Discussion Paper

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Old-growth definitions and management: A literature review

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Abstract

Over the past two decades, scientific discoveries have altered how forest management is viewed, including the understanding of late-successional or old-growth forest communities. Some accept that old-growth forests should be managed, but the process of identification and management of these forests has proven to be very difficult. This review examines literature on old growth and old-growth management from a broad North American base with a focus on the special issues associated with high-frequency forest disturbance regimes. The purpose of this paper is to: examine the various old-growth definitions and management approaches; review the importance of old-growth management and conservation; and draw conclusions and make recommendations based on the information reviewed. Old-growth definitions were divided into three categories: conceptual functional, conceptual structural, and quantitative working. The relative merits and challenges of each category are discussed using examples from different forest types across North America, but the focus is on northern fire-dependent forest ecosystems. The authors recommend the establishment of landscape-level objectives for old-growth retention that include: approaching management from an ecological perspective; recognizing the importance of varied natural disturbance patterns; increasing funds for detailed inventories (especially in more contentious or ecologically sensitive areas); developing a regional old-growth attribute scoring theme or index; using a top-down approach to old-growth management; and developing a monitoring plan to determine the effectiveness of established objectives.

KEYWORDS: *landscape-level objectives, late-successional, old growth, old-growth management, natural disturbance.*

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Introduction

It is widely acknowledged that forests should be managed in an ecologically sustainable manner (Lindenmayer *et al.* 2000). According to Daniels (2003), three major paradigm developments occurred in the latter part of the 20th century concerning our understanding of vegetation dynamics:

1. The forest is recognized as a dynamic ecosystem that is never in an equilibrium state.
2. A multiple-scale approach with an involvement of landscape ecology has been adopted.
3. Human impacts are recognized as agents of disturbance in the forest ecosystems.

These paradigm changes have altered the way many aspects of forest management are viewed, including a change in our understanding of late-successional or old-growth forest communities. With the increased understanding of forest dynamics comes a growing voice in the scientific community for the need to inventory, understand, manage, and conserve representative examples of older forests, thus allowing future generations access to old-growth forests with their associated characteristics and values (Kimmins 2003).

The importance of maintaining old-growth attributes in managed landscapes is now relatively well accepted (Greensburg *et al.* 1997; Arsenault 2003), but the process of identification and management of old growth is difficult. The literature surrounding old growth and its management is diverse and well-established but very inconclusive about the most efficient way to capture the true essence of an old-growth stand (Hendrikson 2003). Old growth has been described in terms of stand structure; stand development processes; genetic, population, ecosystem, and landscape levels; aesthetics; and timber management (Spies 1997). In order to establish objectives for old-growth retention and management there must be an accepted definition of what constitutes an old-growth forest (Hayward 1991; Arsenault 2003). Establishing a definition is problematic and leads to a wide range of management approaches and techniques (Hessburg and Smith 1999; Arsenault 2003). Although a wide variety of mechanisms and plans are in place, the overall success of most old-growth management schemes is unknown.

This review examines literature on old growth and old-growth management from a broad North American base with a focus on the special issues associated with high-frequency forest disturbance regimes.

With the increased understanding of forest dynamics comes a growing voice in the scientific community for the need to inventory, understand, manage, and conserve representative examples of older forests, thus allowing future generations access to old-growth forests with their associated characteristics and values.

The purpose of the review is to:

- examine the various methods that have been used to define old growth;
- appraise the identified importance of old-growth management and conservation;
- analyze the various proposed approaches to old-growth management and planning; and
- draw conclusions and make recommendations to aid North American forest managers and policy makers in developing landscape-level objectives for managing old growth.

History

From an ecological perspective, the concepts of old growth and old-growth management are relatively new, evolving since the 1970s when a grassroots movement in the U.S. Pacific Northwest began to seek a clear definition of old growth (DeLong 2000). With continued harvesting of old growth in these coastal temperate rainforests, concern about a loss of biological diversity was widespread by the late 1970s (Carey 1998). In response to this outcry, in 1982 the United States Department of Agriculture (USDA) Forest Service, Pacific Northwest Research Station, implemented several accelerated research programs into old-growth forest wildlife and other biodiversity attributes (Boyce 1995; Carey 1998). After several years of research, the National Old Growth Task Group was formed in 1988 (Devall *et al.* 1991; Boyce 1995). The group identified the need to manage old growth by officially recognizing it as a forestry resource (Boyce 1995). The USDA Forest Service issued a national policy in 1989 that recognized the important ecological, social, and economic values of old-growth forests. This first management step was followed by the development of a generic definition and description of old-growth forests to serve as a starting point for future work.

