The retention system: reconciling variable retention with the principles of silvicultural systems

by S.J. Mitchell[1] and W.J. Beese[2]

The philosophy of ecosystem management seeks a balance between protecting natural systems and using them to meet societal demands. The objectives of silvicultural systems listed in standard texts focus on the sustained production of timber and maintenance of quality growing stock. These objectives need updating for situations where the broader goal is to sustain ecosystem function and productivity. The "retention system" recently adopted in British Columbia is a silvicultural system designed to implement the "variable retention" (VR) approach to harvesting. With VR, trees are retained to meet ecological objectives such as maintaining structural heterogeneity and protecting biological legacies. The contribution of retained trees to yield or regeneration may be low or even negative. Among the challenges in implementing the retention system is the adjustment of yield expectations and target stand projections to account for the expected health and vigour of the future stand.

Keywords: silvicultural system, retention system, variable retention, ecosystem management

La philosophie de l'aménagement écosystémique cherche un équilibre entre la protection des systèmes naturels et leur utilisation pour répondre aux demandes sociétales. Les objectifs des régimes sylvicoles énumérés dans les textes courants se concentrent sur la production soutenue de bois et sur le maintien de la qualité des stocks en croissance. Ces objectifs doivent être mis à jour dans le cas de situations où l'objectif général vise à maintenir les fonctions et la productivité de l'écosystème. Le « système à rétention variable » récemment adopté en Colombie-Britannique est un régime sylvicole conçu pour implanter une approche de « rétention variable » (rv) au niveau de la récolte. Avec la rv, des arbres sont préservés pour répondre aux objectifs écologiques comme le maintien de l'hétérogénéité structurale et la protection de l'héritage biologique. La contribution des arbres préservés au niveau du rendement ou de la régénération peut être faible ou même négative. Parmi les défis contenus dans l'implantation d'un régime de rétention, on retrouve l'ajustement des attentes en matière de rendement et des projections visées pour le peuplement qui tiennent compte de la santé et de la vigueur anticipée du peuplement dans l'avenir.

Mot-clés: régime sylvicole, régime de rétention, rétention variable, aménagement écosystémique.

Introduction

In the past decade, the philosophy of "ecosystem management" has largely replaced that of "multiple use" which had guided forest management from the 1960s to the 1980s. This reflects a shift of societal perspectives from forests as sites for balanced production of extractive and non-extractive commodities, to acceptance of forests as dynamic ecosystems with diverse structure and functions. Ecosystem management seeks a balance between protecting natural systems and using them to meet societal demands (e.g., Vogt *et al.* 1997). Its basic principles include: accounting for changing objectives and values of interest to owners and society as a whole; ensuring a minimum level of integrity, resiliency and diversity across managed stands and forests; and consideration of the effects of management at a landscape scale over the long term, including economic viability of treatments, constraints on future management and potential for undesirable or irreversible ecological change (Brooks and Grant 1992). Naturalistic silvicultural systems that attempt to maintain natural forest structure and dynamics are not new to forestry and have long been recognized as a means for reducing economic and ecological uncertainty (e.g., Bruenig and Klemp 2000). For example, the single-tree selection system has been used to regulate yield and maintain continuous cover in uneven-aged forests for over 100 years; however, traditional silvicultural systems are better suited for maintaining quality of growing stock than for maintaining structural heterogeneity and protecting biological legacies. The need for an approach and terminology that better reflects an emphasis on non-timber objectives lead to the adoption of a new silvicultural system in British Columbia.

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The Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (CSSP) was established by the government of BC to develop forestry practices for the temperate rainforest ecosystems of Clayoquot Sound that were consistent with the principles of ecosystem management. The panel of respect-

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ed scientists and First Nation's leaders cited the following specific ecological objectives for harvesting old growth forests while retaining intact habitat for forest biota:

> "to provide, immediately after harvest, habitat (e.g., large trees, snags, and logs) important to the survival of organisms and processes that would otherwise be lost from the harvested area either temporarily or permanently; to enrich current and future forests by maintaining some remnant structural features and organisms from the previous stands [which] might otherwise be absent from the cutting unit for decades after logging; and to improve 'connectivity' between cutting units and forest areas by facilitating the movement of organisms through the cutover areas." (CSSP 1995).

