SUSTAINABLE FOREST MANAGEMENT NETWORK
RÉSEAU DE GESTION DURABLE DES FORÊTS
Networks of Centres of Excellence
Réseaux de centres d'excellence

Variable Retention: Research Findings, Trial Implementation and Operational Issues

(Final Version)

By:

Sylvie Sougavinski, Biologist

Frédérik Doyon, For. Eng., Ph. D.

Institut Québécois d'Aménagement de la Forêt Feuillue

April 2002

Technical Summary

Conventional harvesting practices such as clearcutting are no longer meeting growing social and environmental demands for forest-biodiversity maintenance. Studies have demonstrated that, with respect to several ecological processes, after natural disturbances such as fire, windthrow and insect infestations, residual stands demonstrate greater resilience than they do after harvesting. An alternative to traditional cutting would thus be to preserve essential structural elements (live or dead single trees or clumps of trees, woody debris, etc.) after harvesting in order to emulate such disturbances. This method, called variable retention, should make it possible to maintain substantial output without threatening forest biological integrity. In this paper, we will summarize the information available on this new approach.

1) What is Variable Retention?

Variable retention is a silvicultural system that maintains habitat structural elements inside the cutblock. These elements may be trees (live or dead) woody debris, or any other element deemed vital to proper ecosystem functioning. Generally speaking, however, variable retention involves retaining a minimum of the stand's original canopy cover (between 10% and 70%). The residual structural elements must remain on the cutting area for at least one complete rotation; the treatment is applied to final harvests in stands that have reached their economic or biological maturity.

Variable retention differs from traditional silvicultural systems in that the focus is on what is retained rather than on what is cut, and regeneration is not the primary objective.

2) What are the Advantages of Variable Retention?

The potential advantages of variable retention involve a number of ecological processes, such as the beneficial effect of enriched second-growth stand structural diversity on biological diversity and increased ecological-niche variability. The habitats created may serve as source habitats or temporary shelter, or become stepping-stones and help increase inter-habitat connectivity and facilitate species dispersion.

The literature indicates that there is a positive relationship between cutblock biodiversity and the quantity of structural elements retained. Plant communities (understory, mosses, and lichens) and wildlife communities (birds, small mammals, and micro-arthropods) are more like those found in continuous old-growth forests when more structures are retained. This increased diversity also seems related to the fact that variable-retention cutblocks contain species that prefer open environments (e.g.: after clearcutting) as well as those that seek out cover (e.g.: in a mature forest). At the same time, however, structural retention may prove detrimental to certain organisms by creating conditions favourable to predation.

Practices associated with variable retention also make it possible to more rapidly re-establish important stand ecosystem functions (succession, productivity, and water, element and energy cycling). They create a range of micro-climatic conditions that are often more beneficial to the establishment and survival of partially or completely immobile organisms. The cover maintained has a direct effect on hydrometeorological processes, owing to energy-balance changes. Furthermore, variable retention reduces erosion by maintaining a root structure that in turn keeps mineral and organic soil in place. It enhances ecosystem productivity by maintaining shelter (inocula) for mycorrhizal fungi and nitrogen-fixing bacteria. Lastly, quality live residual trees increase the environment's natural seeding capacity, thus preserving genetic diversity.

Variable retention can also have certain social advantages, including public perceptions that harvesting operations are being managed with a view to ensuring forest esthetics and proper stewardship, as well as empowering and recognizing forest workers. On the other hand, the structures left standing may constitute a higher risk for workers during harvesting and subsequent operations.

It is likely, however, that timber potential will decline, given that part of the harvest is left on the cutblocks and that the productivity of regenerating cohorts is reduced because of the shading and competition for resources produced by retained trees. Moreover, retention results in operational difficulties for crop-production treatments for young stands (soil scarification, aerial spraying, etc.). On the other hand, the increased economic value of the logs from retained trees harvested during the second rotation may offset these initial losses.

Variable retention modifies the composition of developing stands. Contrary to pioneer species, shade-tolerant and inner-forest species both benefit from this approach because of the shade created, the reduction in soil disturbances, and the understory vegetation. These tolerant species generally grow more slowly than pioneer species, thus affecting potential.

Variable retention also involves additional costs, which stem from the need for more complex planning, essential training for forest workers, increased supervision during operations, and changes to traditional harvesting methods.

3) How is Variable Retention Implemented?

Before variable retention is implemented, the following questions must be answered: What should be retained (i.e., what elements, with what characteristics)? How much should be retained? What spatial pattern should be selected?

A large variety of structures can be maintained on cutblocks in order to meet biodiversity conservation requirements:

- live trees that provide habitats for several different organisms and constitute a source of snags and woody debris;
- snags in various stages of decay that constitute important shelter, reproduction and feeding sites for many animal species;

- coarse woody debris that provides cover, microclimates and suitable reproduction sites;
- understory patches (shrubs, herbs, and mosses) that influence geomorphic processes such as erosion and sediment retention, thus playing a major role in supplying habitats;
- protection for soil characteristics that influence vegetation dynamics.

The choice of elements to be retained will depend on their characteristics (species, size, dbh, stability, safety, stage, cavities) and management goals. Guidelines may be developed to maintain quality habitats for a given species or to maintain biodiversity in general; they may also be developed from a broader perspective of coarse-grain ecosystem management. Although this difference is reflected in element selection, number and distribution, guidelines must still be adapted to the specific characteristics of each managed forest.

The density and distribution of the structural elements retained may vary, depending on whether the desired outcome is dispersed or aggregate retention. Whereas dispersed retention provides the entire site with structural complexity and has a greater influence (positive and/or negative) over the cutting area, aggregate retention allows more forest-ecosystem components to be retained, and makes it easier to practise multiple- or subsequent-intervention silviculture. Patches are particularly useful for the safe retention of unstable snags and trees, and limit the risks of windthrow. Aggregate retention can also facilitate harvesting by expediting equipment traffic flow around retained trees. However, additional benefits can be derived from the combination of the two approaches (e.g.: landscape connectivity).

4) The Canadian Variable-Retention Experience: Implementation Guidelines, Operational Feasibility, and Monitoring

By and large, the best candidates for retention are dying, large-diameter trees with good wildlife potential (cavities, nests). Most guidelines are not specific about the tree species to be retained, but instead, in an effort to minimize the impact of this approach, stress the need to maintain adequate representativeness within the cutting area (species, age classes). When the objective is specifically related to biodiversity maintenance, however, the emphasis is on retaining particular wildlife-friendly species. The poplar, for example, may be selected because of its propensity to create suitable cavities for certain birds. Where the goal is natural-disturbance emulation, species that are more fire resistant (mainly those providing provide cover (e.g: hardwoods)) and/or are located in areas where fire would be less aggressive (slope bottoms, wetlands) will be selected. Often, however, a combination of these approaches is used, with some involving eight to 12 trees per ha (eight being the figure regularly employed) and others focusing on the proportion of the stand to be retained (including single trees and aggregates). This proportion varies between 5% and 70%, but the figure most often employed is about 15%.

Most documents encourage the retention of a maximum of snags, without necessarily specifying quantities. Only the *Forest-Management Guidelines for Biodiversity Protection in the Fundy Model Forest* contains specific biodiversity objectives in this regard: i.e., 12 to 15 snags/ha between 30 and 50 cm dbh.

The guidelines recognize the importance of coarse woody debris as well as snags, and encourage its retention. Here, too, quantities are not stipulated except for the Fundy Model Forest, where the authors recommend there be a minimum of 200 pieces/ha of coarse woody debris (average piece diameter >10 cm).

The size of the aggregates to be retained varies between 0.1 and 1 hectare, depending on the document, and is defined by cutblock area and site characteristics. Aggregate retention is clearly preferred over dispersed retention, mainly because of the lower windthrow risks associated with this method, but also because it makes it possible to retain a higher percentage of structural elements (unstable trees, undergrowth). Aggregates are included in the 5% to 70% of recommended retention mentioned above.

For reasons of practicality and biodiversity, but also to emulate natural disturbances, suitable environments for retention include wetlands, fragile and inoperable areas, steep slopes, distinct wildlife habitats, etc. Some operators also try to maintain an influence throughout the site, limiting the distance between the single trees or clumps retained (two to four tree heights) and advocating the proper distribution of elements over the entire cutblock rather than in strategic locations.

Various retention rates may be implemented, depending on the harvesting approach used (ground-based, cable or helicopter yarding). It is important that the method and equipment used during yarding be flexible, efficient and safe. The specific factors dictating the system to be used are topography, soil type, silvicultural system, timber characteristics, accessibility, and yarding distance and direction.

Certain particular problems may arise, such as injuries to residual trees occasioned by the felling of others or delicate yarding operations. Retaining structures on the site inevitably reduces equipment-maneuverability options, and this factor must be considered at the planning stage. For example, although most variable-retention operations by Weyerhaeuser Coastal B.C. are conducted by hoe forwarders (on slopes under 30%) or cable-logging systems, the company also employs a technique that allows single stems to be removed by helicopter without setting them on the ground.

Weyerhaeuser Coastal B.C. intends to offset the additional costs associated with variable-retention harvesting through technological innovation and improved performance, and hopes to fine-tune its ability to take advantage of market cycles by synchronizing stand harvesting in order to maximize the value of dominant-species sales.

Monitoring variable-retention implementation guidelines requires a structured procedure that is thoroughly understood by all stakeholders. In Alberta, Weyerhaeuser uses oblique air photographs and ground surveys: the results of these two methods show how effective the approach has been and indicate if retention objectives have been met. Alberta-Pacific Forest Industries Inc. monitors performance with the help of surprise counts and audit sheets completed by operators during cutting.

Monitoring programs intended to ensure that goals have been met must be long-term and flexible. Weyerhaeuser B.C. compares the treatments used with certain targets or indicators and evaluates habitat structure in retention areas, as well as studying various organisms. The treatments implemented will be compared with one another, and the company will use prediction tools to determine their effect.

TABLE OF CONTENTS

FIGURES AND TABLES

Introduction

Over the past 20 years or so, forest-management objectives have become increasingly complex. Ensuring a sustained timber yield and the co-existence of a variety of uses is no longer sufficient: the ecological integrity of the forest ecosystem must now also be maintained.

Biodiversity concerns are largely at the root of this phenomenon, and have become of capital importance for the forest industry everywhere in Canada. This ecological issue quickly became an economic one when non-governmental organizations blamed the loss of biodiversity on the stewardship of this country's forests, using scientific research to back their claims that, because conventional practices such as clearcutting no longer meet conservation requirements for ensuring forest-ecosystem integrity maintenance, they must be replaced. Defenders of the new methods (alternative silvicultural systems) argue that, by modifying treatments, substantial output can be maintained without threatening biological integrity (Hunter and Seymour 1992).

One way of dealing with these concerns is to maintain essential structural elements during critical ecosystem-development periods. The importance of such elements in ecosystem functioning and biodiversity maintenance has been widely acknowledged (Franklin *et al.* 1997).

On the basis of this observation, several approaches intended to incorporate this aspect into forest management have been suggested, and taken together can be called "variable retention". Variable retention promotes the creation of structurally more complex stands by retaining structural elements on cutblocks after the final harvest (Franklin *et al.* 1997). Using this approach, a sufficient biological legacy is maintained to ensure ecosystem functional resilience.

In this bibliographical summary, we will first attempt to define variable retention, as well as to explore different related definitions and interpretations. Next, we will deal with the ecological, social and economic considerations involved, identifying which retained structural elements provide the benefits in question. Lastly, the various applications of variable retention in Canada will be discussed, with an emphasis on how silvicultural systems have been adapted and the implications of these adaptations, from the viewpoint of operational feasibility as well as economic feasibility.

1 Variable Retention

1.1 What is Variable Retention?

Variable retention is a system developed in northwest Canada and the United States as an alternative to conventional systems that were not meeting tree regeneration and growth demands, so as to satisfy new biodiversity-maintenance goals (Beese *et al.* n. d.a). The term "variable retention" was first used by the Clayoquot Scientific Sound Panel in 1995, and subsequently further clarified by Franklin *et al.* in 1997. However, variable retention is also known by other names, depending on the kinds of structure involved (green-tree retention, clearcutting with reserves, snag retention, and biological-legacy retention (Barg and Hanley 2001)).

The concept of variable retention originated in the observation of residual stands after natural disturbances such as fire, windthrow and insect infestations. The characterization of these stands provided an enormous amount of information on the structure patterns typically found after such disturbances, which typically include isolated, intact residual forest patches or single trees accompanied by dead or dying trees that rapidly produce woody debris on the forest floor. The study of how these residual stands function has revealed a higher level of resilience for several ecological processes.

The primary goal of variable retention is thus to preserve the range of residual structures that are functionally important for maintaining the forest-ecosystem processes found naturally in a stand, both immediately after a disturbance and throughout stand development. More specifically, this system makes it possible to conserve the structural elements associated with old-growth forests in order to enhance the structural diversity of second-growth stands.

Variable retention is a silvicultural system characterized by the type and quantity of elements retained inside management units (watersheds) and cutblocks (Clayoquot Scientific Sound Panel 1995). It promotes the post-harvest retention of structural elements spatially distributed in accordance with precise guidelines. Retained elements are usually single trees or clumps of trees (patches or aggregates)—whether live or dead (snags)—and woody debris. Retained structures must therefore create forest characteristics similar to the patterns and remnant structures left after natural disturbances (Hunter and Seymour 1992, Franklin *et al.* 1997).