Through the 1990s, all the USDA Forest Service stations and regions began developing old-growth definitions for specific forest types (Harms 1996). Although this was an attempt to define old growth in different forest types, many of the current problems with the definitions stem from an early ecological view of all old-growth forests as behaving like thousand year-old temperate rainforests. Other forest types have very different development patterns, natural disturbances, and appearances, and not all of them are progressing through an autogenic succession towards a steady-state equilibrium (Ontario Ministry of Natural Resources 2003). For example, although an old-growth Douglas-fir stand may grow for centuries without disturbance, an old-growth ponderosa pine forest requires frequent surface fires to reduce the shade-tolerant species and regenerate the canopy species (Spies 2004).

The early 1990s led to more widespread public and scientific pressure to increase the understanding and protection of old-growth forests across all forest types. Research results lead to the development of preliminary management strategies and plans by several agencies. For example, the government of British Columbia developed an Old Growth Strategy in 1992 (B.C. Ministry of Forests 1992) and that same year, the Ontario Ministry of Natural Resources appointed an Old-Growth Forests Policy Advisory Committee (Ontario Ministry of Natural Resources 2003) to make recommendations for an old-growth strategy. With the body of literature growing during this time, there was still divergence over the fundamental components of old-growth forests and their management.

Following an increase in the amount of research conducted in the last half of the 20th century, Natural Resources Canada in partnership with the Ontario Ministry of Natural Resources hosted a symposium on Canadian old-growth forests in 2001 in Sault Ste. Marie, Ontario (Canadian Forest Service 2002). The meeting showcased old-forest science conducted over the previous decade in Canada (Canadian Forest Service 2002; Mosseler *et al.* 2003). Consensus was reached on several issues, but many areas remained open to contentious debate (Mosseler *et al.* 2003). The forest industry and government departments in Canada have adopted conservation of old growth as a new priority in forest management (Work *et al.* 2003), but the variety of conceptual and working definitions of old-growth forests is making their conservation exceptionally difficult.

Defining Old Growth

At the 2001 Canadian Old-growth Forests symposium, most participants agreed that old-growth forest was a valid concept and that there was a need to develop working definitions of it, but little consensus was found on how old growth should be defined (Mosseler *et al.* 2003). There are social and economic definitions of old growth (Timoney 2001; Suffling *et al.* 2003), but the focus in the literature has been primarily on ecological definitions. Perera *et al.* (2003) argue that although there are economic, social, and cultural dimensions to consider, old-growth definitions must be based on rigorous ecological information.

Economic and Social Definitions

Although the current focus may be on ecological definitions of old growth, it is important to recognize the traditional cultural and economic underpinnings of the concept of old growth. Old-growth stands were often given harvesting priority because they:

- have the highest standing crops of commercial timber;
- are considered to be at a greater risk of deterioration through root rot or insect infestation; and
- occupy land that could be used for more productive young, second-growth stands (Bragg 1999; Burton *et al.* 1999; Arsenault 2003).

The Royal Commission on Forestry in British Columbia exemplified this view by noting that old forests should be harvested before they rot and have no value (Sloan 1956, cited in Arsenault 2003).

Social perceptions of old growth are also important. Among the general public today, the term old growth is usually associated with tree age or size (Bonar *et al.* 2003) or lack of human activity. Many people think large means old and vice versa (Kimmins 2003). Much of the confusion over the definition of old growth may stem from its early origins when old growth was a word generally associated with temperate rainforests of the Pacific coast, which are dominated by big and long-lived trees (Hayward 1991; Ontario Ministry of Natural Resources 2003). This can be problematic in areas where growth is slower and tree life spans are limited. There are also mystical or spiritual connotations associated with old-growth forests. According to Kimmins (2003), humans are a highly visual and emotional species, and they judge things they see as much from their hearts as from their heads. Images of old growth arouse strong emotions in many people. This has led to organized protests by environmental groups and First Nations to stop the harvest of old-growth forests. In British Columbia, an example of this began in 1984 when the Friends of Clayoquot Sound (FOCS) and local First Nations blockaded harvesting on Meares Island to protect spiritual values and an important source of drinking water (Langer 2002). This protest expanded to encompass Clayoquot Sound and culminated in a significant demonstration of civil disobedience in the summer of 1993 at Kennedy Dam. In the Kootenays area of southeastern British Columbia, the Applied Ecological Stewardship Council of British Columbia sought protection in 1995 for the "singing forest," an area of old-growth redcedar, western hemlock, and Sitka spruce. Their actions were based on its spiritual value, age, scarcity in the region, and its contribution to biodiversity (Heald 1995).

Ecologically Based Definitions

Although it is essential to keep in mind the traditional social and economic views of old growth, most scientists and managers tend to agree that an ecological approach to management is necessary. Hemstrom *et al.* (1998) identified several aspects of the current understandings of forests that cause problems for ecologically defining old growth:

- Definitions of old growth give emphasis to static rather than dynamic processes.
- Frequently when old growth has been defined in a successional context, features of the forest development process such as mortality and regeneration have not been included.
- A threshold age has sometimes been used to divide old-growth and younger forests, but because disturbance factors vary, forests develop at different rates.
- The definition of old growth often includes a concept of value. When value is used to define old growth, the classification becomes subjective and prone to change as human values change.