This approach was also consistent with social objectives such as the protection of culturally important sites, scenic quality and recreational values. A harvesting strategy termed "variable retention" was proposed by the CSSP in which structural elements of the existing stand are retained for the long term throughout a harvested area to achieve specific silvicultural, ecological, habitat, biodiversity and economic objectives. Variable retention (VR) recognizes that natural disturbances such as fire, wind or disease nearly always leave some standing structure from the original forest, typically with a high degree of spatial variability. This structural heterogeneity plays an important role in forest ecosystem function and biological diversity (Bunnell *et al*. 1999). The VR approach uses a wide range of retention with varying amounts, types and spatial patterns of living and dead trees to address a wide array of forest management goals. Franklin *et al*. (1997) described this harvesting approach, its potential for broader application and some of the management issues associated with its application. Neither the CSSP nor Franklin *et al*., however, reconciled variable retention with the objectives and requirements of silvicultural system design.

Weyerhaeuser and several other forest products companies have recently adopted variable retention as the basis for their stand and forest level planning in coastal British Columbia. Because none of the existing silvicultural systems terminology was suitable for describing this new approach in legal prescriptions, the "retention system" was defined in legislation. The emphasis in implementing this new system to date has been on the design of the initial harvesting entry and condition of the stand immediately afterward. To be considered a silvicultural system and not simply a description of the target stand or harvesting approach, the retention system must meet a number of conditions. The objective of this paper is to discuss these conditions and identify challenges that managers will need to meet in order to implement this system successfully over the long term. In this discussion we also suggest that the objectives of silvicultural systems listed in standard texts need updating in order to be consistent with the principles of ecosystem management.

Silvicultural System Terminology

Reaching common agreement on the meaning of technical concepts and their associated terminology is essential for communication between professionals. Terms and definitions are useful only if they are uniformly understood and clearly communicate the intentions of the user. Communication is aided if the terms used are descriptive. In the following discussion, we attempt to conform to the norms of silvicultural terminology and clarify the distinction between the terms "variable retention" and the "retention system."

Definition of a silvicultural system

Matthews (1989) defines a silvicultural system as a complete regime for regenerating, tending and harvesting forests. It is the process by which the crops constituting a forest are tended, removed and replaced by new crops, resulting in the production of stands of distinctive form. Silvicultural systems are designed for specific stands to meet specific sets of management objectives and ecological conditions, and should fit into the overall plan for the forest of which the stand is a part. It is expected that these systems evolve over time as circumstances change and as knowledge improves (Smith *et al*. 1997).

Silvicultural system names

In traditional silvicultural systems nomenclature, methods of reproduction are grouped into classes based on the source of regeneration and arrangement of cutting areas in time and space. Silvicultural systems are typically named after the reproduction method and may result in a variety of stand structures over time. On completion of the regeneration period, the clearcut, patch cut, shelterwood and seed-tree systems usually result in even-aged stands; however, reserves can be maintained in any of these systems leading to a two-aged stand. The arrangement and timing of overstory removal in the shelterwood system can be modified to produce multi-aged stands. The selection system maintains uneven-aged stands through periodic and continual removal of individual trees or groups.

Target stand and prescriptions

Silvicultural interventions are intended to move a stand from its current condition towards a desired future condition or "target stand" (Naumann *et al*. 1991). The challenge for silviculturists is to integrate a series of treatments over time with consideration for the continued growth and development of the vegetation community on a given site. A clear expression of the target stand greatly assists prescription development and design of a site-specific silvicultural system. The target stand is a "product," while the silvicultural system is a "process" that incorporates the future care, development and replacement of stands over time (Fig. 1). We recommend using the term variable retention at both the stand and forest levels to describe the broad target condition, as one would use the term "even-aged." At both scales, VR represents the product of management, not the process by which this result is achieved. We recommend using silvicultural system names to describe the stand level process for achieving variable retention, and the term "variable retention approach" to describe the forest level process.

