereas others studied a reduced set of treatments. Similarly, some studies were designed to examine the effects over the entire 10 ha treatment unit (e.g., boreal forest songbirds; **Harrison 2002**), whereas others focussed on detailed mechanisms within leave strips or machine corridors (e.g., ectomycorrhizal fungi, or bunchberry reproduction; **Martin 2001**). Table 2 provides an abbreviated summary how numerous components of biodiversity responded to treatments at EMEND. Symbols differentiate whether the values refer to leave strips (§) or machine corridors (‡) within treatment units, or whether they apply to the entire 10 ha treatment unit (no symbol). Unless stated otherwise, we use relative abundance to gauge differences among treatments; species richness, reproductive measures, or an index of community similarity (Morisita-Horn [Krebs 1989]) are presented in some instances. Community similarity indices take into account the number of different species and their relative abundance (100% means that two communities have the same number of species and abundances, whereas 0% means that they share no species). Data were obtained from completed graduate student theses or by contacting authors directly when work was still in progress. Relationships in this table can be qualitatively examined for linear or stepwise (i.e., threshold) responses. In the case of forest songbirds, quantitative analyses were done to determine thresholds by formally evaluating competing models using Akaike's Information Criteria (AIC; Table 3). Competing models were designed to evaluate the relative strength of threshold models compared to linear relationships.

Ultimately we are interested in how organisms respond to our attempts to create harvest patterns that resemble natural disturbance patterns. EMEND is an attempt to do so.

EMEND treatments cover a broad range of retention levels, and may be useful to discover "thresholds"

Threshold models were defined as those having a slope that was not constant across the range of retention levels. Threshold models included exponential, exponential to maximum, and logistic growth, whereas simple linear models were considered to lack threshold relationships (Fig. 3). The interpretation of exponential models means that even a small removal of volume (e.g., the 75% retention treatment) has a disproportionately negative effect on a species' relative abundance. Exponential-to-maximum models mean that even a low volume of retention (e.g., 10%) has a strong positive influence on the relative abundance of a given species. We adopted **Jacobs *et al.* (2002)** terminology by calling exponential models "early" thresholds and exponential-to-maximum models "late" thresholds. These models were evaluated for each of the seven foraging and nesting guilds and four forest cover types identified by **Harrison (2002)**. AIC units are useful to evaluate competing models because they help select the most parsimonious model (Burnham and Anderson 1998). Parsimony is a compromise between bias (too few parameters) and variance (too many parameters). More complicated models (e.g. logistic models) require more parameters, and AIC units provide a means of evaluating whether the additional parameter(s) are a meaningful explanation of the data (Burnham and Anderson 1998).

Four types of models were evaluated

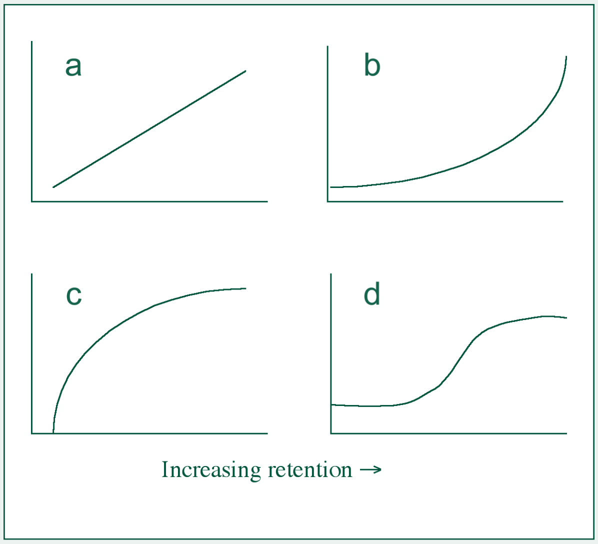

Figure 3. Four models used in the determination of the "best" (most parsimonious) model: a = linear; b = exponential growth (early threshold); c = exponential to maximum (late threshold); d = logistic growth. Models a through c require 2 parameters, whereas model d uses 3 parameters. Models b through d were considered threshold models, whereas model a was not considered to have a threshold. Each model was fit to all bird data sets and assessed for parsimony using AIC (see text).

With higher harvest intensity, shrub cover increased and snag densities decreased

Two years after harvesting, shrub cover (shrubs 50-140 cm tall) was generally higher in the more intensive harvest levels (Table 2). Similarly, downed wood cover was inversely related to the level of harvest. Of course, long-term levels of downed wood (particularly larger pieces) will depend on the level of recruitment from live trees and snags. Predictably, snag densities declined with increasing harvest intensity (Harrison 2002).

Increased light levels from the machine corridors likely caused the higher proportion of flowering bunchberry (Cornus Canadensis) ramets (the clonal portion of some plant species) in the 75% retention treatment (Martin 2001). In contrast, mechanical damage caused by tree removal in the retention strips of the 50% retention treatment probably explains why fewer bunchberry ramets yielded flowers in this treatment. Bunchberry fruit weight was higher in both harvested treatments, probably because of higher light and moisture levels (Martin 2001).

Table 2. Response of various species and guilds to 6 levels of retention (i.e., values are relative to the 100% control column), for some of the components of biodiversity that were examined at EMEND. Different colours represent biologically different results, based on between-treatment variability. Most results are 2-3 years post treatment.

Ecosystem component[1,2]	**% retained**						**Refs**[3]
	0	**10**	**20**	**50**	**75**	**100**	
Shrub cover – Year 2	192	126	90	187	91	100	1
Snag density (mixedwood sites)	0	29	24	47	35	100	1
Downed Wood (% cover)	343	246	380	277	198	100	1
Ectomychrorial fungi, % active root tips‡	19	-	17	29	21	100	2
Ectomychrorial fungi, % active root tips§	19	-	60	60	97	100	2
Bunchberry % ramets with flowers§	-	-	-	69	128	100	3
Bunchberry % stigma covered by pollen§	-	-	-	161	155	100	3
Bunchberry fruit weight§	-	-	-	209	139	100	3
Wolf spiders (Lycosidae; species richness)§	136	100	109	100	109	100	4
Wolf spiders (Lycosidae)§	539	350	295	218	76	100	4
Sheet web spiders (Linyphiidae; species richness)§	67	63	67	76	67	100	4
Sheet web spiders (Linyphiidae)§	15	22	23	26	28	100	4
Saproxyic beetles (species richness)§	-	93	100	93	110	100	4
Saproxyic beetles§	-	19	24	22	41	100	4
Spider community (% similarity to controls)§	20	41	59	66	88	100	4
Ground beetle (Carabid) community (% similarity to controls; deciduous sites)§	66	92	87	92	87	100	4
Wood-dependant beetle (saproxylic) community (% similarity to controls)§	-	42	60	45	55	100	4
Lepidopterans – Noctuidae	-	-	26	45	-	100	5
Lepidopterans – Geometridae	-	-	12	29	-	100	5
Lepidopterans – Uraniidae	-	-	3	12	-	100	5
Foliage foraging birds	2	45	40	59	80	100	1
Ground foraging birds	182	320	230	207	187	100	1
Bark foraging birds	0	75	61	44	61	100	1
Aerial foraging birds	8	37	7	12	16	100	1
Shrub/tree nesting birds	12	52	48	59	78	100	1
Cavity nesting birds	3	70	64	77	84	100	1
Ground nesting birds	77	169	100	105	107	100	1
Swainson's thrush (reproductive rank)	0	8	14	17	17	100	1

[1]Measurements taken from leave strips (§), machine corridors (‡), or across entire 10ha treatment (no symbol). Unless specified otherwise (e.g., Swainson's thrush), values refer to relative abundance.

[2]Bird data averaged across all cover types (except reproductive rank, which was measured only in deciduous/understory stands). Fungi and bunchberry sampling were done only in coniferous types;

[3]References: 1 = Harrison 2002; 2 = Lazaruk 2002; 3 = Martin 2001; 4 = Jacobs et al. 2002; 5 = Morneau 2002.