In determining how to define an old-growth forest, a wide range of qualitative definitions have been presented, but quantitative definitions have been more difficult to establish. The quantitative definitions often lack any ecological or scientific merit and are sometimes based on clearly arbitrary numbers (Wells *et al.* 1998; Mosseler *et al.* 2003). For example, single age numbers are often used in planning models because stand age estimates are available in forest inventories and age estimates are easy to integrate into spatial or aspatial planning models (B.C. Ministry of Forests 1992; Bonar *et al.* 2003). This model does not represent a holistic idea of an old-growth forest or its characteristics.

Several authors have attempted to categorize the wide array of old-growth definitions based on their characteristics (Spies 1997; Kneeshaw and Burton 1998; Wells *et al.* 1998; Mosseler *et al.* 2003). Mosseler *et al.* (2003) classified old-growth definitions into three categories based on their:

1. structural features (e.g., presence of dead, fallen wood in various states of decay);
2. compositional features (e.g., long-lived, shade-tolerant tree species associations); or
3. process features (e.g., relatively low rates of biomass accumulation).

For the ease of reviewing the ecological definitions of old growth, the authors have divided them into conceptual functional, conceptual structural, and quantitative working definitions.

Conceptual Functional Definitions

In some of the literature, old growth is defined by its dynamic attributes. The process and function-based definitions focus on the way forests develop rather than the way they appear at particular stages. Spies (1997) considers functional definitions superior to structural definitions primarily where old forest conditions do not currently exist, and in situations where management is directed towards maintaining processes within current old-growth stands and across landscapes as a whole. The disadvantages of these types of definitions are in applying them to models and inventories.

Kneeshaw and Burton (1998) conducted a literature review and classified the functional attributes on which a definition of old growth can be based:

- climax forest
- undisturbed by humans
- net annual growth close to zero
- older than natural disturbance interval
- final stage of stand development
- replacement of overstorey by secondary tree recruitment
- steady-state condition
- nutrient retention
- all-aged structure

- snags and logs in all stages of decay
- past commercial timber rotation age
- complex food webs and associated animals
- increased understorey productivity
- stand ages that have exceeded the maximum life span for the species
- cathedral-like, or humbling scale, revered for heritage value and scarcity

Even when definitions are grouped into categories, there is still a wide divergence of what the most prominent or distinguishing features of old growth might be. Traditionally, it was thought that all forest types followed a pattern of successional development that could be described by the mono-climax theory. This theory is based on the idea that plant communities are converging toward a single and predictable end point (Whittaker 1975). The contemporary view of ecosystem dynamics recognizes the complex arrangement of plant communities, the importance of natural disturbances, and the role of initial plant composition in creating many potential end points to succession (Arsenault 2003). Pinto (2003) argues that structural and compositional changes are always occurring in the forest and this dynamic nature must be considered in any conceptual definition. Some of the literature focusses on boreal or sub-boreal forests where natural disturbances on the landscape are more frequent. Kneeshaw and Burton (1998) argue that in high-frequency disturbance areas, it is necessary to develop an old-growth definition which addresses the dynamic nature of forest development and natural disturbances across the landscape. Different perspectives on ecosystem disturbance and patch dynamics will have a strong influence on how ecologists view the world and describe old-growth forests (Arsenault 2003).

Another contentious aspect of functional old-growth definitions is the debate over whether a forest disturbed by humans (e.g., harvested) can still be considered old growth (Hendrickson 2003). Some ecologists argue that an old-growth forest ecosystem can only be restored over thousands of years, if ever. Hunter (1989) defined old-growth forests as relatively old and relatively undisturbed by humans. Kneeshaw and Burton (1998) argue that terms such as "primeval" adequately describe uncut forests, and need not be included in the concept of old growth. Based on discussions of the 2001 Canadian Old-growth Forests symposium, it can be assumed that the idea that old-growth forests must be primary forests is not generally accepted by most scientists today. Participants at the symposium widely agreed that secondary forests, over time, can become old-growth forests again (Mosseler *et al.* 2003).

Conceptual Structural Definitions

As opposed to functional definitions, structural definitions are based on physical parts of the forest and their arrangement. Structural characteristics are widely described in the literature (see Table 1) and are generally the most commonly used definitions of old growth within the scientific community (Franklin *et al.* 2002; Daniels 2003). The advantages of structure-based definitions are that they can be applied to most forest inventories and many of their attributes can be easily measured. The disadvantages are that they do not provide information on the processes that created the structures and it is difficult to extrapolate structural definitions from one forest type to another (Shear *et al.* 1997; Spies 1997; Andison 2003; Daniels 2003).