Argument for a new silvicultural system

At the landscape level, variable retention can be achieved by creating a mosaic of stands managed under different silvicultural systems interspersed with reserve stands. At the stand level, an argument can be made that the structural goal of variable retention can be achieved through modification or combination of existing silvicultural systems, and it is therefore unnecessary to define a new silvicultural system to describe the process. However, the intent and outcome of the process used to achieve variable retention differs substantially from the

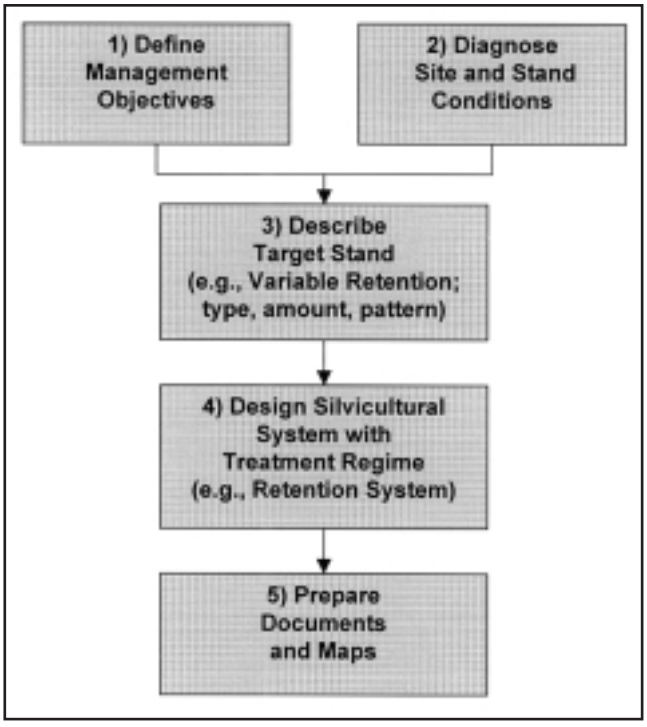

Fig. 1. The steps in preparing a silviculture prescription. The target stand (Step 3) integrates management objectives (Step 1) and site/stand conditions (Step 2). The silviculture system with treatment regime (Step 4) is the process that over time takes the stand towards the target condition.

norms for existing systems. While it is possible to use traditional terminology to describe prescriptions that produce variable retention in some stands (e.g., clearcut with reserves, irregular shelterwood), more often the existing terms are awkward or confusing in relation to the objectives. The argument for having a new system is not that stand level variable retention is unattainable through modification of the application of classical silvicultural systems, but that defining a new system will improve clarity of intent.

Silviculturists can choose to retain trees and stand structures that have the best qualities for timber production, trees and structures that have the highest quality for biological diversity, or some combination of the two. It is unlikely that a condition that maximizes timber production will also maximize biological diversity. Classical systems are well suited where the objective is to optimize timber production while maintaining stands that meet various non-timber objectives. High-quality trees are reserved from cutting in order to provide seed and maximize increment. The desired stand structure is achieved through cultivation of regeneration and release of existing trees. The retention system is best suited where timber production is desired but maintenance of the structural complexity and biological legacies found in older forests is as important as, or even supersedes, yield and the improvement of growing stock. Desired structures are not produced through cultivation of young growth, but through retention of pre-existing elements. Structural elements include biological legacies such as old, large, decayed, dying and dead trees, and large logs whose features take many decades or centuries to produce. Distinctive within-stand communities such as patches of vegetation associated with localized site features and natural edges (e.g., rock outcrops, wetlands) are also retained to increase the heterogeneity of the resulting vegetation community. In contrast to the design criteria for silvicultural systems intended to improve growing stock, the retained trees may be very old, of poor timber quality and low vigour, but have features that increase their value for wildlife habitat.