Soil compaction from harvesting machinery reduced the amount of active ECM fungi

The residual strips of the 75% retention treatment contained the same percentage of Ectomychorrizal (ECM) fungi active root tips as controls because no harvesting takes place in that portion of the 75% treatment unit (Lazaruk 2002)(Table 2; see EMEND study design above). Also, the machine corridors of all retention levels were similar to clearcuts, because all trees were removed from machine corridors (Table 2). On the other hand, machine corridors were within the rooting zone of the adjacent residual strips, so soil compaction from the harvesting machinery likely played a role in the lower levels of active ECM fungi in residual strips. Tree removal in the residual strips also contributed to lower ECM levels (Lazaruk 2002). Despite the absence of trees, clearcut stands contained a small percentage (4% relative to 23% percent in controls) of active ECM root tips. This may have been because they were persisting on carbon reserves in existing roots. Once the reserve strips were harvested (i.e., the 50% and 20% treatments), the percentage of ECM active root tips decreased, although there was no difference between the 50% and 20% retention treatment (Lazaruk 2002).

There was no difference in active ECM fungi between 50% and 20% retention

Wood-dependent beetle communities differed greatly between controls and 75% retention ("early threshold" response)

The diverse group of invertebrates found at EMEND displayed a variety of responses to the harvesting treatments (Table 2). Out of the three Lepidopteran families presented here, the Uraniidae showed the most dramatic decline in abundance (Morneau 2002) (Table 2). Wood-dependent (saproxylic) beetles displayed sharp declines in all cutting treatments three years after harvest. A distinct community shift occurred within this beetle taxon whereby disturbance adapted species replaced forest interior species. Note that the community similarity index, relative to controls, dropped to 55% even at high levels (75%) of retention, meaning that the beetle communities were quite different between those 2 treatments (Table 2). **Jacobs *et al.* (2002)** concluded that dispersed variable retention for forest-interior species was probably not worthwhile because so few of those species remained (three years after harvest), even at high levels of retention.

Wolf spiders benefited from forest harvesting whereas sheet web spiders were negatively impacted

Wolf spiders, active hunters that do not rely on webs for prey capture, were more abundant and diverse with increasing harvest intensity. They were probably responding to a warmer forest floor resulting from increased light penetration. In contrast, sheet web spiders declined in both richness and abundance with increasing harvest intensity. Even in the 75% retention treatment, they were only 28% as abundant relative to unharvested controls (**D. Shorthouse**, University of Alberta, unpubl. data). Sheet web spiders probably declined in harvested sites because of changes to the microclimate resulting from the removal of the forest canopy and reduced litter thickness. The opposite pattern shown by these two groups has been corroborated by other studies (Coyle 1981; McIver et al. 1992; Pajunen et al. 1995). The community similarity of each harvested treatment (relative to controls) decreased linearly with increasing harvest intensity. However, when spiders were examined solely in the uncut residual islands (i.e., aggregated retention, not shown in Table 2) of each treatment, the communities were very similar to uncut controls, particularly when the larger (0.46 ha) island was examined. This suggests that aggregated retention, which tends to maintain a higher proportion of undisturbed forest, is more effective at maintaining the spider communities seen in uncut forests.

Ground (carabid) beetles were less affected by harvest intensity, except in clearcuts, where species composition and relative abundance was quite different from unharvested sites. The authors concluded that this group benefited greatly from even low levels of retention (similar to late threshold models presented above).

Ground beetles benefited from low levels of retention ("late threshold" response)

Bird species with life-history requirements based on open habitats were unaffected or benefited from the harvesting treatments. These species comprised two out of the seven guilds identified in **Harrison (2002)**; those two guilds were ground nesters and ground foragers. This pattern was probably because ground-based species are less reliant on vertical structure for foraging and nesting (Norton and Hannon 1997). Thus, many of their life-history requirements can be met as long as there is adequate understory vegetation such as shrubs or tall forbs. Birds reliant on vertical structure showed negative relationships between volume removed and relative abundance. They included foliage, bark, and aerial foragers, and cavity and shrub/tree nesters. The clearcut treatment (which included two residual islands) seemed incapable of maintaining many groups of forest birds. Bark and foliage-foraging guilds, and cavity nesters were virtually absent from the clearcut treatment. These species all rely on mature cover to fulfill at least one life-history requirement. However, even 10% retention appeared to disproportionately increase the abundance of shrub/tree nesters, foliage foragers, and cavity nesters, by at least a factor of 4 (“late threshold” response). For cavity nesters and foliage foragers, the increase in abundance was by a factor of 23 and 22, respectively (note however that many of these detections were singing males, which may not indicate that mating pairs were residing in these stands; see section below on reproduction as a better indicator than abundance). In the case of bark foragers, there appeared to be little benefit to leaving 75% retention over 20% retention (albeit sample sizes were very limited for this guild). However, scale likely played an important role here, with the surrounding matrix influencing the abundance of these birds, particularly in the low-retention (10 or 20%) treatments.

Birds adapted to open habitats benefited from harvesting

Foliage, bark and aerial foragers, and cavity nesters, were negatively affected by forest harvesting, but low levels of retention benefited some guilds

The results of the threshold analyses revealed that even a small removal of trees resulted in substantial declines for aerial foragers. This pattern is evident from the qualitative presentation in Table 2, and was confirmed by the AIC modelling (Table 3). With all cover types combined, the exponential growth model best explained this guild (i.e., an “early threshold” response; lumping all cover types is appropriate in this case because variance partitioning revealed that retention level explained 40% of the variance, year-to-year variation explained 60% of the variance, and cover type didn’t explain any variance).

Aerial foragers were negatively affected by even a small (25%) level of forest removal

Table 3. Best models and coefficients of determination for each guild and habitat type, for boreal birds studied at EMEND. Data from **Harrison (2002)**.

Guild	Cover type†	Best models‡	R^2
Bark foragers	Deciduous	Linear	0.261
		Exp. growth	0.258
		Exp. to max	0.201
	Mixed	Exp. growth	0.140
		Linear	0.106
	Coniferous	Exp. to max	0.285
	Decid understory	Exp. to max.	0.097
	All combined	Exp. to max (y-int)	0.137
Cavity nesters	Deciduous	Linear	0.250
		Exp. to max	0.244
		Exp. Growth	0.222
	Mixed	Exp. to max	0.174
		Exp. growth	0.138
		Linear	0.120
	Coniferous	Exp. to max	0.473
	Decid understory	Exp. growth	0.042
		Linear	0.041
	All combined	Exp. to max	0.202
Aerial foragers	Deciduous	Exp. Growth	0.759
	Mixed	Exp. to max	0.105
		Exp. growth	0.049
		Linear	0.044
	Coniferous	Linear	0.127
	Decid understory	Exp. to max	0.061
		Linear	0.004
		Exp. Growth	0.000
	All combined	Exp. Growth	0.136
Foliage foragers	Deciduous	Exp. to max	0.753
	Mixed	Exp. growth	0.676
		Linear	0.662
	Coniferous	Exp. to max	0.866
	Decid understory	Linear	0.659
		Exp. Growth	0.650
	All combined	Linear	0.645
Ground foragers	Deciduous	Linear	0.091
	Mixed	Linear	0.268
	Coniferous	Linear	0.086
	Decid understory	Linear	0.286
	All combined	Linear	0.174

Table 3. (Continued)

Guild	Cover type†	Best models‡	R^2
Ground nesters	Deciduous	Exp. growth	0.192
		Linear	0.181
	Mixed	Linear	0.158
	Coniferous	Linear	0.168
	Decid understory	Linear	0.001
		Exp. Growth	0.000
	All combined	Linear	0.004
		Exp. Growth	0.000
Shrub-tree nesters	Deciduous	Linear	0.783
		Exp. Growth	0.777
	Mixed	Linear	0.640
		Exp. Growth	0.618
	Coniferous	Exp. to max	0.878
	Decid understory	Exp. growth	0.549
		Linear	0.540
	All combined	Linear	0.571

†n = 12 for all habitat types, except "All combined" where n = 48.