Variable retention may be used in conjunction with several other silvicultural systems (Franklin *et al.* 1997, Barg and Hanley 2001, Beese *et al.* n. d.a.); this flexibility is possible thanks to the broad spectrum of retention options available to meet specific management objectives (Franklin *et al.* 1997). Systems in which one normally finds less than 10% original-cover retention are comparable to traditional even-aged silvicultural systems using clearcutting (including shelterwood-felling final harvests) (Figure 1); in this regard, Hunter and Seymour (1992) consider the resemblance with traditional systems that occasionally leave residual elements to be purely superficial. Similarly, variable retention prescriptions for which more than 70% of the cover is retained can be compared to traditional uneven-aged harvesting methods such as selection cutting.

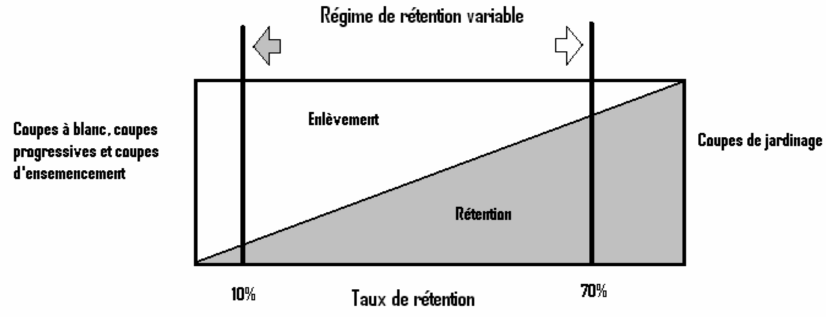

Figure 1: Forest-Cover Retention Levels Used by Variable-Retention Systems, as Compared with Those of Traditional Silvicultural Systems

Source: Mitchell (2001), adapted by Franklin (1997)

[TR: (l to r) Clearcut, Seed-Tree, & Shelterwood Systems; Variable-Retention Systems; Selection Systems; Retention Level; Removal; Retention]

How do variable-retention silvicultural systems differ from traditional systems? There are several major distinctions between the two. First, the focus is on what is retained, rather than what is harvested, and regeneration is not the only goal.

Second, all the authors consulted agree that, for a harvesting system to be considered one of variable retention, the structural elements retained must remain on the cutblock permanently, or for a minimum of one complete rotation (Hunter and Seymour 1992, Clayoquot Scientific Sound Panel 1995, Franklin *et al.* 1997, Barg and Hanley 2001, Beese *et al.* n. d.a). This characteristic is important, because it distinguishes variable retention from shelterwood felling and seed cutting; in these two cases, the residual partial cover is usually intended for harvest well before the end of the rotation of the stand established during the first pass.

Third, variable retention is practised in stands that have reached their economic, if not biological, maturity (Hunter and Seymour 1992, Franklin *et al.* 1997), thus excluding uneven-aged silvicultural systems. In the case of selection cutting, unless the trees to be maintained for biodiversity purposes have been explicitly designated by marking, this is not a true variable-retention technique per se (Hunter and Seymour 1992).

For Beese *et al.* (n. d.a), the very definition of a variable-retention silvicultural system goes beyond such distinctions. These authors state that, for variable retention to be anything but a simple variation on clearcutting, it must keep more than half the original forest surface under the influence of trees surrounding or inside the cutblock. This definition was established based on the biological definition of clearcutting given by Keenan and Kimmins (1993) and Kimmins (1997): i.e., a surface inside of which the influence of trees above and below ground has been removed over more than half the area. The minimum size for an opening created by clearcutting varies in accordance with the height of the surrounding forest and the shape of the cutting area, and is approximately equal to a surface area larger in diameter than four tree heights.

For the purposes of this review, a silvicultural system is considered to be based on the variable-retention approach when the objective is to preserve forest ecological integrity by retaining the structures on the site for one complete rotation.

2. Variable-Retention Considerations

Ecologists have suggested retaining cover trees and increasing rotation time in order to produce larger trees with greater variations in size, a multi-story forest canopy, and the recruitment of coarse woody debris. But what ecological functions does the maintenance of these structures provide? And, from a forest-management and socio-economic perspective, what are the advantages of variable retention? This section deals with these questions by briefly discussing the related literature.

2.1 Ecological Considerations

2.3.4 Biodiversity

The anticipated benefits of the structural complexity created by variable retention involve several ecological processes. First, there are the benefits associated with the enriched structural diversity of second-growth stands on biological diversity, and the fact that a lack of structural complexity decreases habitat quality for many species associated with mature and overmature forests (McComb *et al.* 1993). Indeed, ecological theory states that the complexification of habitat structures translates into increased ecological-niche variability. A number of organisms requiring specific environmental conditions and/or structural elements in late-successional stands can therefore maintain a population in early developmental stages that are usually hostile without these elements.

Theories on island biogeography (MacArthur and Wilson 1967) and metapopulations (Hanski and Gilpin 1991) indicate that species diversity, and therefore population persistence, is directly related to the number (and size) of quality habitats and inter-habitat connectivity. Depending on the characteristics of the habitat created in relation to the requirements of the species concerned, these habitats may act as source habitats where the population has a positive productivity budget, or as temporary shelter in the opposite case. Even if these environments do not become partially usable habitats, variable retention can make them more open to dispersion, thus helping to increase the connectivity of quality habitats within the landscape by acting as stepping-stones in hostile areas and providing “lifeboats” to ensure species survival and dispersion after harvesting (Franklin *et al.* 1997).

Working from these premises, a number of studies have shown that biodiversity in cutblocks is positively related to the number of structural elements retained, with plant and animal communities bearing a greater resemblance to those found in continuous old-growth forests when more structures are retained. Hansen *et al.* (1995), for example, simulated the response of forest birds to nine different retention levels and four rotation lengths for the Western Cascades Province in western Oregon. The results showed that stand structure for each retention level was more like that in a natural forest before entry than after clearcutting. However, size-class variability was not as great as that observed in natural forests under intermediate retention levels. The authors found that bird-species composition was highly related to retention level and rotation length. Generally speaking, the data suggest that forest-cover retention increases structural complexity beyond that of clearcutting for some 200 years after harvesting.

On Vancouver Island, British Columbia, the Montane Alternative Silvicultural Systems (MASS) experiment is still ongoing (Arnott *et al.* 1995). The project compares a range of microclimatic and residual-forest cover conditions created by patch cuts, green-tree retention, and shelterwood felling with a 69-ha clearcut and an adjacent old-growth forest. Although these practices have brought about dramatic changes in breeding-bird communities, there were generally few losses or additions of avian species after a three-year period (Beese and Bryant 1999). The 70% basal-area shrinkage in this forest reduced its attractiveness to insectivorous species, both foliage and bark gleaners, as well as cavity nesters. On the other hand, these treatments created more suitable habitats for three ground-feeding species.

Stuart-Smith (2001) showed that, in the southern Rocky Mountains of British Columbia, retaining trees in managed stands can significantly increase the variety and number of songbirds without necessarily increasing nest predation. The author compared the songbird species found in stands that had been harvested or destroyed by fire (five to 45 years) with variable cover and under understory densities. Predation was also evaluated by means of natural and artificial nests. The findings suggest that retaining even low densities or volume proportions in harvested stands can significantly increase the variety and number of songbirds that use these stands. Because the species responded both positively and negatively to the residual trees, the author suggested preserving a range of densities throughout the landscape to provide a suitable habitat for most of them.

In 1997, Steeger and Quesnel launched their Enhanced Forest Management Pilot Project study (Steeger and Quesnel 1998). The purpose of the study was to test the ability of wildlife reserves inside the forest, or of comparable stands, to maintain wildlife values after various partial harvests (control non exploité, 70% and 40% basal-area retention). Data collected prior to treatment resulted in silvicultural prescriptions that select old-growth forest structural attributes (large-diameter live and dead or dying trees, and/or trees used by wildlife). Surveys did not reveal any drastic changes in the density of active cavity nests found after treatment. It would thus appear that, to date, partial-cutting treatments have succeeded in maintaining the number of breeding birds using cavities inside these units.

As part of the MASS project, certain analyses have shown that structural diversity has a strong influence on micro-arthropods (Mitchell 2001). The author emphasizes the importance of retaining vertical structure as a vital element in maintaining the habitat of these organisms, probably because of the microclimatic variations provided by the different levels of forest cover. The link between a diverse substrate (branches, mosses, and lichens) and a thriving arthropod community is certainly positive (Mitchell 2001).

North *et al.* (1996) explored the influence of tree retention on the diversity of understory plants and the increase in cover-tree basal area. The authors noted that the total variety of understory species was higher with retention systems than for other types of treatment (clearcutting and 65-year-old forests). The general composition of these species was more like that found in clearcutting (dominated by intolerant species), but also included a broad range of tolerant species required for maintaining understory diversity. Composition in sites using variable retention was thus more varied.

Understory vegetation cover, frequency and number decreased after harvesting with all treatments examined by the MASS study (Beese and Bryant 1999). Cover was reduced to 10% of pre-harvest levels with the clearcut, green-tree retention and patch-cut systems, and to 50% with shelterwood felling. After three years, however, the cover increased, primarily because of colonizing species (*Epilobium angustifolium*). These preliminary findings suggest that herbaceous species and bryophytes are the most vulnerable to harvest-induced losses. Shelterwood felling, where vegetation was protected in undisturbed aggregates, maintained the greatest level of understory tree, shrub and bryophyte species diversity as compared with other systems.

Arnup *et al.* (1998) state that, in the boreal forest of eastern Canada, the use of the harvest with advanced regeneration protection (HARP) system, or harvesting with protection of small merchantable stems (CPPTM), as it is known in Quebec), makes it possible to maintain a greater diversity of species as compared with clearcut areas. The authors cite the study by Courtin and Beckerton (1997) that confirms this statement with respect to small mammals.

Retaining structures may, however, prove inadequate for some organisms inside cutting areas, by creating favourable conditions ("killing grounds") for their predation (Franklin *et al.* 1997).

2.3.4 Ecosystem Functions

Variable-retention practices also make it possible to re-establish such vital ecosystem functions as succession, productivity, and water, element and energy cycling faster than conventional methods, thus improving ecosystem resilience (the ability and speed at which it can revert to pre-disturbance conditions).

Variable retention creates more micro-climatic condition diversity (air and soil-surface temperature, light intensity, and soil-surface moisture), and associated harvesting systems are usually less extreme, i.e. more favourable to the establishment and survival of organisms that are partially or completely immobile (plants, lichens, fungi and amphibians).

On a larger scale, variable retention also affects the forest climate. Greater cover retention has a direct effect on hydrometeorological processes (interception, transpiration, snow accumulation, thawing, etc.) because of energy-balance changes. Askin and Dragunas (1995), for example, found an inverse relationship between snow accumulation and retention level on MASS-site treatment areas: the greater the cover, the less the accumulation.

Variable retention reduces erosion by maintaining a root structure that keeps mineral and organic soil in place.

Ecosystem productivity may also be enhanced through the use of variable retention. Retained live and dead trees, as well as coarse woody debris, provide shelter (inocula) for mycorrhizal fungi and nitrogen-fixing bacteria (see Freedman *et al.* 1996).

2.4.1 Social Considerations

Furthermore, variable retention may result in certain social benefits (even if this is not an explicit objective), including public perception that harvesting operations are being managed with a view to ensuring forest esthetics and proper stewardship, as well as empowering and recognizing forest workers.

2.3.4 Perceptions and Esthetics

Today, public perceptions and the visual aspect of logging operations are of major importance to the industry, which has been obliged to incorporate these considerations into its management strategies. Variable retention makes it possible to meet public demands for esthetic forest values. Indeed, opinions of the forest setting are immediately more positive for cuts in which variable retention has been used. It should be noted that for some parties, however, the fact that dead trees and coarse woody debris have been left on the cutblock may be viewed as poor stewardship. Educating the public about various forestry operations—variable retention included—is therefore paramount.

2.3.4 Worker Empowerment

Worker empowerment and accountability can also benefit from this approach. The experiments with variable retention mentioned in this document demonstrate the importance of considering workers' experience in planning and implementing such systems, and workers gain from such recognition of their know-how. A corporate recognition system also encourages workers to be professional (Anonymous 2000b). These new practices thus make cooperation between the various stakeholders—both internally, between managers, silviculturalists and forest workers, as well as with other forest-resource users—a must (Beese *et al.* n. d.b, Washington State Department of Natural Resources 1992, Phillips 1995, Clayoquot Sound Scientific Panel 1995, Bennett and Gilpin 1996).

Because the variable-retention approach provides considerable flexibility, it also allows managers, silviculturalists and forest workers to be innovative in their decisions and adjust prescriptions in accordance with the specific objectives established, as well as with the natural characteristics that may be unique to certain environments.

2.3.4 Risks for Workers

Structures left standing, especially those that are dying, may constitute a higher risk for workers during harvesting and crop-production work in early-development stages.