Distinction from other systems

Prior to defining the retention system, foresters wishing to create stands with variable retention used existing terminology such as "clearcut with reserves." The problem with this term is two-fold: 1) there are no quantitative, spatial and temporal requirements for the retention; and 2) the terminology is an oxymoron that does not describe the objective in a positive way. There are clear principles for implementing the single-tree selection system in a way that maintains an uneven-aged stand of high quality trees for sustained yield and improvement of growing stock (BDq regulation). It is unwise to undermine the present clarity of this system by using it to describe prescriptions where irregular structures containing trees with low timber quality and vigour are the goal. Similarly, the term "irregular shelterwood" is inappropriate when the function of the retained trees is not to promote regeneration through shelter.

The definition of the "retention system" adopted in British Columbia legislation is: "a silvicultural system that is designed to retain individual trees or groups of trees to maintain structural diversity over the area of the cutblock for at least one rotation, and leave more than half the total area of the cutblock within one tree height from the base of a tree or group of trees, whether or not the tree or group of trees is inside the cutblock" (Forest Practices Code of BC Act, Operational Planning Regulations, March 1999). The definition contains two key elements that distinguish the retention system: long-term structural diversity throughout a harvesting unit, and a spatial distribution that maintains forest influence on the majority of the harvested area. Although the objective is to maintain structure in perpetuity, there may be reasons to substitute new retained trees and groups over time; hence, the "for at least the next rotation" clause is used to allow flexibility. The requirement to maintain "forest influence" adds criteria for the amount and spatial distribution of reserves and distinguishes the retention system from clearcutting with reserves.

Forest or residual tree "influence" is defined as the biophysical effects of forests or individual trees on the environment of the surrounding land. The degree, type and distance of influence can vary widely; however, within and adjacent to harvested areas, most forest edge and residual tree influences begin to diminish significantly at distances greater than one tree length from a standing tree, group of trees or forest edge (Keenan and Kimmins 1993). The retention system, therefore, must maintain greater than half of the original forest area within the influence of surrounding trees, or trees retained within the harvested area, and create openings that are generally less than four tree heights across. The retention system is designed to maintain these influences on the majority of the cutblock area using one co-dominant tree height as a practical average (Fig. 2). Overstory influence is retained over the majority of the opening throughout the rotation—sometimes at the expense of the growth and vigour of regeneration and sapling layers. Where several age classes are retained