‡Best models based on lowest AICc score using least squares estimation. All models within 1 AICc value of the best model are listed. "Exp. growth" = exponential growth model (early threshold); "Exp. to max" = exponential growth to maximum model (late threshold); "Exp. to max (y-int)" = exponential growth to maximum model with y-intercept (late threshold).

Overall, 50% of the comparisons (7 guilds x 4 cover types = 28 comparisons) resulted in 'ties' between threshold and non-threshold models, whereas 21% of the cases were best explained by late threshold models, and 25% were linear. Early thresholds models won in one case (4%). If we discount ties by considering only the 'winning' models (models with the lowest AIC score), those numbers shift to 21% for early threshold models, 32% for late threshold models, and 46% for linear models. Thus, roughly one fifth of the guild/cover-type comparisons revealed sharp declines when low volumes of timber were removed and one-third showed marked improvements when only small amounts of timber were retained. The remaining 50% of the comparisons showed relationships that were directly proportional to the amount of timber that was removed.

1/5th of guilds were greatly affected by low levels of removal, whereas 1/3 benefited greatly from low levels (10%) of retention

The highest occurrence of linear relationships were among the ground nesting and ground foraging guilds, whereas guilds that are more reliant on vertical structure (standing live and dead trees; e.g., bark foragers, cavity nesters, aerial foragers) were more likely to show threshold-type relationships. This is an important result because standing live and dead trees are features that are most directly manipulated with forest harvesting. Furthermore, these guilds most often contain species that are of management concern in North American forests (e.g., woodpeckers).

Guilds reliant on vertical structure were most likely to respond in a threshold manner

Reproduction may be a better indicator than abundance

Several authors studying variable retention have correctly pointed out that reproductive parameters may be more sensitive than abundance when gauging the effectiveness of partial-harvesting treatments (Hannah 2000; ***Hannon and McCallum 2002***). For example, **Harrison (2002)** found that even low-volume removals resulted in substantially lower reproductive ranks of Swainson's thrush (Catharus ustulatus), whereas point counts (which only measure abundance) did not reveal significant declines. In each study we reviewed that compared the sensitivity of relative abundance to reproductive parameters, the latter showed greater sensitivity to forest harvesting. In other words, reproductive indices dropped off before abundance indices (Harrison 2002). There is also concern that variable retention stands may act as population sinks (i.e., through mechanisms such as increased nest predation), despite abundance values that portray a more optimistic scenario. Currently, however, there is no strong evidence indicating that reproductive sinks are occurring in partially harvested stands, although this question has not been examined thoroughly (Tittler and Hannon 2000; Stuart-Smith 2001).

There was no optimum retention level at EMEND

The diverse responses shown by different species at EMEND clearly demonstrate that there is no single optimum retention level that is universally best for all species. In their extensive review of how boreal birds respond to forest harvesting, Schieck and Song (2002) note that there were no overall patterns in how birds respond to residual retention - some species responded in a linear fashion whereas others displayed stepwise patterns. At EMEND, groups such as carabid beetles (in the dispersed retention areas), and aerial foraging birds declined sharply even with low levels of wood removal. On the other hand, bark foraging and cavity nesting bird abundances showed strong increases with low levels of retention (10%). The similarity of spider communities to uncut stands showed a linear change (in dispersed retention treatments) with increasing harvest intensity, but interior-associated communities were well maintained even in small residual islands (aggregated retention).

Operational monitoring will help confirm the experimental studies from EMEND

The findings reported here need to be verified with longer-term studies, across larger areas of the boreal forest. Controlled experiments such as EMEND are unlikely to be replicated in the near term. Thus, learning from operational forest activities in an adaptive management context will be necessary to corroborate the findings seen at EMEND. This approach will also provide the benefit of incorporating landscape metrics (i.e., the characteristics of the surrounding forest) into the stand-level responses reported here.

Unmanaged areas are especially important for species that displayed "early" threshold responses

Clearly unmanaged areas are important for some groups of organisms, particularly those that show early threshold responses or those reliant on attributes that are frequently salvage logged or affected by fire suppression. ***Huggard's (2003)*** SFMN document presents a description of the utility of unmanaged areas, how they can be evaluated via an analysis of ecological representation, and how the findings of such an evaluation can be integrated into landscape and stand-level planning. A key point of this report is that instead of trying to determine an often-arbitrary target of how much unmanaged area is enough, any increase is better from a conservation standpoint, but with diminishing marginal values with increasing area. Defining marginal value curves will depend on the natural disturbance regime of a given ecosystem, with more frequently disturbed systems having steeper curves and lower asymptotes. Aside from the difficult task of defining targets or marginal value curves, from a practical standpoint, a representation analysis provides the following direct links to management: guiding where discretionary reserves, conservation or mixed land-use zones should be located; helping to guide the amount and location of stand-level retention, and focusing fine-filter monitoring in under-represented ecosystems (Huggard 2003).

2. Harvest pattern: the Sicamous Creek Silviculture experiment

Most silviculture-wildlife experiments focus on testing the wildlife response to different logging intensities. An exception to this trend is the Sicamous Creek Silvicultural Experiment, located in high-elevation spruce-fir forests of southern BC. The Sicamous project was designed to test the ecological effectiveness of alternatives to clearcuts by holding the volume removed constant and applying 4 different harvest patterns. Each harvesting pattern was based on removing 1/3 of the wood volume in a 30-ha experimental unit. The 4 patterns were a 10-ha clearcut, 1-ha and 0.1-ha patch cut arrays, and uniform individual tree selection (ITS), each replicated 3 times. These respective treatments progress from the most concentrated to the most dispersed cutting pattern. Huggard and Vyse (2002) summarized 22 components of biodiversity including forest structure, birds, small mammals, insects and arthropods (Table 4; 30 other resource values were also summarized, but they are not the focus here; much of this summary is taken from Huggard and Vyse's (2002) review).

The Sicamous creek study examined 4 different harvest patterns (from concentrated to dispersed) by holding the volume of removal (33%) constant

The ITS treatment resulted in very low snag densities and an absence of dense canopy. A dispersed cutting pattern, snag falling guidelines for worker safety and higher rates of windthrow explain these findings. Correspondingly, organisms associated with snags or continuous cover such as woodpeckers, spruce grouse *(Dendragapus canadensis)* and marten (Martes americana) were least abundant in this treatment. Marten were also at low densities in the 10 ha treatment because of the comparatively large area with no forest cover, but they were least affected by the 0.1 ha treatment, presumably because the small openings were positively influenced by cover from adjacent uncut leave strips. Red-backed voles *(Clethrionomys gapperi)* were also least affected by the 0.1 ha treatments.

The dispersed cut pattern resulted in fewer snags and no dense canopy, hence woodpeckers and marten were rare in those treatments

Shrews benefited from most harvesting treatments, although some species were least abundant in the 1 and 10 ha openings. Songbirds that are usually found in older forests were least abundant in the 10-ha and ITS treatments, which correspond to the most concentrated and most dispersed cut pattern, respectively. Ice crawlers (Grylloblatids), a rare subnivean insect, displayed a similar bi-modal distribution, but they actually benefited from the intermediate-sized openings. Ants were much more abundant in all harvested treatments, which could be a concern because they can outcompete many other invertebrate groups (Huggard and Vyse 2002).

Shrews benefited from harvesting; songbirds associated with old forests were least affected by the intermediate cut patterns

Millipedes and slugs were least abundant in the larger openings (10 and 1 ha) and were less affected by the smaller openings. These organisms depend on moist humus layers or rotting wood. Spiders and other hunters were more abundant in all harvested openings, probably responding to the warmer forest floor.

Diverse responses means that it is important to "not do the same thing everywhere"

The diverse response to the harvest treatments is proof that "not doing the same thing everywhere" is an important tenet of forest management (Bunnell 1997; Huggard and Vyse 2002). No single harvest treatment was consistently most effective at mitigating effects of forest harvesting. Although this was an important finding, the research at Sicamous also revealed patterns that went beyond this basic conclusion.