2.4.1 Economic Considerations

The use of variable retention may have major economic repercussions on the volume of wood harvested, operational feasibility of subsequent treatments, regeneration of forest-tree species, and risks associated with forest fires, insect infestations and disease.

2.3.4 Effects on Potential (Reduction and Losses)

Certain concerns have emerged regarding reduced timber volumes due to the retention of part of the harvest on cutblocks. Data obtained through simulation in a study by Hansen *et al.* (1995) show major reductions in timber production with increased retention levels and rotation lengths. Because of the size and high value of the large logs, however, the net wood-product value did not decrease as rapidly with greater retention level or rotation length.

Retaining live trees and an understory forest stratum will create shading and competition for resources (water, nitrogen) (Mitchell and Arnott 1995) that effectively reduces growth rates. In the MASS project, height and diameter growth in *Abies amabilis* and *Tsuga heterophylla* seedlings was significantly less with shelterwood felling than the patch-cut and green-tree retention systems (Koppenaal *et al.* 1995). The authors associated this phenomenon with the higher levels of shading created by shelterwood felling.

Some writers have suggested thinning understory species in retained aggregates or patches in order to reduce losses in growth (Zenner *et al.* 1998), while others advocate plantation and natural regeneration to attain diversified composition in variable-retention stands (Beese *et al.* n. d.a).

2.3.4 Effects on Regeneration

In addition to the shelter potential provided by clumps of retained trees, there may also be an economic value associated with the retention of small clumps or single trees scattered throughout cutblocks. Quality live residual merchantable trees increase the potential for natural seeding and thus preserve the environment's genetic diversity.

There are also economic benefits associated with the preservation of lower-quality stems on the cut site. The harvest of small-diameter stems in overmature boreal forests, for example, requires more handling and provides few economic advantages (Riopel *et al.* 2000, Bégin and Riopel 2001). The use of the HARP method, as advocated by researchers, may reduce the crop-production costs associated with regular stands, increase average tree dimensions, decrease smallwood harvests, heighten forest productivity, and shorten upcoming rotations, as well as offsetting anticipated 30-to-50 year stockouts. At the same time, however, some timber may be underutilized in the short term, and there is a chance of future windthrow losses (Bégin and Riopel 2001).

With respect to the Lake Abitibi Model Forest, the post-harvest condition and survival level for advance regeneration using the HARP method has been very good. Advance-regeneration stems typically respond to release cutting after five to ten years, and produce high volumes in shortened rotations (Parton and Tallman forthcoming).

Stand composition may also be modified by this approach. In comparison with clearcuts, stands with relatively high cover quantities may be associated with higher relative densities of shade-tolerant species. The number and diversity of inner-forest species will actually increase with the proportion of trees retained (especially in aggregates) because of the shading created, the reduction in soil disturbance, and understory vegetation. Inversely, the number and diversity of pioneer species should fall with the increase in retained trees.

Species composition was strongly associated with retention level and rotation length in a study conducted by Hansen *et al.* (1995). The Douglas fir (*Pseudotsuga menziesii*), a shade-intolerant species, lost its dominant position over more tolerant species with intermediate retention rates and longer rotations.

Rose and Muir (1997) took a retrospective approach, using an old disturbance as analogous to post-harvest retention. Based on USDA inventory data for the Cascades Mountains in Oregon and southwestern Washington (western-hemlock zone), the authors selected a series of unmanaged stands (cohorts of 70-110 years with and without cover of trees ≥ 200 years) to represent clearcutting and green-tree retention. Residual-tree density was negatively correlated to regenerating shade-intolerant species. The basal area occupied by regeneration tended to decline with higher residual-density quantities, but only after these reached approximately 15 trees/hectare. Most of this decline stemmed from reduced Douglas fir (*Pseudotsuga menziesii*) regeneration.

2.3.4 Risks Associated with Snags, Fires, Insect Infestation and Disease

The variable-retention approach may help control insect infestations if this factor is taken into account in designating the trees to be retained. Bégin and Riopel (2001), for example, state that CPPTM lessened stand vulnerability to the spruce budworm by reducing the proportion of balsam-fir basal area.

The presence of dwarf mistletoe on western hemlock on the MASS project site had been determined beforehand (Nevill and Wood 1995). To date, these infestations have been particularly well controlled in green-tree retention areas. According to Beese and Bryant (1999), the incidence of dwarf mistletoe was reduced from 18% in the original stand to 6% in the shelterwood felling cutblock, and to 3% with green-tree retention, thanks to proper identification of retained trees.

However, the operational problems (restricted equipment maneuverability, inexperience of workers) related to this approach may cause more tree injuries than conventional methods, and such injuries may become pockets of infestation.

Residual-tree windthrow, which is sometimes desirable from an ecosystem perspective, may also result in a loss of expected revenues. Beese and Bryant (1999) state that, three years after treatment in the coastal montane forest of British Columbia, there was a 25% loss of residual trees to windthrow (6 stems/ha - 1) using green-tree retention; with shelterwood felling, the figure was 5% (11 stems/ha - 1).

After two growth seasons, windthrow rates of between 9% and 30% for protected merchantable stems were observed (Bégin and Riopel 2001). In most areas, these losses are acceptable (2- 4 m^3/ha; 10% - 20% of stems), and do not cast doubt on the advisability of retaining 14-cm dbh stems. On the other hand, losses of up to 9 m^3/ha have also been noted (Bégin and Riopel 2001). Further research is now being conducted, and should make it possible to better evaluate the extent of such losses.

While retaining deadwood and woody debris in cutblocks as advocated by the variable-retention system would probably increase fire-related risks, none of the literature shows an increase of such risks caused by the direct use of this approach.

2.3.4 Treatment Costs

Variable-retention systems must, like any silvicultural system, promote succeeding-stand regeneration in order to provide for anticipated harvest rates. However, retention systems sometimes result in management difficulties for subsequent stands (Franklin *et al.* 1997); they are said to interfere with the use of fertilizers, pesticides and herbicides.

The costs related to subsequent treatments may nonetheless be reduced, given the fact that variable retention results in greater seeding capacity and creates a bridge between the old stand and the next. This is the case, for example, for several stands harvested by means of the CPPTM and HARP systems (Bégin and Riopel 2001, Parton and Tallman forthcoming). In Ontario, Abitibi-Consolidated estimates that 70% of stands harvested using these systems can be regenerated naturally, and that only 30% require artificial regeneration. This ratio is reversed with clearcutting (Arnup *et al.* 1988, Natural Resources Canada n. d.). Furthermore, it is rare for such stands to require herbicidal treatment (Parton and Tallman forthcoming).

2.4 Retention Techniques

2.4.1 Retention Elements

A broad variety of structures may be left behind, depending on management goals. As we have seen, these can include large live or dying trees, dead trees (snags) in various stages of decay, coarse woody debris, and patches of understory (mosses, herbs, and shrubs).

2.4.1.1 Live Trees

Large-diameter live and decadent trees are particularly important structural elements, as they provide critical habitat for many organisms that would otherwise be absent (Franklin 1997). These trees also constitute major future sources of snags and woody debris. Although retaining snags on cutblocks is important, it is even more important to provide for future recruitment (British Columbia Ministry of Forests 1995). The management of dying or partially dead trees is therefore essential.

When choosing trees for retention, conservation requirements for biodiversity and management objectives must be taken into account. The different characteristics of hollow-bearing trees meet the needs of dependent wildlife in various ways. The attributes of the cavity itself (dimensions, depth, type, orientation), as well as the tree species in question (tendency to bear hollows, fire resistance), stage of senescence, and size (cavity number and dimensions vary with diameter) must all be considered (Gibbons and Lindenmayer 1996).

According to Hunter and Seymour (1992), retained trees must be long-living if they are to ensure long-term structural diversity, if possible beyond the first decade or two after harvest. They should also offer as little direct competition as possible to the developing stand. The economic value and volume of such trees will thus continue to grow, providing financial motivation for future operations.

Because of the safety provided by improved stability, live trees may be favoured over dead ones (Washington State Department of Natural Resources 1992); if so, more specific instructions on selection must be given. In its pileated woodpecker habitat-provision guidelines, for example, the Ontario Ministry of Natural Resources advocates the use of live hollow-bearing trees rather than dead ones (Ontario Ministry of Natural Resources 1996).

Beese *et al.* (n. d.a) also stress the importance of preserving quality merchantable trees (species and diameter) in order avoid affecting the health and genetic potential of regenerating stands, comparing the dangers of such a practice with those inherent in high grading.

2.4.1.2 Standing Dead Trees (Snags)

Dead trees in various stages of decay, which are often lacking after conventional harvesting operations, constitute important shelter, reproduction and feeding sites for many animal species (see literature review by Darveau and Desrochers 2001). Furthermore, woody-debris recruitment depends heavily on an abundance of snags. British Columbia's *Biodiversity Guidebook* even states that maintaining a good source of snags in managed forests in itself constitutes the most important practice with respect to biodiversity maintenance (British Columbia Ministry of Forests 1995).

In order to optimize bird-population diversity and density and meet a wide variety of avian needs, the snags retained should represent a spectrum of decay stages. Schreiber and deCalesta (1992) examined the relationship between cavity-nesting birds and snag density and attributes in Oregon. They concluded that, to establish conditions meeting the needs of all cavity-dependent birds in the area, forest managers should provide a minimum of 14 snags between 28 and 128 cm dbh per hectare, varying from 6.4 to 25 meters in height, with a bark cover of at least 10% to 40%. They also stated that most snags should rank between 3 and 4 on the hardness scale.

Where not enough snags can be recruited, it is also possible to create wildlife trees. One way of doing so is to high-cut stumps during the use of feller-bunchers (British Columbia Ministry of Forests 1995).

Snag spatial distribution is also important. Hunter (1990) estimated that standing dead trees represent an average of 5% to 10% of all trees in a forest, but this figure may vary from 0% to 100% locally. Heterogeneous spatial distribution is thus an important characteristic to consider.

2.4.1.3 Woody Debris

Woody debris is also an important habitat component for a multitude of species. Logs decaying on the forest floor provide cover, suitable microclimates and breeding sites, and can provide shelter for certain organisms during forest fires. In Great-Lakes area forests, woody debris constitutes a refuge for one-third of all vertebrate species present (Naylor *et al.* 1996). These elements also play an important role in supplying habitats for aquatic ecosystems, and influence geomorphic processes such as erosion and sediment retention (Franklin *et al.* 1997).

Woody debris and cull material from harvesting may be left on the ground to provide the forest with this element. Several methods have been developed to ensure sites have an adequate supply of debris: tree-length harvesting and the use of site-preparation equipment and techniques that do not damage or crush ground debris are two of the most common (Naylor *et al.* 1996). Large woody debris is often preferred for retention purposes, as it provides increased longevity (British Columbia Ministry of Forests 1995). Retained snags can also provide a continuous supply of woody debris.

2.4.1.4 Other: Shrubs/Thickets, Undergrowth, Undisturbed Soil

The above elements will be discussed together, as very few silvicultural prescriptions refer to them directly. They can be maintained on cutblocks, but only by means of aggregate-retention trees (live or dead). The Clayoquot Sound Scientific Panel (1995) refers to these elements indirectly in its recommendation for the retention of no-work zones.

Such elements remain important to ecosystem maintenance. Understory species comprising mosses, herbs, and shrubs constitute vital structural components that may require long periods of time to re-establish once eliminated by logging (Halpern and Spies 1995 (in Franklin *et al.* 1997)).

The structural variability created by the retention of these elements makes for more diverse habitats and micro-climatic conditions than homogeneous stands. The preservation of several forest strata may be needed to meet the requirements of mammals such as the deer, for example. An Ontario Ministry of Natural Resources publication (Voigt *et al.* 1997) contains prescriptions on the cover to be maintained for the white-tailed deer—i.e., residual stands should provide canopy closure of 80% in winter.

Guidelines are also provided with respect to the relationships between cover and understory species.

Soil management in itself has a significant effect on stand cultural characteristics and biodiversity rates. Soil structure, nutritional spectrum, organic-matter content, water retention, drainage, and pH all play a major role in ecosystem vegetation vitality. Maintenance of a range of soil conditions and types is thus a prerequisite for the development and maintenance of diversified fauna and flora (British Columbia Ministry of Forests 1995).

2.4.2 Spatial Distribution

Forest managers can accomplish retention in a number of different ways by adjusting the density and spacing of the structural elements retained; they can distribute them uniformly, as in the case of dispersed retention, or combine them on the cutblock, using aggregate retention (Figure 2).

Despite the fact that dispersed and aggregate retention are both intended to maintain ecosystem complexity and structural diversity, each has its own ecological advantages and disadvantages, as site impact and specific applications differ (Table 1).

Figure 2: Disbursed and Aggregate Retention Systems on Vancouver Island, British Columbia

(Source: Beese *et al.* n. d.a)

However, additional advantages may stem from combining the two approaches, especially as regards maintaining landscape connectivity. Aggregate retention may represent islands of structurally diverse, climatologically moderated habitat, with dispersed retention providing “stepping stones” between those islands. Visual quality may also be better served in this manner (Mitchell 2001).