The most common criticism of structural definitions of old growth is that they fail to recognize the dynamic nature of a forest ecosystem. What happens if the forest structure changes after "old-growth" status has been reached (Shear *et al.* 1997; Spies 1997; Daniels 2003)? Daniels (2003) suggests that we adapt definitions appropriately and acknowledge that developmental processes are the proximate cause of structural attributes such as a large range of tree sizes, horizontal and vertical complexities in the canopy, and accumulation of coarse woody debris. It must also be recognized that the structure of an old-growth stand differs according to many individual site factors (Boyce 1995) and cannot be applied across different forest types (Carleton 2003). In a study of boreal forest dynamics, Cumming *et al.* (2000) showed that some structural attributes can be misinterpreted if all forest types are seen as having similar development regimes. They suggested that parts of the boreal forest may be older than previously thought because stand age may not reflect assessment of time elapsed since fire, as trees may represent a second or third cohort of post-fire trees. In many forest types, especially types prone to frequent low-severity fires, age is a poor indicator of stand condition because the canopy trees may span a wide range of ages.

Quantitative Working Definitions

With all of the various criticisms and complexities of the conceptual definitions, it is not surprising that very few truly comprehensive old-growth definitions have been widely adopted. Many agencies and researchers

TABLE 1. Examples of conceptual structural or compositional definitions of old growth

Old-growth forests are made up of climax or sub-climax ecosystems where dominant trees are close or older than their age of physiological maturity. Unique to each biogeoclimatic region, the old-growth stage may be reached at different ages depending on the site, ecosystem, or dominant tree species (Duchesne 1994).
Old-growth forests contain these structural components: supercanopy trees, canopy trees, understorey trees, shrubs and saplings, decaying wood, ground cover, organic litter, pits and mounds, cavity trees, and snags (Ontario Ministry of Natural Resources 1999).
An old-growth forest, regardless of its history of land use, shows a specific and complex set of structural characteristics and associated organisms (Trombulak 1996).
Structural characteristics of old growth include: large trees; wide variations in tree sizes and spacing; accumulations of large, dead standing and fallen trees; broken and deformed tops; bole and root rot; multiple canopy; and understorey patchiness (Johnson *et al.* 1995).
Attributes most indicative of old-growth status in the Sub-Boreal Spruce zone (mc2) are stand age, numbers of large logs, regeneration density, and numbers of large snags (Burton and Coates 1996).
Old growth forests are structurally and biologically complex, multi-aged, and have a multi-layered canopy (MacKinnon 2003).
Old-growth forests are ecosystems with old trees and related structural attributes. Old growth typically differs from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function (White and Lloyd 1994).
Old growth is a forest that contains live and dead trees of various sizes, species composition, and age class structure that are part of a slowly changing but dynamic ecosystem (B.C. Ministry of Forests 1992, cited in Arseanult 2003).

choose a few of the common structural characteristics of old growth and apply what is available from forest inventories to develop their working definitions (B.C. Ministry of Forests and Ministry of the Environment 1995; Kneeshaw and Burton 1998; MacKinnon and Vold 1998; Gillis *et al.* 2003). For example, the Quebec government queries their database for stand age and dominant species to identify potential forest ecosystems for old-growth areas (Gillis *et al.* 2003). The British Columbia government bases old-growth determination on the stand ages as defined by the provincial forest inventory (Arsenault 2003; B.C. Ministry of Forests 2003). Although provincial forest inventories do not directly measure the abundance or distribution of old-growth forests, Gillis *et al.* (2003) and DeLong *et al.* (2004a) argue that forest-inventory attributes such as canopy closure, stand structure, age, and maturity by species can be used to define areas containing old-growth characteristics. Other methods of quantifying definitions have been suggested. For example, Kneeshaw and colleagues (Kneeshaw and Burton 1998; Kneeshaw and Gauthier 2003) propose using the cohort basal area proportion (i.e., the ratio of the basal area of the understorey cohort to the basal area of the post-disturbance cohort) because it is a structural measure that is very sensitive to changes in the ecosystem.

Following the USDA Forest Service Old Growth Task Force in the late 1980s, the Forest Service began a campaign to quantitatively define old growth in all forest types across the United States (White and Lloyd 1994; Hardt and Newman 1995). The Southeast Research Station alone developed a plan to quantify old growth in 42 different forest types (Greensburg *et al.* 1997; Kennedy and Nowacki 1997; Shear *et al.* 1997; Landers and Boyer 1999). The structural attributes used by the Southeast Research Centre are density; basal area; number of 4-inch size classes; age of dominant and codominant trees; diameter of dominant and codominant trees; abundance of snags; and abundance of coarse woody debris.