A threshold for opening sizes appeared to be 1 ha: > 1 ha functioned as a clearcut, whereas < 1 ha maintained some interior conditions

One of these patterns had to do with determining a "threshold" for opening sizes: which openings function as clearcuts vs. those that retain components of interior forest conditions? For the 51 resource and biodiversity variables summarized at Sicamous, the 10 ha treatment was the same as the 1 ha treatment in 73% of the cases; whereas, the 10 ha treatments was the same as the 0.1 ha and the ITS treatment in only 34% and 33% of cases, respectively. This is an important result because the implication is that 1 and 10 ha openings are similar ecologically, with the 1 ha opening essentially functioning as a clearcut in most cases. Whereas, openings smaller than 1 ha were more affected by the surrounding leave strips or dispersed trees. Thus, the tendency of reducing clearcut sizes from 40 to 10 ha in some jurisdictions to achieve a perceived ecological benefit may be futile. If the objective is to do "softer forestry" by using smaller openings to benefit a given resource value, then openings smaller than 1 ha are probably more appropriate. An example of this application is in BC, where results from Sicamous and other studies have translated into harvesting guidelines that recommend openings that average 0.5 ha for interior-dependant species such as mountain caribou (Rangifer tarandus) (Armleder and Stevensen 1996).

All else being equal, 0.1 ha openings were "less worse" than uniform individual tree selection for conserving biodiversity values

Another key finding is that specific advantages and disadvantages of different cut patterns are now more clear. For instance, the ITS and the 0.1 ha treatments were the 2 biggest departures from clearcutting attempted at Sicamous. When those 2 treatments were compared, the 0.1 ha treatment was preferred 47% of the time whereas the ITS was preferred in 18% of the cases (the remaining comparisons were tied). Thus, relative to controls, small patch cuts seemed to be "less worse" than uniform thinning (ITS), all else being equal. The ITS fared worse in many ecological comparisons because of higher rates of windthrow, higher snow accumulation, higher rates of snag falling, and lower abundance of species that prefer dense canopies such as spruce grouse or marten.

As with EMEND, the findings at Sicamous should be confirmed in an operational setting

The primary conclusions from the Sicamous trials should be tested in other areas and in other ecosystems. These tests will have to be conducted in an operational setting because similar large-scale silviculture experiments are unlikely to be created in the near future (Huggard and Vyse 2002). Operational tests will also help to determine if conclusions hold in a matrix of intensive forest management because the Sicamous site was surrounded mostly by older forest. Operational adaptive management, with associated monitoring, will be the best way to determine how broadly applicable these results are under different ecosystems and landscape-level intensities of forest harvesting.

Table 4. Some of the components of biodiversity that were examined at the Sicamose Creek silviculture experiment in southern British Columbia. Values are standardized to uncut controls (i.e., 100% retained). Different colours represent biologically different results, based on between-treatment variability. Taken directly from Huggard and Vyse (2002).

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

3. Pattern and intensity: the Opax Mountain Project

In response to concerns over widespread use of uniform stand-level partial cutting (also referred to as ITS in some cases) in the dry Douglas-fir *(Pseudotsuga menziesii)* forests of southern interior BC, and a more general need to test many long-held assumptions about appropriate silviculture systems in these forests, a long-term examination of silvicultural options was initiated 20 km northwest of Kamloops, BC, near Opax Mountain. Treatments (logging) were performed in the winter of 1993-94 with subsequent monitoring of a variety of species and effects (Table 5).

At Opax Mountain, volume and pattern were experimentally varied. Patterns included uniform individual tree selection compared to small patch cuts

Briefly (see Klenner and Vyse 1998 for details), the Opax mountain project is a replicated and randomised-block design used to investigate the relative effects of volume removal and cut pattern using ITS and patch cutting on a wide variety of organisms. Two replicates (treatment units were 20-25 ha blocks) each of 6 treatments were performed as follows: (1) 20% merchantable volume removal using ITS, (2) 50% merchantable volume removal using ITS, (3) 35% merchantable volume removal, consisting of 75% of the treatment unit area harvested as 50% volume removal using ITS, and 25% of the treatment unit area retained as uncut reserves, (4) 20% merchantable volume removal by patch cuts of 0.1, 0.4, and 1.6 ha, (5) 50% merchantable volume removal by patch cuts of 0.1, 0.4, and 1.6 ha, and (6) uncut controls.

For red squirrels, volume was more important than pattern, but patch cuts appeared "less worse" than individual tree selection

Herbers (2000) measured the abundance and survival of red squirrels *(Tamiasciurus hudsonicus)* and found that logging pattern had little influence, but squirrel density declined in a 1:1 relationship with the amount of Douglas-fir trees removed. Red squirrels feed on conifer cones (Smith 1968), which is why they were so closely linked to Douglas-fir abundance. There was some weak indication that ITS was less beneficial to red squirrels than small patch cuts (0.1 and 0.4 ha), which is similar to what was found in other ecosystems (See Sicamous results above). Red squirrel recruitment, survival, weight and proportion of animals in reproductive condition did not appear to be affected by logging (Herbers 2000). This means that remaining individuals in harvested treatments were viable and treatments were probably not acting as population sinks.

50% removal using patch cuts appeared to be a threshold where some small mammals increased and others decreased in abundance

Klenner (1998) measured population density and survival of red-backed voles, deer mice *(Peromyscus maniculatus)*, and meadow voles *(Microtus pennsylvanicus)* within each treatment unit during 1994, 95, and 96. Red-backed voles did not respond significantly to any treatment other than the 50% patch cut removals, where they declined significantly. Deer mice and meadow voles responded in exactly the opposite direction and pattern. These species remained at similar densities and survival rates except in the 50% patch cut removals where dramatic increases occurred. Klenner (1998) attributed this shift in species composition to post-harvest changes in habitat structure and relative food availability for the different species. Red-backed voles feed heavily on fungi and fallen arboreal lichen, which are greatly reduced in openings. Conversely, deer mice are largely granivores (feeding on the seeds of grasses and forbs) and meadow voles are herbivores, feeding primarily on grasses, which tend to increase in openings. Since all treatments (except the 50% patch cut removals) did not elicit small mammal responses, it suggests a rather strong perturbation or threshold (50% clearcut openings) was required to change small mammal abundance.

Klenner (1998) also measured population density and survival of three sciurids at Opax Mountain during 1994, 95, and 96: red squirrels, northern flying squirrels *(Glaucomys sabrinus)*, and yellow-pine chipmunks *(Tamias amoenus)*. Red squirrels demonstrated a linear response to harvest levels with densities declining with increased harvest levels. Flying squirrels responded with a similarly linear decline, but with a stronger and steeper decline with corresponding increases in harvest levels — density decreased to approximately 30% of uncut control areas in the 50% partial cut treatment units. In contrast, chipmunks responded in a positive linear fashion to harvest intensity. Survival of all three species was not affected by treatments indicating that while densities were affected by harvest levels, remaining individuals had similar survival rates. Effects on sciurid densities were explained by Klenner (1998), again based on changes in post-harvest habitat and relative food availability. Red squirrels (that feed on conifer seeds and fungi) and flying squirrels (associated with large snags) are associated with late successional forests while chipmunks are primarily associated with early successional forests dominated by shrubs, forbs, and grasses.