2.4.3 Dispersed Retention: Advantages and Disadvantages

The main advantage of dispersed retention is that it provides structural complexity throughout the site (Barg and Hanley 2001). This type of retention ensures that a large proportion of the cutblock will be influenced by the smallest number of surviving trees. As few as 5% - 10% of the trees dispersed over the whole cutblock influence nearly 100% of the area to some degree. While this is sometimes desirable (e.g.: to ensure shelter for young trees), this approach also tends to disperse the impact of harvesting throughout the stand, so that little of the forest understory remains undisturbed during logging (Clayoquot Scientific Sound Panel 1995).

Dispersed retention is most appropriate where ecological objectives require that structures be properly distributed. This may be the case when a supply of coarse woody debris is to be provided over the entire cutblock, for example.

However, dispersed retention may have a larger negative impact than aggregate retention because of the effects of these systems on general regeneration-stand growth and the subsequent reduction in wood yields (Franklin *et al.* 1997).

2.4.4 Aggregate Retention: Advantages and Disadvantages

Contrary to dispersed retention, aggregate retention makes it possible to maintain a greater variety of structural elements, thereby allowing more forest ecosystem components to be retained (multiple strata, understory, soil, etc.) (Franklin *et al.* 1997, Barg and Henley 2001).

Aggregate retention makes it easier to practise multiple-entry even-aged silviculture on cutblocks while keeping all-aged forests in the aggregates (Clayoquot Scientific Sound Panel 1995, Beese and Bryant 1999 (in Beese *et al.* n. d.a)).

Patches of undisturbed forest with understory vegetation and forest floor intact are particularly useful for the safe retention of unstable snags and trees, and are important for maintaining biodiversity (Clayoquot Scientific Sound Panel 1995).

This type of retention can also be used to avoid—or at least limit—the risks of windthrow, by providing better resistance to extreme winds. If stand species are especially subject to windthrow (e.g.: hardwoods vs. conifers, shallow roots), it may be advisable to use aggregate retention with a resistant configuration and orientation (Hunter and Seymour 1992). The patterns left by downed wood in the residual patches studied by Burton (n. d.) indicate that aggregates should be arranged elliptically or in a tear-drop shape, with the longest axis positioned in the direction of the prevailing winds to minimize losses due to windthrow.

Furthermore, safety is of paramount importance in any silvicultural system. It is much easier to deal with safety issues by using the aggregate-retention method (Clayoquot Sound Scientific Panel 1995, Beese *et al.* n. d.b).

Table 1: Contrasts Between Dispersed and Aggregate Retention

Objective on Harvest Unit	**Pattern of Retention**	
	Dispersed	**Aggregate**
Microclimate modification	Less, but generalized over harvest area	More, but on localized portions of harvest area
Influence on geohydrological processes	Same as above	Same as above
Maintenance of root strength	Same as above	Same as above
Retain diversity of tree sizes, and conditions	Low probability	High probability
Retain large-diameter trees	More emphasis	Less emphasis
Retain multiple vegetation (including tree) canopy layers	Low probability	High probability
Retain snags	Difficult, especially for soft snags	Readily accomplished, even for soft snags
Retain areas of undisturbed forest floor and intact understory community	Limited possibilities	Yes, can be as extensive as aggregates
Retain structurally intact forest habitat patches	Not possible	Possible
Distributed source of coarse woody debris (snags and logs)	Yes	No
Distributed source of arboreal energy to maintain belowground processes and organisms	Yes	No
Carrying capacity for territorial snag- and/or log-dwelling species	More	Less
Windthrow hazard for residual trees	Average wind firmness greater (strong dominants), but trees are isolated	Average wind firmness less, but trees have mutual support
Management flexibility in treating young stands	Less	More
Harvesting (i.e., logging) costs	Greater increase over clearcutting	Less increase over clearcutting
Safety issues	More	Less
Impact on growth of regenerated stands	High, generalized over harvest area	Less, impacts are localized

Source: Franklin *et al.* 1997, p. 122

Beese *et al.* (n. d.b) also emphasize that aggregate retention facilitates yarding, especially in cable-based systems, as this reduces the number of route changes needed to go around the trees retained.

Aggregate retention can basically eliminate the problems involved in implementing subsequent treatments, since it makes it possible to manage areas between aggregates more easily (Franklin *et al.* 1997). In these circumstances, distribution should avoid air corridors as much as possible.

3 Geographic Comparison of the Practice of Variable Retention

Silvicultural variable-retention guidelines must deal with three important issues: what to retain, how much to retain, and the spatial pattern for retention (Franklin *et al.* 1997). The choice of approach must be based on the specific attributes of the stand and the way in which the cutblock contributes to management goals at the landscape level (Beese *et al.* n. d.a). Site objectives dictate the number of trees to be retained. Prescriptions must also take account of and incorporate a variety of factors such as safety, ecological values, windthrow and fire risks, the presence of insects and disease, silviculture, operational feasibility, economic feasibility, and scenic quality. Time of year and season may also play a role in the silvicultural system recommended; in the forested areas of Ontario, for example, it is important to distinguish between seasonal habitat requirements for the white-tailed deer (Voigt *et al.* 1997).

Several government and industry documents discuss retention measures and guidelines. In this section, we will provide a region-by-region description of the documents identified to date that contain recommendations, guidelines or measures to be taken into account during entries. For each document we will attempt to highlight which elements have been retained (according to objective), their quality, and their number and distribution within a given stand.

3.1 British Columbia

3.4.1 Biodiversity Guidebook

The *Biodiversity Guidebook* (British Columbia Ministry of Forests 1995) provides guidelines for the implementation of various options designed to meet stand- and landscape-level biodiversity objectives.

The document states first that biodiversity emphasis to landscape units be applied in accordance with the objectives or priorities for a given sector. Next, objectives for maintaining biodiversity within these units must be developed.

Accordingly, the natural-disturbance types characterizing the region must be used. Objectives are therefore based on what is usually encountered during such disturbances for each characteristic, including stand structure. The Guidebook provides advice on how to select stand structures for retention.

The retention level in question must be based on the proportion occupied by each biogeoclimatic sub-zone in the operable area of the landscape unit and the number of interventions that have taken place in the past. The higher the proportion of operable area in a landscape or the more that previous development has reduced tree abundance, the greater the amount of retention required.

Good candidates for retention (always a biodiversity objective) are preferably dead (subject to safety considerations) and provide special habitats for fauna; they are also old or large in diameter (in the upper 10% diameter distribution). Those candidates selected should be representative of the stand. Retention should be based on a pre-activity assessment of tree values and requirements on or adjacent to the proposed cutblock, and on the described actions that are required to accommodate these values.

The importance of tree patches within cutblocks increases with the size of the cutblock. Patches should generally be centered around the most suitable trees and distributed throughout the cutblock, with distances between patches not exceeding 500 meters. Distribution should also minimize windthrow risk.

3.4.2 Clayoquot Sound Scientific Panel (1995)

Based on a review of standard forest practices in Clayoquot Sound, the description of physical attributes, ecological features, regional human values and forest ecosystem-design principles, the Clayoquot Sound Scientific Panel developed recommendations on the changes needed to ensure successful ecosystem management in the area.

The Panel recommended three planning scales—sub-regional, watershed, and stand. Recommended planning is based on zones rather than volume, a change essential to successful ecosystem management.

The planning process identifies the sector in the watershed available for timber production, specifies a watershed rate of cut (annual sector percentage), and identifies harvestable areas. Before mapping out harvest sectors and establishing subsequent specific forest operations, watershed-level reserves based on realistic biological and physical criteria are designated. The annual volume of timber on hand for harvest in the watershed is determined by the planning process and depends on the characteristics of the natural environment available for logging.

The Panel also recommended changes in harvesting operations. The new strategy, rather than concentrating on trees to be removed, focuses on those to be retained. This change applies over the entire watershed level, delineating reserves to protect ecosystem integrity and forest values, and is implemented throughout the stand (station) by specifying the trees to be retained in individual harvest units.

The Panel recommended that traditional silvicultural systems in the forests of Clayoquot Sound be replaced by a variable-retention system allowing for:

- the permanent retention of forest structures or shelter elements (dying large-diameter trees or clumps of trees, snags and woody debris); and
- a range of different retention levels.

More specifically, for cutting units with significant values for resources other than timber (e.g.: visual, cultural or wildlife resources), or with sensitive areas, it is recommended that:

- at least 70% of the forest be retained in a relatively uniform distribution;
- the size of openings be limited to 0.3 ha or less when harvesting small patches;
- at least some larger-diameter old and dying trees; snags; and downed wood be retained throughout the forest (but not necessarily in harvested patches); and
- no-work zones representing a minimum of 15% of the cutting unit area be identified before any harvesting takes place.

On cutting units with no significant values for resources other than timber, or without sensitive areas, it is recommended that:

- at least 15% of the forest be retained;
- most material be retained as forest aggregates of 0.1 - 1.0 ha, well dispersed throughout the cutting unit;
- aggregates properly representing forest conditions in the cutting unit be ensured (i.e., they should not be disproportionately located in the less productive portions of the unit);
- specific areas (aggregates) be kept intact as no-work zones;
- regardless of the retention level, no place in an opening be greater than two tree heights from the edge of an existing aggregate or stand; and
- when dispersed retention is employed, the most windfirm, dominant trees on the unit be selected.

The Panel also recommended that retention prescriptions be tailored to stand attributes, topographic conditions, and other resource values on the working unit, by:

- retaining a representative cross-section of the species and structures of the original stand;
- selecting specific patches and structures to meet ecological objectives (e.g.: provide future for cavity-dependent species);
- selecting patches to protect culturally important features (e.g.: recreation sites, scenic features);
- determining the appropriate amounts of retention based on ecological sensitivity and forest values within the working unit;
- designing the shape, size and location of areas to be harvested within a given cutting unit to comply with topography and the visual landscape management objectives established for the area.

The guidelines also state that windthrow should not be harvested inside retention units unless it constitutes a threat for other value resources. Details as to the type, quantity and spatial distribution of retention elements depend on site characteristics and management objectives.

3.4.3 Iisaak Forest Resources

The general management objective of Iisaak Forest Resources for sectors within the boundaries of Clayoquot Sound is to establish an economically viable harvesting operation while implementing an ecosystem-planning method and a variable-retention approach (Iisaak Forest Resources 2002). The Company has undertaken to incorporate all recommendations of the Clayoquot Sound Scientific Panel in its forest-management approach. Its variable-retention systems involve the retention of 15% of the forest, which, according to the company, has enabled it to attain a 75% retention level on the 10,000 m^3 harvested.

3.4.4 Weyerhaeuser Coastal B.C.

Weyerhaeuser Coastal B.C. has also implemented variable-retention silvicultural systems (Beese *et al.* n. d.a). The company's tenure has been divided into three stewardship zones: timber (with the focus on commercial production), habitat (with an emphasis on the conservation of a multitude of wildlife habitats through the maintenance of different structures), and old-growth forests (with the goal of preserving these forests and associated landscape species). Each of the three zones has different landscape and stand retention goals. Company guidelines state that clumps of retained trees should be greater than 0.25 ha and not be separated by more than four tree lengths. Individual trees or smaller clumps should not be separated by more than two tree lengths.

While the document does not specify the number or quality of the structures actually retained, it does mention that the approach chosen depends on stand-level objectives and the way in which the stand contributes to landscape-level objectives.

The choice of retention structures is influenced by the presence of rare site elements, the need to ensure adequate representativeness, or the requirements of certain species. The decision as to how many elements to retain will be a compromise between ecological, social and economic values, and take account of the number of reserves at the landscape level, the history of natural disturbances, and management objectives. A minimum retention level of 5% to 20% has been established in accordance with the emphasis given and the retention patterns of various zones at the landscape level. Because of the related ecological and economical advantages, Weyerhaeuser favours aggregate retention.

3.4.5 International Forest Products Limited (Interfor)

Interfor has also successfully introduced new harvesting methods by using the variable-retention approach (International Forest Products Limited 2002). According to the company, variable retention was implemented in almost 42% of all sectors harvested in 2000. While Interfor's Web site does not provide any further details, and the company has no formal research reports on variable-retention system implementation, Interfor has launched a research project on system-effect modelling (Gerry Fraser, personal communication).

3.4.6 Tembec

Tembec has issued a pamphlet to enable forest workers to identify important characteristics for wildlife and make the proper decisions about which structures to preserve (Anonymous 2000c).

The publication suggests preserving snags (where possible), nests in branches (surrounded by other trees), salt marshes and muskeg, witches' broom, rocky knolls, woody debris (intact decaying logs), veterans, hardwoods, understory fir aggregates (quality individuals), advance regeneration, and unmarked wetlands and riparian environments). The locations suggested for these structures are wet depressions and coulees, riparian environments, rocky knolls, wildlife (game) trails and other obvious sites used by wildlife, and inoperable sites. In general, the use of aggregates is advocated.

Considerable emphasis is placed on variability. It is important to avoid any resemblance between cutblocks, and aggregates should differ in size and shape.

3.2 Alberta

3.4.1 Harvest Planning and Operating Ground Rules

The document entitled *Harvest Planning and Operating Ground Rules* (Province of Alberta 1994) provides guidelines for vertebrate terrestrial- and aquatic-wildife maintenance during harvesting operations. The following recommendations deal with structural-element retention:

- Preserve at least eight live or dying trees per hectare within each cutblock wherever possible without jeopardizing worker safety. This measure would allow for ongoing recruitment of coarse woody debris. Preference should be given to dead large-diameter trees and live non-merchantable species, as well as dispersed retention.