Although basic inventories of old-growth forests can assist land-use planners in decision making (MacKinnon and Vold 1998), there are many criticisms of this approach. Approaches that use structural attributes from inventories to determine arbitrary old-growth thresholds are not scientifically supported (Arsenault 2003). The arbitrariness of the current working definitions of old growth do not improve management, as the thresholds are often based on limited criteria that are poorly related to stand potential (Hunter and White 1997). Land management agencies argue that these measures are often considered interim because, in most cases, the inventory data for more detailed ecological criteria is not available (Hardt and Newman 1995; MacKinnon and Vold 1998).

There are also limitations to using age as the defining attribute for old growth. Beyond the lack of detailed forest data, the primary problem with working definitions is the lack of clear thresholds for when a forest becomes old (Hunter and White 1997; Arsenault 2003). Yet, the development of working definitions and old-growth management policies require that old-growth forests be identifiable from other forest stages (Kneeshaw and Burton 1998). Hunter and White (1997) conducted a comprehensive review of the old-growth literature to determine if any ecological thresholds had been identified. They speculated that if ecosystem parameters are plotted against stand age, any major ecological thresholds associated with stand age should appear as a step-function (i.e., sharp changes occurring over a few years). Some papers describe models that recognize an old-growth stage but do not indicate that the transition to that stage is necessarily abrupt. Overall, they found no apparent examples of step functions in later stages of succession. They concluded that any specific definition of old-growth stands will be, for the most part, arbitrary.

Because no clear ecological thresholds have been developed to distinguish between old-growth and other forest development phases, it has been suggested that indices, scoring schemes, or other continuous measures of "old-growthness" be established (Spies and Franklin 1988). Examples in the literature include Franklin and Spies (1991, cited in Bragg 1999) who propose a continuous scale that allows for varying degrees of old-growthness. Rusterholz (1996) developed a system of 65 points based on specific vegetation type. Hale *et al.* (1999) applied a logistic regression model to differentiate between mature hardwood forests and unmanaged old growth. Morgantini and Kansas (2003) used an old-growth index score to differentiate between mature and old-growth forests in the Upper Foothills and Subalpine subregions of west-central Alberta. Bragg (1999) proposed the use of an old-growth scoring system ranging from 0 (highly different from old growth) to 1 (completely old growth). Kneeshaw and Burton (1998) also applied an old-growth rating scheme in their case study of the Sub-Boreal Spruce zone of British Columbia. They correlated population structures of a particular stand with a number of structural attributes to devise old-growth rating scores. The development of the scores was based on the recognition of a minimal set of stand attributes that denote the transition to old-growth status in the stand.

Old-growth scoring or ranking systems have been developed by some provincial governments in Canada. In June 1999, Nova Scotia introduced an Interim Old Forest Policy. The policy includes a two-stage approach that defines old growth as forests over 125 years of age and implements a ranking system that scores forests in terms of their old-growth values and restoration potential (Nova Scotia Provincial Government 1999; Stewart *et al.* 2003). In Ontario, a scoring system is not applied, but a range of criteria are considered acceptable. The Ontario old-growth management strategy offers a range of criteria and a definition appropriate to the forest ecosystems in Ontario (Ontario Ministry of Natural Resources 2003).

Although indices are often deemed as more effective than the assignment of arbitrary thresholds, the limitations of this system are discussed in the literature. The problem with indices is that they are very dependent on the quality of the data collected, and that those involved in creating them arbitrarily choose the attributes used to develop them (Arsenault 2003). It has also been suggested that the success of these approaches requires the identification of clear patterns between stand age and other attributes related to old growth (Bragg 1999).

Importance of Old Growth

There is considerable effort in the scientific and resource planning communities to define old growth, but what is it about old growth that makes it special (Bunnell 1998)? It is generally recognized that old-growth forests are an ecologically unique element of landscapes that need to be maintained for a variety of reasons. Trombulak (1996) suggests there are six primary reasons that old growth is important:

1. protection and restoration of biological integrity
2. dependency of many species on old growth
3. comparison with managed forests
4. aesthetic value
5. lack of awareness about many of the values associated with old growth
6. obligation to retain natural landscape features for future generations

Widespread recognition of the unique values of old growth is increasing. For example:

> *The Forest Service recognizes the many significant values associated with old-growth forests, such as biological diversity, wildlife and fisheries habitat, recreation, aesthetics, soil productivity, water quality, and industrial raw material. Old growth on the national forests will be managed to provide the foregoing values for present and future generations* (USDA Forest Service 1989, cited in Hardt and Newman 1995:32).

Canada recognizes the importance of old growth, and pledged at the International Convention on Biodiversity in 2000 to develop its forests' sustainability. Close consideration of old growth will be required to meet this pledge (Mosseler *et al.* 2003). The capacity of old-growth forests to provide ecosystem services may be far more important to society than their use as a source of raw materials (Hendrickson 2003). These services include breathable air, pure water, carbon storage, regeneration of nutrients, maintenance of soils, pest control by insectivorous bats and insects, micro- and macro-climate control, and the storage of a wide variety of genes (Zahner 1996).