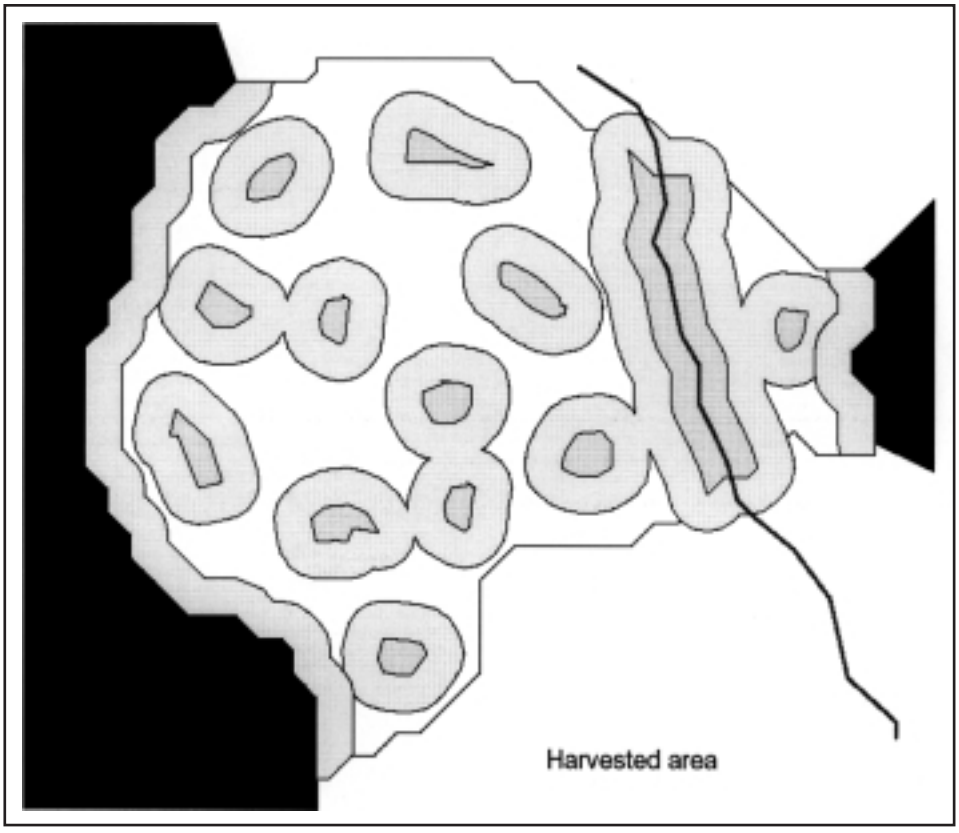

Fig. 2. Group retention cutblock showing 10% of the harvested area in group reserves at least 0.25 hectares in size, including a riparian strip. Half of the adjacent area is forested (black) and the remainder is recently harvested. Forest influence of one 40-m tree height (light shading) and group retention (dark shading) equals 63% of the cutblock area.

within a management unit, this is done not in order to balance age class distribution, but to emulate age class distributions typical of natural disturbances.

Unfortunately, if narrowly applied, the legal definition reduces variable retention to a set of geometric rules and does not sufficiently emphasize the importance of retaining biological legacies such as large trees, snags and coarse woody debris. The desired future condition or "target stand" in retention prescriptions should specify the type, amount and spatial pattern of retained structures required to meet management objectives (Franklin *et al.* 1997). At the landscape level, variable retention objectives are achieved by maintaining forested reserves and by varying retention prescriptions from block to block in harvested areas. While the term "variable" may imply unplanned, deliberate targets should be stated. Within-stand structures and landscape-level stand patterns maintained by natural disturbances such as fire, wind and insects provide an ecological basis for these targets.

Variants—group retention, dispersed retention

Retention system variants can be named in the same manner as variants of classical silvicultural systems. In "dispersed" retention, individual or small groups of trees are left to distribute structural elements throughout the future stand. In "group" or "aggregated" retention, groups of trees are sufficiently large to retain undisturbed understory vegetation and to provide a safe buffer around dead or decaying trees. Groups are typically a minimum of a quarter of a hectare in size. Since the goal with the retention system is to retain spatial heterogeneity, the typical form of the system will include both aggregated and dispersed reserves (Fig. 3).

Making Retention A Silvicultural System

Objectives of silvicultural systems

The traditional focus on sustained production of timber is evident in the seven objectives of silvicultural systems set out by Smith (1986):

- Harmony with goals and characteristics of ownership.
- Provision for regeneration.
- Efficient use of growing space and site productivity.
- Control of damaging agencies.
- Provision for sustained yield.
- Optimum use of capital and growing stock.
- Concentration and efficient arrangement of operations.

Reflecting an increasing emphasis on non-timber values, Smith *et al*. (1997), update this list with three additional objectives.

- Protection of soil and water resources.
- Maintenance of desired plant and animal populations.
- Execution of policies about landscapes, scenery, and aesthetic considerations.

Objectives paraphrased for ecosystem management

That the retention system is a useful addition to existing silvicultural systems and can meet the objectives of silvicultural systems becomes all the more apparent if the list of Smith *et al*. (1997) is re-stated and re-ordered to make it more consistent with the principles of ecosystem management summarized by Brooks and Grant (1992).

- Harmony with goals and characteristics of ownership, *and with societal values concerning environmental protection, species conservation and aesthetics.*
- Provision for regeneration *and for the maintenance of desired structural attributes.*