- Leave piles of cull material in cutblocks in order to provide shelter and cover for birds and mammals.

- Insofar as possible, preserve the forest understory, especially when it represents significant future economic value.

The document also refers to provincial harvesting guidelines in caribou-habitat zones.

3.4.2 Daishowa Marubeni International Ltd. (Alberta)

Subsequent to consultations with various stakeholders, Daishowa Marubeni has established a number of major objectives such as ecosystem-process, biodiversity, variability, stand-structure, and natural-forest preservation; the maintenance of other uses; and wildlife aspects (Anonymous n. d.b).

A stand-level approach has made it possible to meet some of the ecological objectives in question (exactly which ones are not specified). The company decided that a certain number of elements should be designated for legacy purposes, and that, if it left an average of 15% of merchantable fibers after each harvesting operation, all stand-level needs would be met. The goal here was to provide stands with trees and patches and recruit woody debris. The configuration of these fibers has yet to be determined. The plan has received approval from the Alberta government.

A few very general guidelines governing structural-element distribution issued by the company have not yet been approved.

Daishowa suggests that the residual structure, including snags, be representative of the merchantable fiber harvested. Its quantity within a given cutblock would therefore increase, in principal, with the size of the block. The company advocates retaining both patches (160 m in diameter) and dispersed structures (single trees, small clumps). Patches can stay entirely within the cutblock or be located adjacent to it. Structure location would be determined with a view to facilitating subsequent reforestation treatments and ensuring these can be carried out in complete safety. Structural-element variability could also provide a suitable visual barrier once ecological objectives were met.

3.4.3 Alberta-Pacific Forest Industries Inc.

Alberta-Pacific Forest Industries, in order to reach its ecosystem-management goals, is attempting to develop silvicultural strategies that allow for biodiversity maintenance (Anonymous n. d.a). These strategies are based on an understanding of natural-disturbance dynamics. The company feels that an important aspect of an ecosystem approach is the retention of forest structures inside cutblocks. The goal is to create retention patterns that, to every possible extent, resemble those left after a fire.

Alberta-Pacific has developed a manual entitled *An Operator's Guide to Stand Structure* (Anonymous, n. d.a). in order to ensure that structural requirements at the stand level, as defined in the company's detailed forest management plan, are met. The purpose of the document is to help operators understand the reasons behind such an approach and provide guidelines for cutblock-structure decisions.

Those guidelines are as follows:

- Keep an average of eight trees per hectare (average merchantable diameter), whether individuals or small clumps of two or three trees, in a range of species and age categories.

- Keep an average of one aggregate per hectare, with its shape and size (±16 m in diameter) depending on the characteristics of the environment in question as well as the trees and structural attributes in question. Aggregates exceeding one hectare can be maintained in large cutblocks.

- Locate aggregates on steep slopes with northern exposure or in wetlands, inoperable areas and natural gaps.

- Leave undisturbed patches of non-merchantable vegetation.

- Preserve all snags, unless they are located near a road (< 2 tree lengths) or constitute a danger for workers.

- Choose a few large-diameter conifers (e.g.: white spruce, which is windfirm).

- Aggregates should protect snags, large-diameter conifers, natural gaps and sites containing major understory growth.

- Trees in which there are visible nests (falcons, squirrels, etc.) should also be left standing in the middle of the aggregates.

The document emphasizes the fact that each cutblock should be different. The company plans to adapt the above guidelines in accordance with knowledge gained.

3.4.4 Weyerhaeuser Alberta

Like the Alberta-Pacific guidelines, those developed by Weyerhaeuser Alberta in 1998 (Anonymous, n. d.c) take an ecosystem-management approach. This document specifies strategies, targets and procedures for all provincial forest-management areas (Grande Prairie/Grande Cache, Drayton Valley, Edson, Slave Lake) that are aimed at creating residual ecological diversity inside cutblocks, protecting sensitive environments and short- and long-term wildlife habitats, and minimizing the loss of forest-ecosystem nutrients. The company's main priority is to develop a suitable management strategy for each given sector, and implement applicable guidelines. A maximum of 3% of the merchantable volume inside cutblocks is to be retained: this volume may include buffer areas, atypical sites and environments, and small clumps of retained trees or larger patches.

The guidelines specify procedures for six retention elements: snags, live individual trees or clumps of trees (two or three), green-tree patches (clumps of ≥10 trees) coarse woody debris, wetlands, and unique or atypical sites.

All snags are to be left standing. Safety is a priority, however, and the document provides certain instructions in this regard. Where possible, snags can be created by polling live trees at a height of about six meters.

Clumps of retained trees (two to four trees), patches (≥ 10 trees) and single trees should be composed of understory individuals, merchantable and non-merchantable trees, and large windfirm conifers. The best choices for retention are dying but safe balsam fir, larch and birch, veterans, misshapen trees, wildlife trees, or those with large-diameter branch systems.

The size and shape of retained patches (clumps of ≥ 10 trees) may vary, depending on site conditions and cutblock area. There should be an average of one patch for every ten 10 hectares logged. Some patches should be located 30 to 50 meters from the edge of the block, and pre-established slash-free zones should be avoided.

Areas advocated for retention are sensitive, atypical riparian environments taken into account when designing cutting areas, and should be left undisturbed. Inoperable areas and sites protected from the wind are also suitable. The document stresses the importance of selecting windfirm trees (determined according to exposure, root depth, soil resistance, and shape).

With respect to conifer stands, it is suggested that merchantable and non-merchantable trees be retained in small clumps of three or four (one clump per hectare) rather than single trees, unless the latter are windfirm veterans or wildlife trees. Clumps retained in mixed stands should be composed of conifers and hardwoods. At least one tree of above-average diameter should be included in these clumps, for all types of stands.

The quantity of coarse woody debris varies in accordance with cutting area. Piles of debris and scrub should have an average height of 1 to1.5 m, and a diameter of about six meters. Merchantable and non-merchantable debris naturally found on cutblocks should be retained, with at least two piles located eight to 30 meters from the edge.

Supervisors are responsible for determining the location and number of piles to be retained. Pasture land and areas developed for their esthetic value should be avoided.

3.4.5 Millar Western Forest Products Ltd.

According to this company's Web site (Millar Western Forest Products Ltd. 2002), its harvesting techniques are site-specific and matched to the season and area characteristics, so as to maximize utilization while minimizing environmental impact. Current practices are based on a knowledge of natural disturbances such as forest fires, resulting in harvested sites of varying size and shape. Trees, snags and woody debris are left behind as ecological structures in order to provide wildlife habitat.

3.3 Manitoba

3.4.1 *A Guide to Harvesting Practises to Regenerate A Natural Forest* (*draft*)

This document explains in a general way how forest operators should intervene in landscapes and cutblocks so that, to every possible extent, harvest operations resemble the wildfire disturbances usually seen in eastern Manitoba (Ehnes and Sidders 2002).

To that end, the authors suggest that cutblocks be placed in landscapes where large fires usually burn, and that all activity in zones generally spared by fire be avoided.

Ehnes and Sidders also suggest that certain species such as scattered jack pine and black spruce be retained in the logged area and that all remaining merchantable timber be cut; they recommend that slash and treetops be spread throughout the cutblock, that the upper story not be composed of species that are fire intolerant, and that snags be left standing.

3.4.2 Louisiana-Pacific Canada Ltd.

Louisiana-Pacific's retention guidelines advocate maintaining from eight to 12 trees per hectare in any cutblock more than ten hectares in size (Louisiana-Pacific Canada Ltd. 2001). The spatial distribution of aggregates (the form of retention most often used) is generally determined by the district biologist at the planning stage, and by operational personnel thereafter (Donna Gracia, personal communication). In accordance with company guidelines and provincial requirements, operational employees maintain structures around specific environments (e.g.: wetlands and steep slopes (>30%)). The distance separating one aggregate from another, or from another environment capable of providing wildlife cover, should not exceed 200 m.

If possible, all snags are maintained primarily where found in high concentrations, and incorporated into cutblock aggregates. Although the company has not developed specific guidelines on coarse woody debris retention, it requires that all topping be carried out at stump level. Logging debris is to be arranged along all roads inside the harvested site in order to limit site access and minimize hunting, as well as to prevent erosion and help replenish soil nutrients lost during harvesting (Donna Gracia, personal communication).

3.4 Ontario

3.4.1 *Forest Management Guidelines for the Provision of the Pileated Woodpecker Habitat*

In Ontario, the Ministry of Natural Resources has established specific guidelines (Naylor *et al.* 1996) for the pileated woodpecker based on scientific research and expert opinion. The above document contains advice for forest managers on the shelter requirements of this bird.

At the stand level, the Ministry recommends retaining at least six hollow-bearing trees per hectare on all selection-cutting, shelterwood-felling, seed-cutting and clearcutting cutblocks.

Retained trees (hardwood or conifer) should be live, especially in order to reduce risks for workers. They should contain cavities, all have a diameter of over 25 cm, and at least one of them should have a diameter of more than 40 cm. The retention of dead trees (primarily those serving as perches) that do not present a safety hazard for workers is encouraged.

The document suggests a relatively uniform distribution throughout the cutblock, consolidated at the hectare level. For sites to receive additional silvicultural treatments, two clumps of three hollow-bearing trees per hectare, or a single clump of six trees, are recommended.

Retaining woody debris by leaving valueless logging debris and cull on the ground is also encouraged.

3.4.2 *Forest Management Guidelines for the Provision of White-Tailed Deer Habitat*

This document provides for the maintenance or creation of forests whose structure and composition meet the needs of the white-tailed deer (*Odocoileus virginianus*) (Voigt *et al.* 1997).

Once seasonal deer concentration areas have been considered at the landscape level, shrub strata suitable for browsing should be provided at the stand level. Inside mixed stands, it is preferable to retain all conifers in cutblocks at the expense of other species.

The documents states that, as treetops left as a result of harvesting are beneficial to white-tailed deer, whole-tree harvesting should be kept to a minimum in order to ensure adequate treetop distribution over the cutblock.

3.4.3 *Forest Management Guidelines for the Provision of Marten Habitat*

The Ontario Ministry of Natural Resources has also developed management guidelines to ensure a supply of suitable marten habitat in the province's boreal forest (Watt *et al.* 1996). These guidelines are to be taken into account when preparing and implementing management plans in this region.

In stands previously designated as suitable for the marten, silvicultural systems should be modified to provide a minimum of six dead or declining trees per hectare, with at least two of these exceeding 30 cm dbh. Silvicultural practices that retain logs, stumps and other coarse woody debris on the site are also encouraged.

The document suggests that the provision of marten habitat will supply at least some of the habitat required by various other species that are also associated with mature and overmature forests, cavity trees, and coarse woody debris.

3.4.4 *Forest Management Guide for Natural Disturbance Pattern Emulation*

Management operations should be modified to better reflect biological and structural patterns normally found after a wildfire. Once having specified where cutting areas should be located, the guide proposes and/or refers to the measures needed to preserve the structures inside those areas, so as to respect the natural history of fires in Ontario (Ontario Ministry of Natural Resources 2001).

For the purposes of the guide, a clearcut is the harvesting of most of the forest stand while retaining 10% to 34% of the original stand or stands in residual patches and an additional minimum average of 25 individual trees or snags per hectare. The density and selection of individual trees to be retained should be based on species fire tolerance, wildlife-habitat characteristics, and silvicultural-treatment needs. At least six of the 25 trees to be preserved per hectare should be large-diameter; the remainder, which can be live or dead (depending on safety considerations), should be selected in accordance with their cavity-bearing potential (e.g.: large trembling aspen). A range of species and diameters (> 10 cm in diameter and > 3 m in height, including nonmerchantable species) should also be present so as to maximize biodiversity, and spacing should be varied for diversity and machine maneuverability as required. Leaving genetically inferior seed-bearing trees should be avoided.

Forest cover inside residual patches should have similar fire-resistance abilities and be composed of mixedwoods, followed by lowland conifers and upland conifers.

Retained structures (patches, trees and snags) should be distributed in cutting areas so there are at least individual retained trees in each hectare. It is important to ensure a distribution equal to roughly 20% of average residual area in patches less than five hectares, with 35% in patches from 5.1 to 50 hectares and 45% in patches greater than 50 hectares.

Patch location should also reflect local fire history. Preference should be given to wet low ground, hardwood aggregates, backs of hills and the lee shores of lakes and rivers. Course woody debris should be provided through cut-to-length or tree-length harvesting.

3.5 New Brunswick

3.4.1 *Forest-Management Guidelines for Biodiversity Protection in the Fundy Model Forest*

In *Forest-Management Guidelines for Biodiversity Protection in the Fundy Model Forest* (1997), S. Woodley and G. Forbes recommend that, to meet the needs of cavity-dependent birds, a minimum of 12 to 15 snags between 30 and 50 cm dbh/ha be left standing for feeding, plus 10 to 12 live or partially dead mature aspen or beech. Other species such as the maple or yellow birch (25 cm dbh) may be used if the former are absent.