Old growth is often associated with biodiversity (Hendrickson 2003; Mosseler *et al.* 2003). The primary reason is that the structural complexity of old growth supports a variety of habitats for both wildlife and plants (Boyce 1995; Carey 1998). Decaying wood in old-growth stands plays a key role in habitat formation and nutrient cycling (Brookes 1996; Ferguson and Elkie 2003). Another mechanism of old-growth species diversity is time. For species with low mobility or colonization limitations, their occurrence in old-growth stands may be related to the timing of large disturbances (Halpern and Spies 1995). Several species have been identified as being particularly dependent on old-growth forests. Examples from British Columbia include spotted owl (Carey *et al.* 1990), mountain caribou (Stevenson *et al.* 2001), and some lichens (Goward 1994; Goward and Arsenault 2000; Selva 2003). The Ontario Ministry of Natural Resources has identified 28 bird species and 18 mammal species in southern Ontario alone that prefer old-growth habitat (Ontario Ministry of Natural Resources 1999).

Planning and Managing for Old Growth

Management can range from passive (e.g., protection) to active (e.g., harvesting). Some acknowledge that old-growth forests need to be managed because of their unique ecological contributions, but the question of how to manage is far from agreed upon. The difficulty stems from several sources. First, there are landscape and social issues that must be taken into account (Hunter 1999; Braumandl and Holt 2000). The landscape issues include location, size, historic levels of old growth, and biodiversity (Braumandl and Holt 2000). The social issues are revenue and employment generation, land claims by indigenous peoples, intrinsic values of trees, and public perceptions of old growth. Second, good management is hindered by a lack of research describing locally relevant structural, compositional, and functional characteristics of old growth. This limits the reliability and validity of the selected definition. Third, the biodiversity attributes of old growth are not very well understood (Hendrickson 2003). The question of how much old growth is enough to meet various ecological and social goals has not been answered. The final difficulty comes with deciding on the scale of the management (Hunter 1999). Tyrell *et al.* (1998) describe two primary levels for examining and managing old growth: stand level and landscape level. At the landscape level, processes that influence the variability of old growth and its associated features are addressed. These processes are scale-dependent and require assessment of the number, size, and distribution of stands that exhibit old-growth attributes.

Most of the research discussed so far is from a stand perspective, rather than a landscape one. Perera *et al.* (2003) suggest that to overcome some of the management problems, managers should adopt a top-down approach to management and establish the necessary large-scale spatial and temporal context required to use stand-level knowledge. For forest management to achieve its many objectives across spatial stages, there needs to be co-ordination of forest growth, natural disturbances, and human activities (Oliver *et al.* 1999). To be flexible and account for the many complexities that exist on the landscape, it is also recognized that monitoring and adaptive management will be necessary to achieve any established goals for forest ecosystems (Duchesne 1994). For example, the USDA Forest Service has an old-growth effectiveness monitoring plan for its Pacific Northwest forests (Hemstrom *et al.* 1998).

Stand Level

At the level of stand (i.e., an area of relative homogeneity), the goal is generally to manage for the old-growth attributes. For example, Weyerhaeuser's coastal British Columbia tenures have been divided into three stewardship zones: timber, habitat, and old growth. The old-growth zone's objective is to combine the conservation of old-growth forests with uneven-aged stand management to maintain late-successional forest attributes (Beese *et al.* 2003). It is thought by some managers that old-growth forest stands and their associated structural attributes can be maintained while still harvesting some timber (Burton and Coates 1996; Beese *et al.* 2003; Kremsater *et al.* 2003). Burton *et al.* (1999) suggest that boreal and sub-boreal old-growth stands could be partially cut and still maintain old-growth character, as long as threshold levels are maintained. Natural mortality is emulated with scheduled rates of stand harvests, and natural gaps are imitated by planning the size of canopy openings (Boyce 1995). The difficulty is in determining how many trees can be removed before old-growth values are compromised. Burton and Coates (1996) recommend using a scoring system to identify old-growth structural attributes that should be retained after partial cutting of stands. A similar stand-level approach is proposed by Braumandl and Holt (2000). They suggest a two-part strategy:

1. use a coarse-scale methodology for identifying old forest based on appropriate stand structural attributes, and then
2. use a fine-scale scorecard approach to ranking controversial patches based on an index of old-growthness assessed on the ground.

However, there is controversy and debate about whether old-growth stands can be partially cut without compromising old-growth values. It is important to recognize that, while limited harvesting may maintain some aspects of old-growth structure, other attributes associated with old growth are likely to be impacted. Potential changes include damage to residual stems and understorey vegetation, soil compaction during the harvest operation, reduction in coarse woody debris, and changes in species composition.