Mule deer preferred uniform thinning over patch cuts, which is unlike most other findings. Their abundance declined linearly with increasing harvest intensity

Huggard and Klenner (1998) reported winter use by mule deer *(Odecoileus hemionus)*, moose *(Alces alces)*, red squirrels, snowshoe hare *(Lepus americanus)*, and ruffed grouse *(Bonasa umbellus)* within the different silvicutural treatments at Opax Mountain during the post-harvest winters of 1994/95, 95/96, and 96/97. Mule deer responded in a relatively linear fashion with decreasing use as harvest levels increased. Highest track densities were observed in the uncut and lightly partially cut treatment units (20% removal), moderate numbers in the heavier ITS cuts, and almost no tracks within patch cut openings. Contrary to many of the findings above, low-volume ITS was "less worse" than low-volume small patch cut removals. As well, they reported lower track densities in leave areas of treatment units compared to uncut and ITS. Huggard and Klenner (1998) attributed this phenomenon to increasing snow depths with higher canopy removals, which results in lower habitat suitability for mule deer. Moose responded similarly with a generally linear response to harvest removals. However, unlike deer, moose used the uncut leave strips as much as the contiguous forest, which means that overall the patch-cut treatments were used more than the high-intensity ITS units. As well, moose strongly avoided 50% patch-cut units and all clear-cut openings. The abundance of red squirrel tracks showed the same pattern of treatment unit effects as the density estimates reported in Klenner (1998, above), except for the 50% ITS with reserve patches, which had more tracks than expected from overall densities. Huggard and Klenner (1998) suggested this might reflect more frequent travel on snow when squirrels move through the open forest between reserve patches. Snowshoe hare were found almost exclusively in uncut areas and never in open clear-cuts. Some use of leave areas within treatment units occurred, but a strong threshold was demonstrated indicating any amount of harvesting resulted in low hare densities. Grouse tracks were rare in clearcut openings and were considerably reduced in the 50% ITS units, and the two patch-cut treatments. However, they were at similar levels in uncut contiguous forest, leave strips, and 20% ITS units. Thus, grouse densities appeared to demonstrate a threshold where beyond 20% ITS removal resulted in low winter grouse densities.

Snowshoe hare were found almost exclusively in uncut areas and never in open clear-cuts; grouse showed similar patterns

Craig (2002) investigated population dynamics of deer mice, meadow voles, long-tailed voles *(Microtus longicaudus)*, and red-backed voles in relation to experimental manipulations of downed wood in uncut versus clear-cut sites at Opax Mountain. She manipulated sites by removing post-harvest downed wood to three treatment densities (low [removed all post-harvest downed wood > 6 cm diameter], medium [no manipulation of post-harvest downed wood], high

Craig (2002) experimentally manipulated downed-wood levels

[existing snags and downed logs retained and evenly distributed across site]). Deer mice densities were higher in clear-cut sites than uncut sites, consistent with Klenner (1998, above). Deer mice, however, did not respond in any consistent way to variations in downed wood density, and more likely responded to differences in ground vegetation within and among sites. On this basis Craig (2002) suggested that downed wood was not a necessary habitat component for deer mice at Opax Mountain. Meadow and long-tailed voles were not captured in sufficient densities to permit discussion of results from uncut sites, again suggesting consistency with Klenner (1998, above). In clear-cut sites, similar to deer mice, meadow and long-trailed voles did not respond in a consistent way to downed wood at Opax Mountain. Here again, Craig (2002) suggested that meadow and long-tailed vole populations were more related to cover availability and vertical shrub structure, rather than downed wood. Red-backed vole populations declined dramatically on clear-cut sites within 2 years post-harvest, again consistent with Klenner (1998, above). Mean population densities within uncut sites tended to be higher on sites with higher amounts of downed wood. On clear-cut sites, higher amounts of downed wood tended to mitigate the effects of canopy removal, especially immediately following harvesting. These results lead Craig (2002) to suggest that downed wood is important to red-backed vole populations, but their relationship with downed wood varies depending on the ecosystem type and other habitat attributes present. Unfortunately due to the extreme difficulty in isolating effects of downed wood on population response, Craig's (2002) results do not present clear empirical relationships in the form of threshold curves pertaining to downed wood densities and small mammals.

Table 5. Relative effects from six silviculture treatments on relative population indices of mammals at the Opax Mountain research site. 1 = highest relative density, 6 = lowest relative density.Source

Species	Treatment†						Source
	Uncut control	0% ITS	20% PC	50% ITS with res	0% ITS	0% PC	
Red squirrel	1	2	2	3	4	4	Herbers 2000
Flying squirrel	1	2	2	3	4	4	Klenner 1998b
Red-backed vole	1	1	1	1	1	2	Klenner 1998
Deer mice, Meadow vole	2	2	2	2	2	1	Klenner 1998
Yellow-pine chipmunk	4	3	3	2	1	1	Klenner 1998
Mule deer	1	2	3	-	4	5	Huggard and Klenner 1998
Moose	1	2	3	6	5	4	Huggard and Klenner 1998
Snowshoe hare	1	3	3	3	3	2	Huggard and Klenner 1998
Grouse	1	2	3	-	3	3	Huggard and Klenner 1998

†Treatments described by Klenner and Vyse (1998). ITS = individual tree selection, PC = patch cut, ITS with res = individual tree selection with reserve, 20 and 50% refer to volume removal.

4. Other variable retention studies

While variable retention is performed operationally by most licensees across Canada (e.g., Crosina and Morgantini 2003; see **Sougavinski and Doyon 2002** for review), our focus for the purposes of this document was empirical research, rather than operational practices. The following section summarizes other studies that are relevant to the variable retention.

BC's dry fire-driven systems

Small mammals

Sullivan and colleagues studied small mammal responses to variable retention and intensive silviculture (thinning and spacing) treatments

In response to the dearth of studies using experimental manipulations to measure small mammal response to alteration of habitat structure in managed forests, Tom Sullivan and colleagues have been measuring long-term small mammal population response to a variety of silviculture treatments in the dry forests of south-central BC since the late 1980s. His research focussed on different levels of variable retention harvest of mature forests, and intensive management practices (thinning and spacing) of young forests to try and accelerate "mature" forest characteristics.

Red-backed vole abundance was 3-7 times higher in old-growth sites; richness was highest in seed-tree sites

Sullivan *et al.* (2000) investigated the relationships between stand-structure diversity and small mammal populations among young, seed tree, and old-growth lodgepole pine *(Pinus contorta)* forests near Summerland, BC. The study was an experimental randomized-block design with three replicate blocks of young pine (17 yrs old), seed tree (young pine with residual mature Douglas-fir up to a maximum of approximately 100 mature trees/ha), and old forest (mix of Douglas-fir, lodgepole pine, subalpine fir [Abies lasiocarpa], and spruce from 70 to 133 yrs old). Mean annual abundance of red-backed voles was consistently between 3.1 and 7.3 times higher in old-growth than in young pine and seed tree sites; similar abundances of red-backed voles were found between young forest and seed tree units. Deer mice numbers were similar in all stand types, as predicted by their generalist habitat affinities. Northwest chipmunks (Tamias amoenus) were most abundant in the young pine and seed tree units, and highest in the seed tree. Interestingly, small mammal species richness and diversity tended to be highest in the seed tree sites followed by the young forests and lowest in old-growth units. Old stands contained primarily red-backed voles and deer mice, while seed tree stands contained up to 10 species including the heather vole (Phenacomys intermedius) and western jumping mouse *(Zapus monticolus)*, both of which were considered uncommon in this area, suggesting that the presence of seed trees in young forests contributed to higher species richness. Interesting as well, no small mammal species occurred only in old-growth forests.

Structure and small mammals were compared among clear-cut, single seed-tree, group seed-tree, patch-cut, and uncut forests

Sullivan *et al.* (2001a) and Sullivan and Sullivan (2001) investigated the effects of variable retention silviculture systems in the mixed Douglas-fir and lodgepole pine forests in south-central British Columbia (near Summerland) on post-harvest stand structure diversity and small mammal populations. They measured post-harvest (for 4 yrs following harvest) stand structure attributes and small mammals within three replicates of the following five treatments listed in increasing order of retention: (1) clear-cut, (2) single seed-tree, (3) group seed-tree, (4) patch-cut, and (5) uncut forest. In all cases, Douglas-fir was left as residual trees on harvested sites, with most lodgepole pine and spruce removed. Single seed-tree units resulted in average residual stem densities of 9.0 stems/ha; group seed-tree units resulted in average residual stem densities of 16.3 stems/ha. Patch cut units averaged residual retention of 34.1 % canopy cover, where openings were 0.5 to 0.7 ha. Structurally, the abundance and diversity of herbs and shrubs was similar among treatments and increased significantly with time, although differences in species presence occurred. Species richness and diversity of trees was highest in uncut forests. The most significant difference among the treatments with variable retention was spatial pattern of residual trees with individual seed-tree representing a dispersed pattern, and group seed-tree sites an aggregated pattern.