Based on concentrations determined by means of research conducted in the greater Fundy ecosystem, the authors also recommended that there be a minimum of 200 pieces/ha of coarse woody debris (average piece diameter >10 cm) and a minimum total of 10 m^3/ha throughout the rotation of the stand.

Partners in the this project are now carrying out a case study on an area equal to about one-third of the model forest, implementing the guidelines and recommendations contained in the document.

3.4.2 J. D. Irving Limited

The J. D. Irving company has also developed guidelines for clearcut blocks in which plantations are anticipated **(**Brunston and Pinette 2001).

For these areas, the guidelines advocate the retention of:

- appreciable vertical-structure patches (0.2 ha minimum) in every 10-hectare opening;

- appreciable vertical-structure aggregates (at least 50 m^2, or 0.005 ha) in every two-hectare opening.

The document suggests that patches and aggregates be structured around major wildlife characteristics, site particularities (snags, nesting sites, rare species), or advance regeneration quadrats, and that hardwoods and large merchantable trees not be retained. Structures to be conserved inside protected areas (e.g.: watercourse buffer areas) are included in these values. Single-tree retention is strongly discouraged because of the high windthrow probability and reduced operational effectiveness involved.

Retention criteria may change as a function of site characteristics.

3.6 Nova Scotia

3.4.1 *Wildlife Habitat and Watercourses Protection Regulations*

The new *Wildlife Habitat and Watercourses Protection Regulations* (Province of Nova Scotia 2002), which are based on guidelines and standards developed in 1989 (Nova Scotia Department of Natural Resources 1989), state that, on any harvest site comprising an area greater than three hectares of forest land, at least 10 living or partially living trees are to be left standing for each hectare of forest land cut during a complete rotation. These trees are to be retained in clumps (1/8 ha) of at least 30 individuals, and composed of species that are representative of the stand harvested (species, dbh). The regulations also stipulate that clumps are to be situated no more than 200 m apart, and at least 20 m but no more than 200 m from the edge of the forest stand being cut.

Furthermore, the regulations require forest operators to provide levels of snags and coarse woody debris on all harvested sites that are similar to natural patterns to the fullest extent possible.

3.4.2 *Forest/Wildlife Guidelines and Standards for Nova Scotia*

These 1989 guidelines were designed to enrich forest fish and wildlife habitat (Nova Scotia Department of Natural Resources 1989). As most aspects involving variable retention have been incorporated into the *Wildlife Habitat and Watercourses Protection Regulations* (section 2.6.1), we will not discuss them here. New provisions bear on the preference of cavity-dependent birds for the maple and yellow birch and the preservation of nest-bearing trees inside aggregates large enough to conceal them.

4 Implementation Issues

4.1 Operational Feasibility

Planning, education and training are essential to the successful implementation of any harvesting or silvicultural system (Clayoquot Sound Scientific Panel 1995). Forest workers can provide extremely useful information on the relative merits of various systems and methods involving different conditions and topographies. Such information must be incorporated into silvicultural prescriptions. Many operational problems could be eliminated if a proper site assessment is conducted and specific abilities, equipment, processes, planning and communication are all taken into account (Washington State Department of Natural Resources 1992).

The authors agree that implementing variable retention requires close cooperation among the various stakeholders involved—including operators, on whom their success depends (Beese *et al.* n. d.b, Washington State Department of Natural Resources 1992, Phillips 1995, Clayoquot Sound Scientific Panel 1995, Bennett and Gilpin 1996).

It is mainly the methods and equipment used in yarding that are critical to meeting variable-retention harvesting objectives (Clayoquot Sound Scientific Panel 1995). Although operational experience with unconventional silvicultural systems is limited, results show that varied retention levels can be obtained by means of ground-based, cable and helicopter techniques.

The variable-retention system requires flexible, efficient and safe yarding methods (Clayoquot Sound Scientific Panel 1995). The specific factors dictating the system to be used are topography (slope steepness, variability), soil type (composition, sensitivity to disturbance), silvicultural system (retention level, number of harvest entries), timber characteristics (log size and volume per hectare), accessibility, and yarding distance and direction.

Topography and soil permitting, ground-based yarding methods provide the greatest flexibility as concerns retention level and distribution. The Clayoquot Sound Scientific Panel (1995) proposed a decision matrix incorporating all these considerations (Figure 3).

Sensitive environments and steep slopes are often avoided during conventional harvesting. International Forest Products Limited (Interfor) field-tested an initial harvest of overmature stands on steep slopes in which high-retention silvicultural systems had been implemented (Bennet and Gilpin 1996). The trial demonstrated the possibility of working such sites with conventional equipment, as well as the opportunity to increase timber yields. Felling and cable-yarding productivity, though lower than that obtained with clearcutting on similar sites, was not as high as anticipated (Bennett and Gilpin 1996).

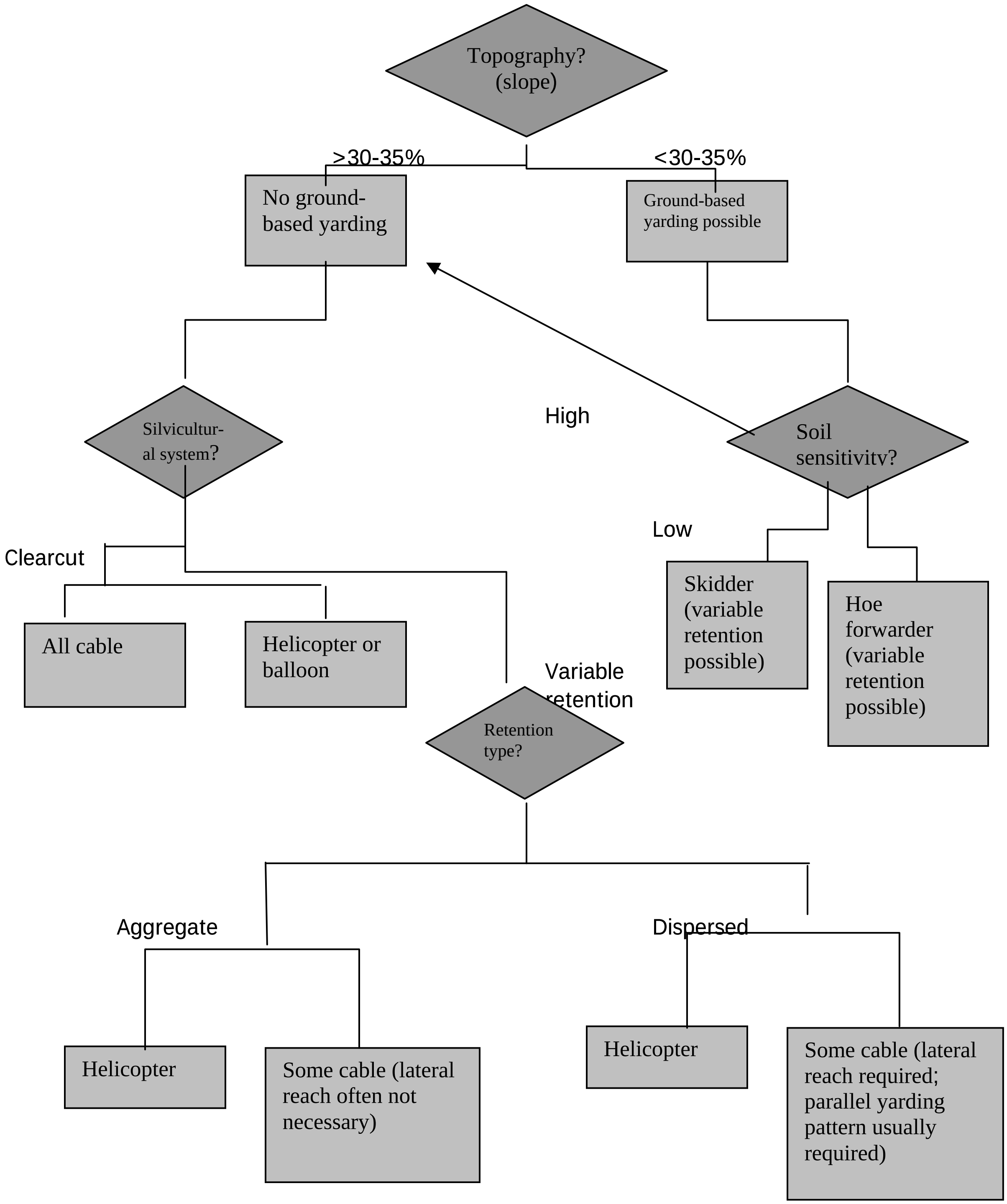

Figure 3: Harvesting Systems Decision Matrix

Source: Clayoquot Sound Scientific Panel (1995), p.102.

Harvesting in spruce wetlands caused irreparable site damage and was not very successful as regards regeneration. In 1993, the Lake Abitibi Model Forest developed the harvest with advanced regeneration protection (HARP) method specifically to solve this problem (Parton and Tallman forthcoming; Natural Resources Canada n. d.). Here, only those trees above an established diameter are removed. The young trees remaining respond well to release cutting, and the result is a variable-size uneven-aged stand. Harvesting is usually conducted by means of a feller-buncher that cuts all trees in its wake, creating a corridor as wide as itself (≈ 5 m). The felling boom extends from each side of the machine and selectively cuts the biggest trees, with advance regeneration remaining intact in residual strips six to nine meters wide. A skidder uses the same trails to move the wood on the side of the corridor. The fact that both types of equipment are track-type and use the same roads adds to the fact that operations are conducted mainly in winter, significantly reducing site disturbances (Parton and Tallman forthcoming, Natural Resources Canada n. d.).

Harvesting with protection of small merchantable stems (CPPTM), which was adapted primarily for the balsam fir and black spruce, makes it possible to harvest most forest-cover merchantable stems and maintain existing regeneration as well as merchantable stems (2 to 12 cm dbh) (Bégin and Riopel 2001). Protection for 14 to 16-cm dbh stems is also considered. Tests conducted as part of these operations demonstrated the feasibility of such harvesting methods in normal logging operations (Légère and Gingras 1998, Riopel *et al.* 2000, Bégin and Riopel 2001). Two harvesting procedures were used: one involving whole trees, feller-buncher and grapple skidder, and the other involving cross-cut trees, single-grip harvester and shortwood forwarder. The cross-cut tree system clearly outperformed the whole-tree system as concerns soil protection, high advance regeneration and small merchantable stems. However, more protected stems were injured using this method.

British Columbia's Montane Alternative Silvicultural System project (MASS) also showed that, while traditional harvesting equipment is suitable for alternative treatments (Phillips 1995, 1996), problems in the field may be considerable. Manual felling used in all experimental treatments resulted in difficulties that had not arisen in conventional clearcutting operations. Some pre-marked trees ended up in the felling line of larger-diameter trees, and suffered a certain amount of damage as a result. Consequently, forest workers had to modify their practices (preservation of advance regeneration patches near trees to be preserved). Yarding also damaged a few residual trees at the outset. As on-site structure preservation inevitably reduces machine-maneuverability options, this factor must be taken into account at the planning stage. However, with experience, operators should be able to minimize the effect of these variables from year to year.

Most harvesting by Weyerhaeuser Coastal B.C. is conducted by means of hoe forwarders or cable-logging systems (Beese *et al.* n. d.b). The former are used only on slopes under 30%; the latter are employed on slopes too steep for hoe forwarders where helicopter yarding is neither necessary nor efficient. Cable systems present the greatest challenge for variable retention and the highest potential cost increase as compared with clearcutting.

Weyerhaeuser also employs a technique that allows single stems to be removed by helicopter without setting them on the ground (Beese *et al.* n. d.a and b). The authors claim this method is particularly advantageous for operations in areas that would be inaccessible using conventional methods (unstable land, riparian zones, specific recreational areas, sensitive environments, particular wildlife-management areas). As these locations were previously considered too steep for harvesting, any opportunity to log without damaging resources is considered a plus.

Weyerhaeuser Coastal B.C. has boosted the proportion of its helicopter logging operations, as this eliminates the need for road construction and provides access to forests that are impossible to reach with conventional systems (Beese *et al.* n. d.a and b). However, the authors note that, according to Sambo (1997), helicopter use augments fuel consumption by 50% to 70% as compared with traditional methods. At the same time, heli-logging uses a grapple, which, in the authors' opinion, reduces both costs and hazards in comparison with the use of ground teams installing cable clamps.

Operations by Iisaak in Clayoquot Sound and by Interfor in retention sites are also conducted primarily by helicopter.

4.2 Economic Implications

Variable retention will likely reduce timber yield as compared to even-aged systems such as clearcutting. Such reduction takes two forms: the volume of wood in structures permanently retained in cutblocks and stand regeneration, because of residual-cover effects (Franklin *et al.* 1997).

Calculating the volumes and values associated with structure retention is uncomplicated, provided the latter are retained permanently. Weigand and Burditt (1992), for example, found that the potential value left behind varies from $102 to $1,114 per acre ($250 to $2,730/ha), depending on the prescriptions used. The real keys are the quantity and type of material left per unit value for this kind of content (Franklin *et al.* 1997). Immediate timber-production reductions may be compensated in part by the higher value of larger, better quality trees resulting from cover retention and longer rotations (Hansen *et al.* 1995).