The harvest of large, commercially valuable trees can impact levels of coarse woody debris not only by removing trees that eventually become debris, either as standing dead trees or fallen logs, but also by breaking or crushing existent debris (Carey and Johnson 1995). For safety reasons, standing dead trees are often felled before harvest operations begin. This could further reduce current and future coarse woody debris levels. DeLong *et al.* (2004b) found a relationship between harvest patterns at landscape and stand scales and the number of snags needing removal for safety purposes. Their models indicated that up to eight times as many snags per hectare needed removal at a stand-level retention of 70% than at a stand-level retention of 10%. They concluded, however, that more research is required on the amount of snag loss with increased retention and to find solutions for protecting workers from falling snags.

Although some wildlife species, such as the flying squirrel, may not be affected by structural changes due to partial cutting (Ransome and Sullivan 2003), impacts on other species have been shown. For example, access roads may have a negative impact on the populations of certain wildlife species such as grizzly bears (Wielgus *et al.* 2002), woodland caribou (Smith 2004), and wolverine (Carrol *et al.* 2001; Craighead 2002).

Lindenmayer and Franklin (1997) suggest that for biodiversity conservation, a variety of strategies implemented at different spatial scales is required. If one strategy is found to be ineffective for a given species, the implementation of other approaches may still allow the species' conservation. They call this "risk-spreading."

Stand-level management for old growth has its own unique set of challenges depending on the dominant disturbance regime(s) and frequencies for the forest type under management. For example, the strategies and approaches used in fire-maintained, old-growth ponderosa pine forests may differ significantly from those used in the wetter cedar-hemlock temperate rainforests.

Landscape Level

The management of forests from a landscape perspective is a relatively recent development. Most of the general characteristics and definitions of old-growth forests focus on properties within individual forest stands or ecosystems, but many researchers have suggested that the concept of old growth also needs to be based on landscape-level properties (Johnson *et al.*1995; Oliver *et al.* 1999; Spies 2004). Historically, forest managers viewed the components that make up the landscape as separate, unrelated entities. Forest fragmentation (D'Eon 2002), natural disturbance regimes (DeLong 2002; Andison 2003), interior forest habitats (Daigle and Dawson 1996; Sacken 1998; Oliver *et al.* 1999), and edge habitats (Daigle and Dawson 1996; Oliver *et al.* 1999) are the primary concepts described in the landscape ecology literature about old-growth forest management. Conservation Biology Principles for Forested Landscapes (Voller and Harrison [editors] 1998) provides a good introduction to, and description of, these landscape ecology concepts. However, it is recognized that focussing on the landscape as an interrelated, interconnected whole is important (Dawson 1996). According to Oliver *et al.* (1999), management at the landscape level requires coordination of spatial and temporal considerations for all stands included in the landscape. According to Burton *et al.* (1999), the main reasons to consider a landscape approach over a stand-level one are a ubiquitous history of natural disturbances and the operational constraints associated with implementing partial cutting stand-level methods. Taking into account a natural distribution of old growth on the landscape level is now highly accepted and advocated (B.C. Ministry of Forests and Ministry of Environment, Lands and Parks 1999; Hessburg and Smith 1999; Veblen 2003).

The primary landscape-level management questions are based on the spatial and temporal arrangement of the old growth across the landscape. An emerging challenge in forest management is to maintain biodiversity in the face of constantly changing forest conditions (Oliver *et al.* 1999). Various approaches have been described in the literature. The standard management approach is to simply exclude some old-growth stands from the operable land base. But Burton *et al.* (1999) express a concern that in boreal and sub-boreal regions (i.e., areas with high rates of natural disturbances) the fate of old-growth stands will usually be to bark beetles, root rot, wildfire or windthrow; only a very small proportion will be maintained over a long period of time. Therefore, protection of old-growth stands can only be a part of a strategy to maintain old growth on the landscape. Plans for regeneration and restoration of "natural" old-growth forests also need to be included (Trombulak 1996; Burton *et al.* 1999; Suffling *et al.* 2003).

It is well recognized that all landscape management ideas should be addressed in terms of landscape ecology concepts (Daigle and Dawson 1996; Dawson 1996; Eng 1996; Parminter and Daigle 1996; D'Eon 2002), especially in terms of natural disturbance patterns (DeLong 1998; Bergeron *et al.* 1999; Euler and Epp 2000; Wimbley *et al.* 2000; DeLong 2002; Kimmins 2003; Lewis *et al.* 2003; Perera *et al.* 2003; Wong and Iverson 2004).