In terms of vertebrate response to the above treatments, Sullivan and Sullivan (2001) reported results for 10 species of small mammals. They stated that this level of faunal diversity precluded generalizations regarding small mammal response to variable retention harvesting, but rather, responses must be considered on a species or species-group level. Voles of the genus *microtus* clearly preferred open homogenous habitats generated by clear-cutting (abundance = 11.3/ha) and seed-tree harvest (6.0/ha) methods, compared to the more closed-canopy treatments of group seed-tree (3.9/ha), patch-cutting (1.8/ha), and uncut forest (0.1/ha). Conversely red-backed voles were most abundant in group seed-tree (abundance = 10.0/ha), patch-cuts (6.4/ha), and uncut forests (16.2/ha). On this evidence they concluded that the abundance of *microtus* will be linearly and inversely related to, and abundance of red-back voles linearly and positively related to, basal areas and density of residual trees. Several other habitat variables were investigated but only percentage ground cover and crown volume index of residual trees showed linear relationships similar to basal area. Deer mice were common within all harvested sites, with the highest numbers reached in clear-cuts, and the lowest numbers in uncut areas. Northwestern chipmunks, montane shrews *(Sorex monticolus)*, and long-tailed voles were all habitat generalists with respect to harvested sites. Meadow voles were found in all harvested sites but displayed a clear preference for clear-cut sites.

Red-backed voles were the major species occupying uncut forests in Sullivan and Sullivan (2001) and were greatly reduced in all harvest units (clear-cut = 61% reduction; single-tree = 77%; patch-cut = 63%), but less so in group seed-tree (31%). A significant conclusion offered by Sullivan and Sullivan (2001) is that the group seed-tree harvest method may provide islands of mature forest habitat that allow red-backed voles to persist for a longer period post-harvest than on clear-cut and single seed-tree sites.

Sullivan and Klenner (2000) tested the hypothesis that large-scale habitat alteration by stand thinning over a range of densities would increase abundances (and related population dynamics) of northwestern chipmunks in regenerating lodgepole pine forests near Penticton, Kamloops, and Prince George, BC. Using a replicated block design, they measured chipmunk abundance and survival for three years following pre-commercial thinning of young lodgepole pine stands (17-24-yrs old). Three replicates at each of three sites were thinned to densities of approximately 500, 1000, and 2000 stems/ha. As well, an unthinned young stand and an old-growth pine stand were used as controls at each site. This design attempted to determine if thinning could increase animal diversity and abundance, and to try and accelerate "mature-old" forest characteristics. As predicted from chipmunk natural history (a preference for open stands), chipmunk density and survival were inversely related to stem density. The relationship appeared to be linear with no obvious thresholds.

In another study, Sullivan and colleagues experimentally thinned regenerating lodgepole pine stands

Thinning young pine stands greatly improved habitat for red-backed voles, but they were at lower densities than old-growth forests

Microtus voles preferred open habitats whereas red-backed voles were more abundant in uncut forests, small patch cuts, and aggregated retention

Stuart-Smith (2001) compared songbird communities in burned and logged stands with a variety of post-burn residual and post-harvest retention levels.

Generally, songbird communities in young burned and logged stands were similar; However, recently burned sites contained more large snag-users than recently logged sites

At the same study sites just described, (Sullivan *et al.* 2001b) investigated 10-yr post-thinning response of stand structure and small mammal communities immediately following pre-commercial thinning, and then again 7-10 years later. Although red-backed voles are considered to be good indicators of late successional forests, in some years their abundance was similar between thinned young stands and old growth; therefore indicating that even thinned young stands provided habitat for red-backed voles. Overall however, thinned stands did not support the high population densities found in the old growth forests (OG densities = 11.78/ha; thinned = 6.85/ha - 7.50/ha). Higher species richness and diversity of small mammals appeared consistent in heavily thinned stands, similar to results of Sullivan and Sullivan (2001). Sullivan et al. (2001b) attribute this to the mix of habitats (open and closed) provided by young thinned pine stands, which provides habitat for a variety of small mammals including Microtus and heather voles which typically prefer more open conditions not found in mature forests. Further, they suggest that thinning of young pine stands accelerates the successional process of natural stand thinning and approximates understory old-growth conditions earlier than a more natural successional pathway. Thinning provides a management tool for enhancing understory small mammal diversity and other understory communities.

Songbirds

Stuart-Smith (2001) studied songbird communities in burned and logged stands with variable tree retention in the Canadian Rocky Mountains in and around Kootenay National Park and the Whiteswan Lake area. She randomly selected 176 point count stations in logged and burned stands, stratified by age class (5-15, 16-30, and 31-45 yrs since disturbance) and disturbance severity (0-10, 10-25, 25-50, and >50% cover of residual trees). Lower elevation sites were dominated by mixes of dry Douglas-fir, white spruce, and western larch (*Larix occidentalis*; hereafter referred to as montane spruce [MS] forests). Higher elevation sites were mixes of Engelmann spruce and subalpine fir (ESSF forests).

Stuart-Smith's results demonstrated that although some species responded somewhat differently to each disturbance type, in general songbird communities in young burned and logged stands were similar (based on similar dominant species, evenness, and diversity measures). However, logged stands had higher mean richness and abundance than burned stands. Stuart-Smith (2001) attributed this to differences in vegetation between the two disturbance types, with logged stands having greater shrub cover and richness, greater basal area of broadleaf trees, generally fewer regenerating trees, and more vertical structure. Shrubs and broadleaf trees are well known as key structural attributes influencing the richness and abundance of forest vertebrates in the Pacific Northwest. One caveat however, is that considering only recently disturbed stands (<5 yrs), more bird species that used large snags (nesting, foraging) were found in burned sites versus logged sites, and that open-country birds were more abundant in logged sites. Strong convergence through time in bird communities occurred in the ESSF and was attributed to snag falling and tree growth that made clear-cuts (the predominant silviculture system used in the ESSF sites) and burns more similar through time.

This phenomenon, however, was not observed in the MS where variable retention logging had produced more complex stand structures.

Bird abundance increased with increasing residual-tree density, particularly with broadleaf trees

In the MS, there was strong association between density of residual trees and bird abundance. The most consistent association was with broadleaf trees, which was positive for all species with one exception (yellow-rumped warbler [*Denroica coronata*]). Species strongly associated with broadleafed trees included black-capped chickadee *(Parus atricapillus)*, dusky flycatcher *(Empidonax oberholseri)*, warbling vireo *(Vireo gilvus)*, and red-naped sapsucker *(Sphyrapicus nuchalis)*. Broadleaf trees were also the only residual trees to significantly influence overall bird richness and abundance. Residual coniferous trees were strongly associated with 16 of 24 species, however, seven of these species relationships were negative (i.e., higher residual coniferous tree density resulted in lower bird abundances), and were generally species that feed or nest on or near the ground in open habitats (e.g., dark-eyed junco [*Junco hyemalis*], American robin [*Turdus migratorius*], MacGillivray's warbler [*Oporornis tolmiei*]). Species with the strongest positive responses to residual coniferous trees were a mix of those preferring open forest stands with large canopy trees (e.g., western tanager [*Piranga ludoviciana*] and Cassin's vireo [*Vireo cassinii*]), and those preferring older closed-canopy forests (Townsend's warbler [*Dendroica townsendi*] and golden-crowned kinglet [*Regulus satrapa*]). Although residual coniferous trees were important stand attributes to fewer bird species in the ESSF, all significant associations were positive.