To date, the experience of Weyerhaeuser Coastal B.C. suggests it will be possible to offset additional costs through technological innovation and improved performance (Beese *et al. a.* and *b*). The company hopes to fine-tune its ability to take advantage of market cycles by synchronizing stand harvesting in order to maximize the value of dominant-species sales. Weyerhaeuser foresees a reduction of its annual allowable cut level because of zoning and variable retention, but also expects that rate to stabilize. Negative repercussions on growth and yield due to retention and shading may also occur. On the other hand, with heightened emphasis on margins and market value, the general economic impact should be positive.

However, this new silvicultural approach may bring about additional costs of another kind. Planning (pre-marking of residual trees, for example), training, supervision, windthrow and fire losses, and modified harvesting methods also influence economic variables.

Research conducted as part of British Columbia's Montane Alternative Silvicultural System project (MASS) showed considerable differences between the costs of alternative harvesting methods and clearcutting (Phillips 1995, 1996). The author states that combined felling and forwarding costs were 10% higher with dispersed-retention harvesting ($7.88/m^3) and variable-retention harvesting ($ 7.87/m^3), and 38% higher with shelterwood felling ($9.92/m^3) than with clearcutting ($ 7.19/m^3). However, costs vary between duplicate implementation of the same type of treatment because of the differences in specific site timber and the experience gained by forest workers (from one site to the next). The author also states that the true significance of such differences will be determined based on the effects of these treatments on regeneration and stand windthrow resistance.

Studies on the economic implications of treatments involving HARP show a considerable number of advantages. Retained trees will allow for the faster return of a productive cohort, and thus an earlier recovery for the next harvest. Based on site characteristics and the stems counted after the treatments had been implemented, the authors feel that, in comparison with clearcutting, HARP may result in reduced rotation times of ten to 35 years (Bégin and Riopel 2001). HARP silvicultural systems also maintain less variable and higher levels of growing stock (MacDonell and Groot 1997). It is thought that the economic and environmental benefits of these systems offset the capital investments needed to develop equipment, as well as supervision, training, and incentive-program costs (Arnup 1998).

5 Monitoring Programs and Flexible Management

Since most guidelines are intended for operators, a number of industries are wondering how to ensure they have actually been implemented. Because operators are paid according to the volume of timber harvested, encouraging them to leave large-diameter merchantable trees, for example, may seem difficult (Margaret Donnelly, personal communication).

Moreover, given that variable retention is a relatively recent approach, it is important to ensure that changes to traditional harvesting operations actually achieve the goals established (Clayoquot Sound Scientific Panel 1995) and produce the benefits anticipated. As a result, there is a need for monitoring and feedback.

5.1 Guideline-Implementation Monitoring

In Alberta, Weyerhaeuser evaluated the success of ecological-guideline implementation three years after the guidelines were issued, so as to determine the numbers of merchantable trees actually left on sites harvested by FMA of Drayton Valley (Morgantini and Crosina 2001).

The number of structures retained in cutblocks was evaluated via oblique air photography of all areas in question, as well as a series of field surveys. Surveillance findings showed that, for 1999 and 2000, guideline implementation was extremely effective and met the retention goals established. Whereas cover retention for more than half the blocks had previously stood at between 1% and 5%, the 1999 and 2000 figures were between 10% and 20% for 37% and 19% of them, respectively.

As for the quantity of merchantable timber left behind, the figures varied between 3.77% for 1999 and 4.33% for 2000. Total retention (merchantable and non-merchantable trees) seems to have declined, falling from 5.25% to 4.85%, whereas merchantable-tree retention increased from 3.77% to 4.33%. The authors admit the figures might have been more accurate had they used the average retention volume per block, the average m^3 per hectare, or even the volume per stem rather than the total volume removed from the blocks. The document also states that some merchantable conifers were left on the cutblocks for silvicultural rather than ecological reasons.

Alberta-Pacific Forest Industries monitors its performance by means of audit sheets completed by operators at harvest, as well as by surprise counts. The company has an incentive program under which the most efficient workers have the chance to win a trip to Las Vegas (Anonymous, 2000 *a*).

5.2 Monitoring Effectiveness

A monitoring program makes it possible to verify whether goals will be met (Clayoquot Sound Scientific Panel 1995). The purpose of variable retention is to preserve a range of structures in order to meet biodiversity, habitat-maintenance and -conservation, productivity, and other objectives. Accordingly, an attendant monitoring system should be capable of determining if the structures chosen for retention are adequate (have the right structures been chosen?; have any been neglected?), sufficient (are there enough%), and properly distributed.

With this end in mind, a long-term monitoring program should be developed (Clayoquot Sound Scientific Panel 1995) to conduct comparative studies on forest status (ecosystems and processes) before and after forest entries, the reaction of harvested forests to one strategy as compared to another, and the condition of harvested as opposed to unharvested forests. The data obtained should then be used to modify management strategies and practices (in other words, the monitoring program must be adaptable).

The flexible management program being implemented by Weyerhaeuser B.C. incorporates viewpoints at both the landscape and stand level (Beese *et al.* forthcoming). The company began by comparing treatments used with certain targets and indicators (as advocated by the Clayoquot Sound Scientific Panel), such as unmanaged stands and well-known species requirements. As regards variable retention, Weyerhaeuser has already evaluated habitat structure in retention blocks and studied a number of organisms, such as nesting birds, owls, gastropods, amphibians, bryophytes, squirrels and lichen. Moreover, the various treatments used will also be compared to one another. Lastly, the company will develop and use prediction tools in order to assess the effect of different treatment combinations implemented on very large spatial or temporal scales. The data from this research will be used to determine the effectiveness of different types of retention in maintaining biodiversity resources and associated ecological processes (Beese *et al.* forthcoming).

Weyerhaeuser staff in Alberta are also monitoring method effectiveness in order to meet wildlife habitat needs and alleviate biodiversity concerns. The company has undertaken to make any adjustments its monitoring operations show are necessary.

Alberta-Pacific is currently working with scientists, governments and other corporations to develop a monitoring program for forest-management agreement areas (Anonymous 2000b).

To date, none of the companies approached has issued a follow-up report on retention-system effectiveness. However, several are in the process of drafting such documents, and the findings will be available shortly. This is the case, *inter* *alia*, for Iisaak Forest Resources in Clayoquot Sound (Barbara Beasley, personal communication).

Conclusion

This summary makes it possible to better understand variable retention on both a theoretical and practical level, and evaluates its importance on a national scale. Variable retention is a silvicultural tool that can minimize the impact of harvesting on forest ecological integrity through the retention of structural elements favourable to biodiversity maintenance and the re-establishment of ecosystem functions. It also makes for improved social perceptions, a factor that is fundamental to modern forestry management. Operational trials have demonstrated the feasibility of the approach; the costs and losses incurred at the outset seem to be offset by future ecological, social and economic gains.

As we have seen, the types of variable-retention systems implemented in Canada reveal a diversity in philosophies. First, there are those that use variable retention to meet specific habitat requirements based on the needs of species deemed important. In these cases, the structures to be maintained can be clearly identified in accordance with species requirements (e.g.: retention guidelines for pileated-woodpecker habitat maintenance in Ontario (Naylor *et al.* 1996)). Unless it includes an overall ecosystem-management policy, however, this so-called “by-the-piece” approach is still risky, as it would be perfectly possible to meet the needs of the species concerned without respecting the integrity of the ecological processes that occur naturally in the managed forest in question.

Second, variable retention is perceived and used as a means to emulate natural disturbances. Here, the structures retained correspond to those usually left behind after recurrent landscape disturbances. The choice, number and distribution of retained elements is therefore based on what has been learned from such disturbances. The species selected will be those that normally survive these disturbances, located in less favourable or more protective environments.

Lastly, variable retention may be used as a tool to attenuate the changes caused by logging. Here, the goal is to preserve the forest conditions that existed in the original stand to every possible extent—in other words, to preserve a forest influence throughout the cutblock. The structures retained thus reflect those of the original stand. In accordance with this viewpoint, more retention is always better.

Clearly, the philosophy of use will make all the difference, as it will determine the structures to be retained, which in turn will likely influence the developing stand. Thus, an approach that simulates a natural disturbance such as fire will attract pioneer species for, example, or wildlife that prefers open areas, whereas preserving an influence over the original stand will eliminate the pioneer phase and promote a very different type of wildlife. Ensuring a suitable habitat for a given wildlife species does not necessarily guarantee the same for another.

Apart from ecological variances, there are certainly economic differences. Attenuating the impact of logging maintains control over the next stand by preserving valuable species and likely ensures a faster return than harvesting that emulates natural disturbances (e.g.: HARP). However, HARP harvesting that emulates natural disturbances may involve more significant immediate economic benefits. The social acceptability level is also different—emulating natural disturbances sometimes means opening up large areas, which can be extremely negative from an esthetical point of view.

Another question is the number, choice and distribution of retained elements. Despite the differences in approach, many guidelines opt for the retention of eight to 12 live trees (15%) per hectare (especially those with wildlife attributes), the maximum possible quantity of snags and woody debris, and aggregate distribution. But is this enough? The fact remains that, regardless of the approach used, variable retention is a relatively recent innovation, and it is still too early to determine its actual capabilities and limitations. The basic question that should be asked before any action is taken is this: From an ecological economic and social perspective, what should the forest be like in the future? Although science has generally demonstrated the value of variable retention as regards biodiversity and ecological-process maintenance, there are few scientific tools that can help managers with variable-retention prescriptions. A tool that would optimize the economic value of a stand while retaining enough structural elements to provide the ecological functions required, and could be adapted to different situations across Canada, is therefore highly desirable.

The importance of long-term monitoring programs will play a vital role in developing such a tool. Program results will make it possible to measure approach effectiveness and establish structure-management guidelines. The measures used must be able to be compared to other methods, forests and conditions, and try to determine if the biological legacies chosen are sufficient, adequate and properly distributed.

In addition to monitoring operations, the active adaptable management approach (Walters and Holling 1990) requires that experiments at the unit level be compared in accordance with a scientific protocol. Certain integrative projects are now being conducted in this vein, and have already attempted to answer questions related to variable retention. This is the case, inter alia, for Alberta's ecosystem management emulating natural disturbance project (EMEND) (Sidders and Spence n. d.) and British Columbia's Montane Alternative Silvicultural Systems project (MASS) (Arnott *et al.* 1995), which are experimenting with large-scale forest harvests. Researchers are attempting to determine which harvesting and regeneration practices make it possible to adequately maintain biotic communities, forest-structure spatial layout, and ecosystem functional integrity in comparison with mixed landscapes that are the result of fire and other natural disturbances. They hope to use economic and social analyses to evaluate these practices in terms of economic viability, sustainability, and social acceptability.

This type of study is essential for sound forestry operations. As the findings of these experiments and monitoring programs will be used to establish and modify management strategies and practices, it is imperative that they be rapidly disclosed, accessible and available. Technology-transfer tools should then be developed to facilitate the work of forest managers in their sustainable-management efforts. This summary constitutes a first step to that end.

Literature Cited

Anonymous. 2000a. *Alberta-Pacific's Detailed Forest Management Plan*. Alberta-Pacific Forest Industries. 170 p.

Anonymous. 2000b. *Alberta-Pacific's Operating Ground Rules for the Alberta Pacific Forest Management Area*. Alberta-Pacific Forest Industries. 99p.

Anonymous. 2000c. *A Forest worker's Guide to Stand Structure*. Tembec: Cranbrook, British Columbia. 2 p.

Anonymous. n. d.a. *An Operator's Guide to Stand Structur*e. Alberta-Pacific Forest Industries. 28 p.

Anonymous. n. d.b. *Landscape Level Targets*. Daishowa Marubeni International Ltd. 9 p.

Anonymous. n. d.c. *Stand Level Ecological Guidelines.* Weyerhaeuser. Edson Forestlands, Alberta. 12 p.

Arnott, J. T., W. J. Beese, A. K. Mitchell, and J. Peterson. 1995. *Montane Alternative Silvicultural Systems (MASS): Canada-British Columbia Partnership Agreement on Forest Resource Development*. FRDA Report 238. Victoria, B.C.: British Columbia Ministry of Forestry.

Arnup, R. W. 1998. *Forest Ecosystem Classification in Ontario, Canada: A Case Study of Its Application to Sustainable Forest Management*. ESG International Inc**.** Santiago, Chile: Roundtable on Forestry Industry. 18-20 November, 1998.

Askin, R. W. and V. P. Dragunas. 1995. "Snow Hydrology Pilot Study." In *Montane Alternative Silvicultural Systems (MASS): Canada-British Columbia Partnership Agreement on Forest Resource Development*, ed. J. T. Arnott, W. J. Beese, A. K. Mitchell, and J. Peterson, 37-40. FRDA Report 238. Victoria, BC: British Columbia Ministry of Forestry.

Barg, A. K. and D. P. Hanley. 2001. *Silvicultural Alternatives: Variable Retention Harvests in Forest Ecosystems of Western Washington. A Guide for Forests Landowners CE-CAHE*. Pillman, WA.: Washington State University. Document EB1899.

Beese, W. J. and A. Bryant. 1999. Effect of Alternative Silvicultural Systems on Vegetation and Bird Communities in Coastal Montane Forests of British Columbia, Canada. *Forest Ecology and Management*. 115(2-3): 231-242.