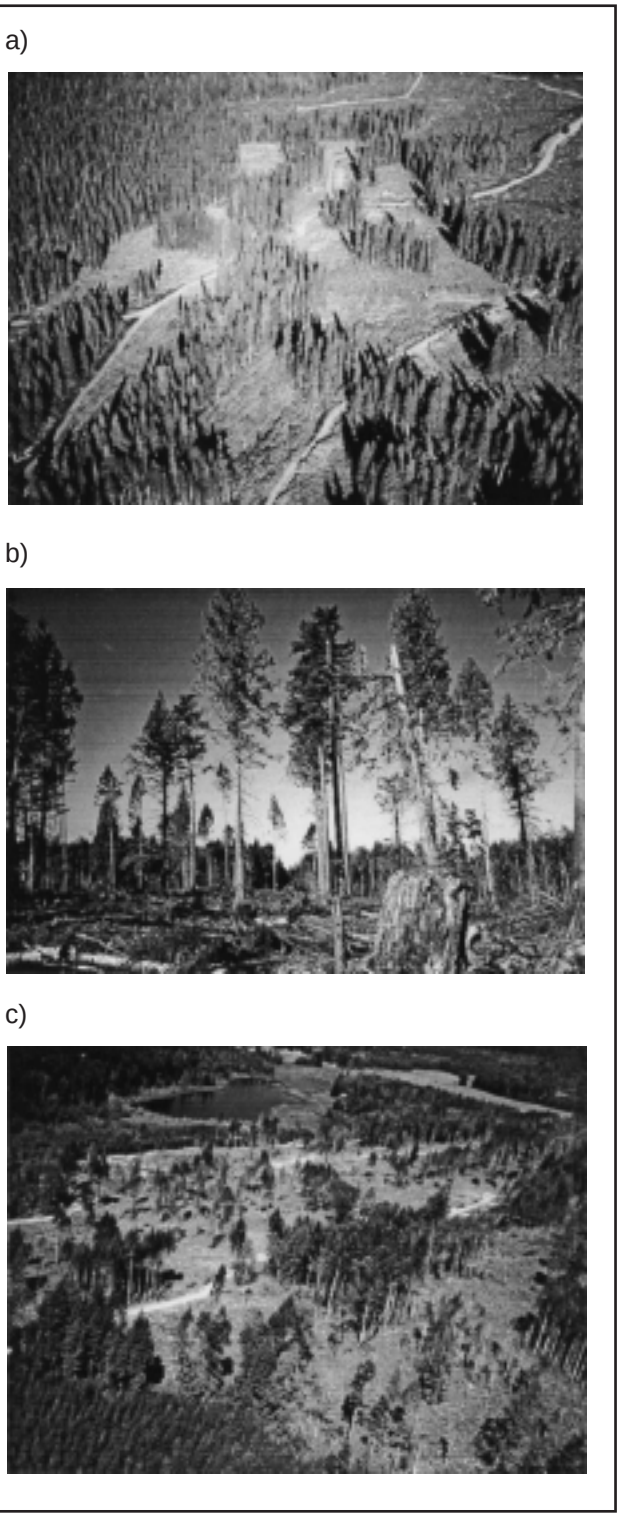

Fig. 3. Examples of retention systems from Weyerhaeuser's BC Coastal Group Operations. a) Group retention, b) Dispersed retention c) combination of Group and Dispersed retention.

- Efficient use of site productivity, growing space, *and existing structural elements.*
- *Provision for natural disturbances, with mitigating strategies where desired.*
- *Provision for the sustained production of desired resources and stand features.*
- *Optimum use of the resource base, existing knowledge, personnel and capital.*
- *Orderly planning of cutting units and scheduling of operations.*
- Protection of soil and water *quality.*
- Maintenance of desired plant and animal populations.
- *Consistency with short- and long-term objectives for the landscape and adjacent stands.*

The definition of a silvicultural system provided by Matthews (1989) might also be updated as follows: a complete regime for regenerating, tending, harvesting stands and *sustaining the desired features of forest ecosystems*. In order to be considered a silvicultural system and not simply a target stand condition, retention system prescriptions must be designed and implemented in a manner that is consistent with these objectives.

Challenges in implementing the retention system

The retention system departs substantially from the view that "the role of silviculture is to progressively improve the condition of the soil and the increment of the growing stock" (Matthews 1989). However, the concept of sustainability is at the core of forest management and when managing under the ecosystem management paradigm the goal becomes sustainability of ecosystem function and productivity.

Silviculture is an orderly discipline, and the challenge to the silviculturist remains the same: to prescribe a series of treatments that is efficient and reliable in moving the stand from its current condition towards a desired future condition. Recognizing the trade-off between maintenance of biological diversity and reduction in the quality of the growing stock for timber production is central to the successful implementation of the retention system.