Some species benefited from residual conifers whereas others did not; however, retention of broadleaf trees consistently increased the abundance of all birds

Stuart-Smith (2001) clearly showed that residual trees had a strong influence on post-harvest bird communities. Unfortunately, data were not presented illustrating the relationships between residual tree density and bird abundance, and therefore precludes discussion of thresholds and other subtleties in the data. However, as pointed out, no single silvicultural treatment or management regime will provide good habitat for all species of forest birds everywhere. Some species were positively associated with residual tree density, others negatively, indicating that a range of residual tree densities is required to maintain species communities. One exception is clear though: all relationships with residual broadleaf trees were positive suggesting that retention of broadleaf trees can be considered universally good. As well, retaining coniferous trees in ESSF forests should universally increase songbird richness and abundance (i.e., no negative relationships were recorded). In MS forests however, responses to residual coniferous trees were mixed and therefore indicates a range of residual coniferous trees should be prescribed on a landscape basis.

BC's wet-belt systems

Winter-resident birds

A study in wet-belt forest compared dispersed and aggregated retention to naturally disturbed, clearcut, and unharvested stands

In the interior wet-belt of BC, Serrouya et al. (2003) compared the benefits of aggregated and dispersed retention (average of 13% retention, range 3-25%) to clearcuts, naturally disturbed (bark-beetle) stands and unharvested stands. Fires in this zone are less frequent than other areas of the BC interior, and dominant trees include western redcedar *(Thuja plicata)*, hemlock *(Tsuga heterophylla)*, and Douglas-fir. The study focussed on non-migratory birds in winter (January to mid-March). This season was chosen because birds depend almost exclusively on trees and snags to meet their daily requirements. Further, ecological confounders that can lead to misinterpretations of abundance estimates (i.e., see Van Horne [1983]) are less likely to occur because territorial behaviour is less pronounced and "transient" detections (e.g., vertical migrations) occur less, hence the species present in the stand are more likely a direct reflection of the habitat quality.

11 out of 12 species absent from clearcuts were present in variable retention treatments

Similar to Norton and Hannon (1997), variable retention sites were intermediate between clearcuts and unharvested controls in terms of relative abundance and species richness. Eleven out of the 12 species that were absent from clearcut sites were present in variable retention treatments. Relative to unharvested sites, stands with dispersed retention had slightly higher community similarity than those with aggregated retention (48% vs 46%, respectively). Black-capped chickadees, mountain chickadees *(Poecile gambeli)*, hairy woodpeckers *(Picoides villosus)*, and three-toed woodpeckers *(Picoides tridactylus)* were more abundant in dispersed sites than those with aggregated retention. Most other studies we reviewed found the opposite trend - aggregated or "mixed" retention (mix of individual tree and aggregated patches) was more beneficial to forest birds. Serrouya *et al.* (2003) speculated that in winter, some smaller bird species avoid flying across larger open areas, which may explain higher abundances in dispersed retention sites that are characterized by more evenly distributed trees.

Bark-beetle infested stands were most similar to dispersed retention and least similar to unharvested stands. However, white-winged crossbills *(Loxia leucoptera)* were present in beetle stands but absent from both partial-harvesting treatments. Pine Grosbeaks *(Pinicola enucleator)* and brown creepers *(Certhia familiaris)* were also much less abundant in partial-harvested stands compared to beetle-infested stands. Thus, Serrouya et al. (2003) suggested that partial harvesting, rather than being designed solely to approximate natural disturbance, be incorporated into the range of planning tools that can be used to enhance habitat attributes that are difficult to maintain in the intensively managed landbase.

Coastal BC: birds, gastropods, and amphibians

Weyerhaeuser BC is engaged in variable retention pilot studies on its coastal tenure that are designed to evaluate the sensitivity of selected organisms to different harvesting treatments (Bunnell *et al.* 2003). Evaluation criteria include adequate sampling precision to detect trends over time and among treatments, sensitivity to forest practices, and cost effectiveness. Candidate organisms were selected to include those that disperse slowly and quickly, those with high and low reproductive rates, and those that have small to large home ranges. In addition to monitoring organisms, structural measurements are being done to compare the relative benefits of dispersed vs. aggregated retention for key habitat elements such as large live trees, snags, downed wood, and shrubs. Both operational (retrospective) and prospective experimental variable retention treatments are being examined, although most of the data collected thus far at the experimental sites has been pre-harvest. Experimental treatments include varying harvest pattern (dispersed, aggregated, and mixed retention [clusters of trees and some occurring individually]) while holding volume constant, or holding pattern constant while retaining different volumes. Each treatment unit is being replicated three times. Organisms that are being investigated in pilot studies include birds (in variable retention blocks and across the entire tenure), gastropods, aquatic amphibians, frog movements, mosses, lichens, squirrels, canopy epiphytes, carabid beetles, and mycorrhizal fungi.

Researchers in coastal BC are studying the response of birds, gastropods, aquatic amphibians, frog movements, mosses, lichens, squirrels, canopy epiphytes, carabid beetles, and mycorrhizal fungi to VR treatments

The vegetation response two years after harvesting showed no measurable edge effects across the gradient of retention patches to cutover areas, meaning that many small patches would retain similar habitat elements as one larger patch (Huggard 2002). Over time, however, edge effects are expected to increase as plant regeneration occurs. Dispersed retention treatments contained trees with larger average DBH, but fewer snags, and fewer overall levels of live trees relative to aggregated retention. Lower snag densities were a function of worker safety requirements, which can require the removal of snags and other dangerous trees in work areas (Huggard 2002).

Early results from retrospective operational bird monitoring programs indicated that for a given volume of retention, bird communities in the aggregated retention treatment were more similar to unharvested controls than either dispersed or mixed retention treatments (Chan-McLeod and Bunnell 2002). However, overall retention level appeared more important than the pattern of retention, at least in the short post-logging time frame of this evaluation. Retention levels ranged from 6 to 30% (mean retention was 15%, SE=1.6, n=19 stands). Variable retention treatments contained all the species that were present in control stands (64 species total), whereas clearcuts only contained 6 species.

Bird communities in stands with aggregated retention were more similar to controls than stands with dispersed retention

Gastropods and plethodontid (lungless) salamanders were studied to determine their suitability as indicators of forest floor conditions associated with variable retention logging. Both groups were chosen as potential indicators of environmental change because of their sensitivity to moisture and relatively stable populations (Gibbs *et al.* 1998). Comparisons were made at operational sites

Snails were less common in logged areas and in the retention patches.

between unharvested and variable-retention harvested sites, with distinctions made between the actual retention patches and the surrounding logged area. Most retention patches were 0.2 to 0.8 ha in size. Two gastropods, the Pacific sideband *(Monadenia fidelis)* and the western thorn, *(Carychium occidentale)*, were found only in control stands, but overall they were caught infrequently. Both gastropods are usually associated with moist, mull-type litter (Cameron 1986). The northwest striate *(Striatura pugetensis)* appeared to benefit from logging treatments, perhaps responding to increased cover of herbaceous vegetation. Three snail groups, the western flat whorl *(Planogyra clappi)*, toothless column *(Columella edentula)*, and vertigos *(Vertigo species)* were less common in logged habitats, both in the aggregated retention patches and the surrounding logged matrix. The western flat whorl has a relatively high association with moist conditions, which may be why they did not fair well in logged blocks (Ovaska and Sopuck 2001). The authors suggest that this abundant species may be a good indicator of forest floor conditions because of their sensitivity to moisture (Ovaska and Sopuck 2002).

Western red-backed salamanders were found within retention patches at similar levels as uncut forests, suggesting a positive lifeboating function

The abundance of western-red-backed salamanders *(Plethodon vehiculum)* were similar in control sites to within the actual retention patches (surrounded by a logged matrix), but were less abundant or absent in the surrounding logged matrix (Ovaska and Sopuck 2002). This pattern was matched by Pacific banana slugs *(Ariolimax columbianus)* and Northwest Hesperians *(Vespericola columbianus)*. Pacific banana slugs are an important species because they consume live and decaying vegetation, thereby facilitating nutrient cycling on the forest floor. In some cases, banana slugs were more abundant in variable retention patches than in control sites, possibly because some individuals moved into these undisturbed patches from adjacent logged areas; for these species, the “life-boating” function of retention patches appeared to be occurring, at least in the short-term (2-yr post harvest; Ovaska and Sopuck 2002). These small, sessile organisms provide an interesting scale of examination for evaluating the success of “life-boating”. Some of them appear to have similar abundances within retention patches compared to unlogged forests, whereas others (such as the snail groups) were less common in the logged matrix and within the actual retention patches. Understanding the natural history of these organisms will probably reveal why they responded in such opposing manners.