Beese, W. J., B. G. Dunsworth, K. Zielke, and B. Bancroft. n. d.a. *Maintaining Attributes of Old-Growth Forests in Coastal B.C. Through Variable Retention*. Weyerhaeuser, B.C. Coastal Group and Symmetree Consulting Group. 25 p.

Beese, W. J., and G. B. Dunsworth. n. d.b. *Variable Retention Harvesting to Conserve Biodiversity in Coastal British Columbia Using Helicopter and Conventional Logging Methods*. Weyerhaeuser, B.C. Coastal Group. 10 p.

Beese, W. J., G. B. Dunsworth, and J. Perry. *The Forest Project: Three-Year Review and Update*. Forthcoming, 8 p.

Bégin, J. and M. Riopel. 2001. *La coupe avec protection des stems marchandes: 4 ans plus tard où en sommes nous?* Université Laval. Faculté de foresterie et de géomatique. 3 p.

Bennett, D. and W. Gilpin. 1996. Implementing High-Retention Silvicultural Stems on Steep Slopes: Harvesting System Design and Productivity. FERIC, International Forest Products Limited, 1996 Annual Meeting E79-E83.

British Columbia Ministry of Forests. 1995. *Biodiversity Guidebook. Forest Practices Code of British Columbia Act. Strategic Planning Regulations. Operational Planning Regulation.*

Brunston, B. and R. Pinette. 2001. *Guidelines to Maintain Structural Diversity Within Harvest Areas Planned for Subsequent Tree Planting*. JD Irving Limited. 2 p.

Clayoquot Sound Scientific Panel. 1995. *Sustainable Ecosystem Management in Clayoquot Sound: Planning and Practices*. Victoria: Queen's Printer for British Columbia. 296 p.

Courtin, G. M. and J. E. Beckerton. 1997. Does the Practice of Careful Cutting Maintain Biodiversity? *Forestry Chronicle*.

Darveau, M. and A. Desrochers. 2001. *Le bois mort and la faune vertébrée – État des connaissances au Québec*. Québec: Ministère des Ressources naturelles, Direction de l'environnement forestier (DEF-0199). 37 p.

Ehnes, J. and D. Sidders. 2002. *A Guide to Harvesting Practises to Regenerate a Natural Forest* (*draft*). 26 p.

Franklin, J. F. 1992. Scientific Basis for New Perspective in Forests and Streams. In *Watershed Management: Balancing Sustainability and Environmental Change*, ed. R. Naiman, 5-72. New York: Springer-Verlag.

Franklin, J. F., D. R. Berg, D. A. Thornburgh, and J. C. Tappeiner. 1997. Alternative Silviculture Approaches to Timber Harvesting: Variable Retention Systems. In *Creating a Forestry for The 21st Century: The Science of Ecosystem Management*, ed. K. A. Kohm and J. F. Franklin, 111-139. Washington, D.C.: Island Press.

Freedman, B., V. Zelazny, D. Beaudette, T. Fleming, S. Fleming, G. Forbes, J. S. Gerrow, G. Johnson, and S. Woodley. 1996. Biodiversity Implications of Changes in the Quantity of Dead Organic Matter in Forts, with Particular Reference to Atlantic Canada. *Environmental Review*. 4:238-265.

Gibbons, P. and D. B. Lindenmayer. 1996. Issues Associated with the Retention of Hollow-Bearing Trees within Eucalypt Forests Managed for Wood Production. *Forest Ecology and Management*. 83:245-279.

Halpern, A. J. and T. A. Spies. 1995. Plant Species Diversity in Natural and Managed Forests of the Pacific Northwest. *Ecological Applications*. 5:913-934.

Hansen, A. J., S. L. Garman, J. F. Weigand, D. L. Urban, W. C. McComb, and M. G. Raphael. 1995. Alternative Silvicultural Regimes in the Pacific Northwest: Simulations of Ecological and Economic Effects. *Ecological Applications*. 5(3):535-554.

Hanski, I. and E. Gilpin. 1997. *Metapopulation Biology: Ecology, Genetics, and Evolution*. New York: Academic Press. 512 p.

Hunter, M. L. Jr. 1990. *Wildlife, Forests, and Forestry. Principles of Managing Forests for Biological Diversity*. Englewood Cliffs, NJ: Prentice-Hall. 370 p.

Hunter, M. L. Jr. and R. S. Seymour. 1992. *New Forestry in Eastern Spruce-Fir Forests: Principles and Applications to Maine*. Maine Agricultural and Forest Experiment Station. Miscellaneous Publication 716. 36 p.

International Forest Products Limited. 2002. http://interfor.com/

Iisaak Forest Resources. 2002. http://iisaak.com/

Keenan, R. J. and J. P. Kimmins. 1993. The Ecological Effects of Clear-Cutting. *Env. Rev.* 1:121-144.

Kimmins, J. P. 1997. *Balancing Act: Environmental Issues in Forestry*. 2nd ed. Vancouver, B.C.: UBC Press. 305 p.

Koppenaal, R. S., B. J. Hawkins and A. K. Mitchell. 1995. Nitrogen Limitations on Early Growth of Natural and Planted Montane Regeneration. In *Montane Alternative Silvicultural Systems (MASS): Canada-British Columbia Partnership Agreement on Forest Resource Development*, ed. J. T. Arnott, W. J. Beese, A. K. Mitchell, and J. Peterson, 41-47. FRDA Report 238. Victoria, B.C.: British Columbia Ministry of Forestry.

Légère, G. and J.-F.Gingras. 1998. Évaluation de méthodes de coupe avec protection des petites stems marchandes. Forest Engineering Research Institute of Canada (FERIC). Technical Report RT-124. 12 p.

Louisiana-Pacific Canada Ltd. 2001. Forest Management Licence #3. *2000-2001 Annual Report*. Louisiana-Pacific Canada Ltd. Swan Valley-Forest Resources Division Forest Management. 68 p.

MacArthur R. and E. O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton University Press. 203 p.

MacDonell, M. R. and A. Groot. 1996. *Uneven-Aged Silviculture for Peatland Second-Growth Black Spruce: Biological Feasibility*. Sault Ste. Marie, Ont.: Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre. NODA/NFP Technical Report TR-36. 14 p.

McComb, W. C., T. A. Spies, and W. H. Emmingham. 1993. Douglas-Fir Forests: Managing for Timber and Mature-Forest Habitat. *Journal of Forestry*. 91:31-42.

Millar Western Forest Products Ltd. 2002. http://www.millarwestern.com/

Mitchell, A. 2001. Variable-Retention Harvesting–Potential for the Boreal? New Knowledge and Solutions for Forest Management. January 29-30, Senator Hotel, Timmins, Ontario. http://www.lamf.net/Conference/ConferenceProceedings.htm

Mitchell, A. K. and J. T. Arnott. 1995. Montane Alternative Silviculture Systems: Ecophysiology of Regenerating Conifers. In *Montane Alternative Silvicultural Systems (MASS): Canada-British Columbia Partnership Agreement on Forest Resource Development*, ed. J. T. Arnott, W. J. Beese, A. K. Mitchell, and J. Peterson, 69-80. FRDA Report 238. Victoria, B.C.: British Columbia Ministry of Forestry.

Morgantini, L. and W. Crosina. 2001. *Weyerhaeuser Drayton Valley FMA Stand Level Retention Monitoring Report: 1999 - 2000*. Weyerhaeuser in Alberta. 6 p.

Natural Resources Canada. n. d. *Harvest with Regeneration Protection: Planning and Operating Manual*. Forestry Canada. 17 p.

Naylor, B. J., J. A. Baker, D. M. Hogg, J. G. McNicol, and W. R. Watt. 1996. *Forest Management Guidelines for the Provision of the Pileated Woodpecker Habitat*. Queen's Printer for Ontario: Ontario Ministry of Natural Resources. 26 p.

Nevill, R. J. and C. Wood. 1995. Hemlock Dwarf Mistletoe and Decay Organisms Associated with Western Hemlock and Amabilis Fir at the Montane Alternative Silviculture Systems (MASS) Research Site in Coastal British Columbia. In *Montane Alternative Silvicultural Systems (MASS): Canada-British Columbia Partnership Agreement on Forest Resource Development*, ed. J. T. Arnott, W. J. Beese, A. K. Mitchell, and J. Peterson, 19-24. FRDA Report 238. Victoria, B.C.: British Columbia Ministry of Forestry.

North, M., J. Chen, G. Smith, L. Krakowiak, and J. Franklin. 1996. Initial Response of Understory Plant Diversity and Overstory Tree Diameter Growth to a Green Tree Retention Harvest. *Northwest Science*. 70(1):24-35.

Ontario Ministry of Natural Resources. 2001. *Forest Management Guide for Forest Disturbance Pattern Emulation*. 66 p.

Parton, S. and J. Tallman. *Harvest with Regeneration Protection (HARP): An Alternative Silvicultural System for Black Spruce – Developed Through the Lake Abitibi Model Forest*. Forthcoming. 3 p.

Phillips, E. J. 1995. Harvesting Logistics and Costs. In *Montane Alternative Silvicultural Systems (MASS): Canada-British Columbia Partnership Agreement on Forest Resource Development*, ed. J. T. Arnott, W. J. Beese, A. K. Mitchell, and J. Peterson, 9-13. FRDA Report 238. Victoria, B.C.: British Columbia Ministry of Forestry.

Phillips, E. J. 1996. *Comparing Silvicultural Systems in a Coastal Montane Forest: Productivity and Cost of Harvesting Operations*. FRDA Report. FERIC Special Report No. SR-109. Her Majesty the Queen in Right of Canada. 42 p.

Province of Alberta. 1994. *Harvest Planning and Operating Ground Rules*. Alberta Environmental Protection.

Province of Nova Scotia. 2002. Wildlife Habitat and Watercourses Protection Regulations Made Under Section 40 of the *Forest Act* R.S.N.S. 1989, c. 179 OI.C. 2001-528 (November 15, 2001, effective January 14, 2002), N.S. Reg. 138-2001.

Riopel, M., J. Bégin, and J.-F.Gingras. 2000. Une option pour la récolte en forest boréale : la coupe avec protection des petites stems marchandes. *Avantage* 1(17): 8 p.

Rose, C. R. and P. S. Muir. 1997. Green-Tree Retention: Consequences for Timber Productions in the Forests of the Western Cascades, Oregon. *Ecological Applications*. 7(1):209-217.

Sambo, S. M. 1997. *Fuel Consumption Estimates for Typical Coastal British Columbia Forest Operations*. Forest Engineering Research Institute of Canada. Tech. Note TN-259. 4 p.

Schreiber, B. and D. S. deCalesta. 1992. The Relationship Between Cavity Nesting Birds and Snags on Clearcuts in Oregon. *Forest Ecology and Management*. 50:299-316.

Sidders, D. and J. Spence. n. d. *Ecosystem Management Emulating Natural Disturbance: Research Study and Field Guide*. Network for Sustainable Forest Management, Natural Resources Canada, Forestry Canada.

Steeger, C. and H. Quesnel. 1998. *Impacts of Partial Cutting on Old-Growth Forests in the Rocky Mountain Trench: Interim Report. Enhanced Forest Management. Pilot Project*. Project Summary 9. 7 p.

Stuart-Smith, A. K. 2001. Songbird Communities in Burned and Logged Stands with Variable Tree Retention in the Canadian Rocky Mountains. Dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Oregon State University. 77 p.

Swanson, F. J. and J. F. Franklin. 1992. New Forestry Principles from Ecosystem Analysis of Pacific Northwest Forests. *Ecological Applications*. 2:262-274.

Voigt, D. R., J. D. Broadfoot, and J. A. Baker. 1997. *Forest Management Guidelines for the Provision of White-Tailed Deer Habitat*. Ontario Ministry of Natural Resources: Queen's Printer for Ontario. 33 p.

Walters, C. J. and C. S. Holling. 1990. Large-Scale Management Experiments and Learning by Doing. *Ecology*. 71:2060-2068.

Washington State Department of Natural Resources. 1992. *Reserve Tree Selection Guidelines*. State of Washington, Department of Labour and Industries. 24 p.

Watt, R. W., J. A. Baker, D. M. Hogg, J. G. McNicol, and B. J. Naylor. 1996. *Forest Management Guidelines for the Provision of Marten Habitat*. Ontario Ministry of Natural Resources, Forest Management Branch: Queen's Printer for Ontario. 26 p.

Weigand, J. F. and A. L. Burditt. 1992. *Economic Implications for Management of Structural Retention of Harvest Units at the Blue River Range District, Willamette National Forest, Oregon*. Research Note PNW-RN-510. Washington, DC: USDA Forest Service.

Woodley, S. and G. Forbes, eds. 1997. *Forest Management Guidelines To Protect Native Biodiversity in the Fundy Model Forest*. Greater Fundy Ecosystem Research Group. Fredericton, N.B.: University of New Brunswick, Co-operative Fish and Wildlife Research Unit. 42 p.

Zenner, E. K., S. A. Acker, and W. H. Emmingham. 1998. Growth Reduction in Harvest-Age, Coniferous Forests With Residual Trees in the Western Central Cascade Range of Oregon. *Forest Ecology and Management*. 102:75-88.