Managing the landscape for a greater range of habitat conditions may be essential for some organisms, and may facilitate migration, home range movements or shifts and dispersal of some species (Hunter 1997). Emulation of natural disturbance patterns is often cited as an objective of ecosystem management. While observation of the stand structures and patterns of stands across landscapes produced by natural disturbances provides potential models for the desired stand and landscape condition, it may not be practical nor desirable to emulate the full range of the type, scale and severity of disturbances present. Simplification of natural structures and patterns may be necessary to improve the efficiency of management, balance the supply of products or features, or to meet other societal objectives. Subdividing large management areas into compartments composed of smaller landscape units can assist in design of target conditions, scheduling of activities and regulation of production.

Retention of biological legacy trees to achieve structural objectives should be clearly distinguished from removal based solely on economic criteria, avoiding the pitfalls of "high-grading." The stand must meet the stocking, regeneration and growth objectives that provide viable future harvest entries. To ensure reserves survive to provide long-term benefits, damage to residual trees should be avoided through careful design of yarding patterns.

Under ecosystem management, a "healthy forest" is one that has integrity, resiliency and diversity (Brooks and Grant

1992). A functioning forest, therefore, includes fungal pathogens, insects and abiotic disturbances. The manager should not aim to exclude pests but identify acceptable levels of damage from biotic and abiotic agents for different target stands and attempt to predict the likelihood of damage exceeding this acceptable level. Where excess damage is predicted, mitigating actions should be taken to bring damage levels within the acceptable range.

Shade-intolerant early successional tree species often have the high initial growth rates desired for timber crops. Maximum yield will likely be compromised for these species under the retention system. Some of these species are also very long-lived—a strategy that enables them to persist between stand-replacing disturbances and makes them suitable candidates for retention. Managers need to establish the light and microsite conditions required by different crop and non-crop species and prescribe the appropriate retention level, pattern and site preparation treatment. Artificial regeneration can assist in prompt regeneration and provides the opportunity to shift the composition of species or genotypes towards the desired condition, offsetting potentially dysgenic retention of parent trees.

The implications of target stand structures for survival and growth of trees in different layers including retained overstory trees must be considered. Conditions in the target stand may reduce timber productivity below site potential, particularly where low vigour overstory trees are retained, or where pests spread from overstory to understory trees. Permanent reserves reduce the area of land under management. It may be desirable to leave dead and dying trees unsalvaged to recruit snags and large woody debris. Yield expectations and projections of the future stand condition must be adjusted accordingly, including the incorporation of risk of periodic loss.

Conservation of soil and water quality is central to ecosystem management. True emulation of natural disturbances such as windthrow or flooding would require more disturbance to forest soils than may be acceptable. Harvesting and silviculture prescriptions should incorporate soil conservation measures that protect soil fertility, including maintenance of soil organic matter and structure. Access plans should be designed on a compartment level that facilitates re-entry for silviculture, salvage and subsequent harvest in contiguous stands. This requires considerable planning prior to the first entry. The percentage of cutblock area in roads required to harvest a given quantity of timber will increase under variable retention compared to clearcutting, except for aerial harvesting methods. Where roads will be reincorporated into the productive landbase, use of forwarding systems could avoid the need to build and de-build roads. The percentage of roads on the landscape may or may not increase under VR, depending upon policies regarding the spatial and temporal distribution of cutblocks, harvesting methods and adjustments to allowable harvest levels.

Humility is necessary in dealing with complex systems. In keeping with the principles of adaptive management, treatments should be based on the best available information and be considered "hypotheses." The outcomes of management activities should be monitored and contrasted with the development of unmanaged ecosystems to check for consistency with expectations and to improve knowledge of ecosystem processes.