Key findings and implementation

Rationales for using VR

The current research provides three rationales for implementing variable retention. The first is simply to increase stand complexity relative to clearcuts, making use of landscape-level context (i.e., ecological representation) to guide stand-level retention. The second rationale is to emulate natural disturbance patterns by implementing green-tree retention levels based on patterns and amounts of post-fire residuals. Finally, meeting the requirements of indicator species (umbrellas or keystones) to guide retention levels was the third rationale presented.

Integrating ecological representation with natural disturbance-based management

The rationales for VR presented above are not mutually exclusive. For example, both the natural disturbance template and ecological representation are coarse filter concepts that seek to account for unknown species and processes that cannot be managed individually. Because of these shared concepts, there are ample opportunities for integrating fire-based green-tree retention with ecological representation. Integration is necessary because an obvious shortcoming of basing stand-level harvesting patterns (i.e., green-tree retention) on post-fire residuals is the much lower snag abundance following harvest relative to fires (Schieck and Song 2002). A mechanism to help account for this difference is by nesting fire-based management (i.e., stand-level green tree retention) within a framework of representative unmanaged areas. That way, in the managed landbase, some aspects of natural disturbances (i.e., green-tree retention levels and patterns based on fire patterns) could be implemented, which will account for some ecosystems processes. However, because we can never be sure how well our attempts to resemble natural disturbance are accounting for unknown ecological processes, the representative unmanaged areas would act at a coarser level than the natural disturbance template, allowing for processes such as succession or natural disturbances to occur, free from interventions such as salvage logging.

The major objective of doing a landscape-level representation analysis is not to reach an arbitrary target, but rather to highlight weaknesses and provide opportunities for improved representation. This way, discretionary reserves (e.g., old-growth management zones or species-specific constraints such as caribou management areas) could be focussed in underrepresented systems, and potentially increase the contribution of unmanaged areas. Marginally operable areas could also contribute to the unmanaged landbase. An example of marginally operable areas include upland habitats that are difficult to access because they are surrounded by lowland inoperable ground. Consideration could be given to include these areas in the unmanaged landbase because the economic costs of doing so would be less than constraining easily accessible upland areas.

These unmanaged areas would serve the dual goal of continuing to recruit deadwood into the system, and when those areas burn, they will provide a source of fire-origin snags for the species that depend on them. Then, within the managed landbase, green-tree retention strategies that use fire pattern as a guide could be implemented. Thus, the managed landbase that uses fire pattern as a guide (which is often referred to as a coarse filter) would be nested within a "coarser" level strategy of ecological representation.

The approach presented here has similarities with Schieck and Song's (2002) suggestion of retaining a portion ((3%) of each landscape as burned forest that is not salvaged. In other words, they recommend salvage logging only when at least 3% of a management unit is burned and left unsalvaged (other useful implementation guidelines are provided on p. 9-43 to 9-44 of their document).

Post-fire residuals

The occurrence of post-fire residuals were summarized to provide a guide to those desiring to use natural disturbance as a template for green-tree retention strategies. Although information was limited, we provided summaries from 6 different studies in 4 different provinces and provided broad targets for post-fire residual proportions and patterns. We found that retention levels varied from 1% in boreal Quebec to 13% in southeastern BC. However, these numbers do not include unburned peninsular areas that often extend into burned zones. The size-class of retention patches was also summarized when those data were available (Fig. 2). Extrapolating results from different ecosystems (even within Canada's boreal) is not recommended because variability is very high both within and especially between ecosystems where different cover types, fire patterns and fire intensities exist **(Bergeron et al. 2002)**.

Biotic response to green-tree retention

We examined several experimental and operational responses by organisms to different volumes and patterns of green-tree retention. EMEND is a harvesting experiment that attempts to quantify the response of organisms to green-tree residuals. Some species appeared to remain at high abundances until most of the trees were harvested, whereas others dropped off sharply even with high levels of retention. Songbirds reliant on vertical structure were most likely to show threshold response, with tree nesters, foliage foragers, and cavity nesters benefiting disproportionately from low levels (10%) of retention (i.e., late threshold response). In contrast, aerial foragers were disproportionately impacted from low levels of removal (25%; early threshold). In other study areas, threshold responses were also displayed by flying squirrels (late threshold) and amphibians (early threshold). In contrast, red squirrels displayed a 1:1 relationship between harvesting intensity and abundance (Herbers 2000). Clearly, unmanaged areas will play a role for some groups of species, particularly those that display "early" threshold responses (e.g., Tittler *et al.* 2001). ***Huggard (2003)*** provides a means of assessing the contribution of unmanaged areas and incorporating them into landscape-level planning.

The Sicamous Creek Silviculture Systems Study demonstrated that there was no optimal harvesting pattern that was universally best for all species. Organisms responded differently to different harvesting patterns - some preferred dispersed cut patterns whereas others preferred concentrated cut patterns. The main message from this work is to "not do the same thing everywhere." Beyond this, we also learned that 0.1 ha openings were preferred over uniform individual tree selection (volume removed was equal). Finally, there appeared to be a threshold whereby openings 1 ha and larger were functionally equivalent and acted as clearcuts, whereas openings less than 1 ha provided a different set of ecological conditions. We also learned more specifics about how individual species respond to alternative harvest patterns.[2]

[2]"Alternative harvest patterns" mean alternative relative to clearcuts

From the studies reviewed, there appeared to be little evidence that variable retention stands were acting as population sinks. That is, the remaining individuals (albeit often at lower abundances) had similar reproductive and survival rates as control sites (Klenner 1998; Herbers 2000; Tittler and Hannon 2000; Stuart-Smith 2001). However, few studies have examined this question in detail hence it remains a concern.

Operational monitoring

For controlled experiments like EMEND, Sicamous, and Opax, strict replication is unlikely to occur in the future. Key findings from these studies should be seized upon by operational managers and researchers, to see if the results hold at larger scales or across different areas. This may require retrospective sampling, as well as actively designing operational harvesting to validate some of the more important findings. Whether the studies are experimental or operational, long-term monitoring will be required.

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TAKE-HOME POINTS

- Rationale for using variable retention

  - ✓ increase structural complexity
  - ✓ emulate natural disturbance
  - ✓ meet requirements of indicator species

- Landscape-level context (e.g., under-represented ecosystems) can help focus where higher amounts of stand-level retention should occur

  Step 1. Landscape scale ecological representation
  Step 2. Stand-level variable retention

- Post-fire residuals: what can we use?

  - ✓ Ranges from 1% in boreal Quebec to 13% in SE British Columbia

- Biotic responses to green-tree retention: what can we use?

  - ✓ Songbirds reliant on vertical structure (e.g., cavity/tree nesters, foliage foragers) disproportionately benefit from even 10% retention
  - ✓ But, aerial foraging songbirds disproportionately impacted by even 25% removal
  - ✓ Thus, "representative" unmanaged areas are important, especially for more sensitive "early threshold" species
  - ✓ Some species (e.g., red squirrels) decline linearly with volume removal
  - ✓ Others (e.g., chipmunks) increase linearly with volume removal
  - ✓ Some small organisms (salamanders, slugs, spiders, beetles) were well accommodated in aggregated retention (0.3 – 0. 8 ha patches)
  - ✓ Uniform thinning is generally less beneficial than small (<1 ha) patch cuts
  - ✓ Openings larger than 1 ha function as clearcuts; smaller openings retain some interior conditions
  - ✓ Some components benefit from smaller openings, but others preferred concentrated disturbance: **Don t do the same thing everywhere!**

- Test key findings using operational forestry, across other ecosystems

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