A checklist of considerations

In summary, prescriptions for application of the retention system should address the following basic questions:

- What type, amount and spatial pattern of structural elements are to be retained?
- What condition does the target stand represent within the range of disturbance types, periodicities and severities present on the landscape?
- How should unique vegetation communities be incorporated?
- What is the medium- and long-term target stand condition?
- Does the regeneration plan adequately address the stocking and composition objectives with suitable genotypes and propagules?
- Are the future effects of forest influence on growth, yield and health of regeneration and sub-canopy layers accounted for?
- Have the effects of partial harvesting on the growth, yield and health of overstory trees been evaluated?
- Have yield expectations and target stand projections been adjusted for the expected health and vigour of the future stand?
- Have the effects of natural disturbances been accounted for, and are damage mitigating strategies in place?
- Is there an access plan for first and subsequent entries, and is it consistent with objectives for protection of soil, water and regeneration?
- Are the access plan and treatment schedule optimized with those of adjacent stands in the compartment?
- Will the stand condition be contributing to landscape level objectives over the term of the landscape plan?

Conclusion

The demands placed by society upon forest ecosystems and the need for economic use of capital, personnel and the resource base necessitate the continued practice of orderly and efficient forest management. In forests managed under the ecosystem management paradigm, a balance is sought between protecting natural systems and using them to meet societal demands. The retention system satisfies the need for a new silvicultural system that clearly defines the management intent where retention of biological diversity is paramount. The retention system meets the objectives of silvicultural systems, particularly if those objectives are broadened to include the principles of ecosystem management. As with other silvicultural systems, successful implementation of the retention system requires clear identification of a desired future condition of the stand and landscape, and an ability to predict ecosystem response to management interventions over the short and long term.

References

Brooks, D.J. and G.E. Grant 1992. New approaches to forest management, Part one. J. For. 90: 25–28.

Bruenig, E.F. and C.F. Klemp 2000. Economic and ecological risk management in near-natural forestry. *In* G.H. Stewart, U. Benecke and J. Hickey (eds.). Sustainable management of indigenous forest. Proceedings of a symposium held at Southern Connection Congress III, Lincoln University 17–22 January 2000. pp. 2–15. Wickliffe Press, Christchurch, NZ.

Bunnell, F.L., L.L. Kremsater and E. Wind. 1999. Managing to sustain vertebrate richness in forests of the Pacific Northwest: relationships within stands. Environ. Rev. 7: 97–146.

Clayoquot Sound Scientific Panel (CSSP). 1995. Scientific Panel for Sustainable Forest Practices in Clayoquot Sound, Report 5, Sustainable ecosystem management in Clayoquot Sound: planning and practices, Victoria, B.C. 296 p.

Forest Practices Code of British Columbia Act. 1999. Operational Planning Regulations. S.B.C., c. 41.

Franklin, J.F., D.R. Berg, D.A. Thornburgh and J.C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. *In* K.A. Kohn and J.F. Franklin (eds.). Creating a Forestry for the 21st Century: The Science of Ecosystem Management. pp. 111–139. Island Press, Washington, D.C.

Hunter, M.L. 1997. The biological landscape. *In* K.A. Kohn and J.F. Franklin (eds.). Creating a Forestry for the 21st Century: The Science of Ecosystem Management. pp. 57–68. Island Press, Washington, D.C.

Keenan, R.J. and J.P. Kimmins. 1993 . The ecological effects of clear-cutting. Environ. Rev. 1: 121–144.

Matthews, J.D. 1989. Silvicultural systems. Clarenden Press. Oxford. 284 p.

Naumann, B., J. Chew and C. Stewart. 1991. Target stands – a silvicultural vision of the future. Proceedings of the National Silviculture Workshop, Cedar City, Utah May 6–9, 1991.

Smith, D.M. 1986. The practice of silviculture. 8th edition. John Wiley and Sons. New York. 527 p.

Smith, D.M. B.C. Larsen, M.J.Kelty and P.M.S. Ashton. 1997. The practice of silviculture: applied forest ecology. 9th edition. John Wiley and Sons. New York. 537 p.

Vogt, K.A. J.C.Gordon, J.P. Wargo, D.J.Vogt, H.Asbjornsen, P.A.Palmiotto, H.J.Clark, J.A.O'Hara, W.S. Keaton, T.Patel-Weynand and E.Witten 1997. Ecosystems: balancing science with management. Springer-Verlag, New York. 470 p.