One of the main arguments for considering natural disturbance regimes in old-growth management is that instead of trying to control natural systems, we should enhance their adaptive capacities by emulating natural patterns (Bunnell 1998; Arsenault 2003; Hendrickson 2003). A better understanding of natural systems has resulted in new ideas about forest management. One idea being that managed natural disturbances should be designed to achieve the landscape patterns and habitat conditions that are normally maintained in nature (DeLong 1998; Wong and Iverson 2004). This coarse filter approach to biodiversity conservation recognizes ecological processes and provides for a dynamic distribution of old growth across the landscape.

There are several examples of how researchers and agencies have attempted to quantify natural disturbance patterns for managing old growth (DeLong 2002). The Government of British Columbia presented information about managing forests based on natural ecosystem processes in the Biodiversity Guidebook (B.C. Ministry of Forests and B.C. Ministry of Environment 1995). Based on historical natural disturbance regimes, the guidebook groups the province's forests into five categories. A common criticism of this and other applications of natural disturbance patterns is the difficulty in positively determining historical landscape patterns. Therefore, very different ecosystem types are placed in the same category of disturbance (Andison 2002). In an attempt to increase regional accuracy, more specific local patterns need to be quantified (Bonar *et al.* 2003; Lewis *et al.* 2003; Perera *et al.* 2003). Bonar *et al.* (2003) conducted an old-growth analysis in the Foothills Model Forest in Alberta and developed a strategy based on natural disturbance patterns to incorporate into a local forest management plan. Using a model called the Boreal Forest Landscape Dynamics Simulator (bfolds), Perera *et al.* (2003) demonstrated that the disturbance regime is variable, and therefore the area under older age classes varies with time. Other examples of differences in natural disturbance patterns include:

- old-growth forests that are self-maintaining through gap replacement versus fire-dependent old-growth forests (Duchesne 1994);
- areas that are prone to frequent large-scale insect infestations versus those with few large infestations (Fleming *et al.* 2000); and
- areas with a high-frequency and low-severity fire regime versus those with a low-frequency and high-severity regime (B.C. Ministry of Forests and B.C. Ministry of Environment 1995).

However, although natural disturbances can be used as a template or to provide some estimate of the range of normal old growth, it cannot be assumed that mimicking natural disturbance patterns will produce the same ecological conditions as expected historically (e.g., the amount of dead wood and residual structure left after harvesting is typically much less than after a forest fire).

Another significant problem with estimating natural disturbance patterns is that disturbance regimes are always changing (Timoney 2003). Simulations by Wimberly *et al.* (2000) in the Oregon Coast Range suggest that the mean percentage of old growth over the last 1000 years ranged between 45 and 46% and in the 1000 years before that the range was between 51 and 55%. If the central idea of ecological forestry is that management of a forest ecosystem should work within the limits of natural disturbance patterns prior to extensive human alteration of the landscape (Seymour and Hunter 1999), how do we manage sustainability in a period of dynamic ecological developments? Land-use practices of this century have altered disturbance regimes and spatial and temporal patterns of vegetation, and reduced ecosystem resilience to native and human disturbances (Hessburg and Smith 1999; Hughes and Drever 2001).

Conclusions and Recommendations

In the last 10 years there have been advancements in old-forest management. Although progressing, the current scientific understanding of old growth is still in its infancy. Without clear definitions and standards on which to base management decisions, avoiding ecological catastrophes can become difficult. Hendrickson (2003) identified significant questions that still remain in our understanding of old-growth forests:

- What plant and animal species are found in old-growth ecosystems?
- Can mature stands of shorter-lived trees exhibit old-growth structural features?
- Can we quantify the structural features of old-growth forests that make them critical for wildlife?
- Can we quantify the value of old-growth forests as gene reserves?

In resource management, a flexible and adaptive approach is warranted where there are still many unknowns to be answered. Hunter and White (1997) suggest that in cases where a definition is difficult to develop, managers need to select a definition that is not so restricted that protection becomes a moot point, nor so broad that protection efforts cannot be prioritized. The Convention on Biological Diversity (2000) has developed a definition, principles, and operational guidelines for this style of adaptive management called the ecosystem approach. The following quotation comes from the Conventions Section on operational guidance:

> *Ecosystem processes are often non-linear, and the outcome of such processes often shows time-lags. The result is discontinuities, leading to surprise and uncertainty. Management must be adaptive in order to be able to respond to such uncertainties and contain elements of "learning-by-doing" or research feedback. Measures may need to be taken even when some cause-and-effect relationships are not yet fully established scientifically.* (Convention on Biological Diversity 2000:2).

Based on the literature and the conclusions discussed above, the authors recommend the following considerations to establish landscape-level objectives for old-growth retention and management:

Although progressing, the current scientific understanding of old growth is still in its infancy. Without clear definitions and standards on which to base management decisions, avoiding ecological catastrophes can become difficult.

- Although it is essential to consider the social and economic views of old-growth forest management, an ecological approach is necessary.
- To establish objectives for retention and management, a scientifically accepted ecological definition of what constitutes an old-growth forest in different ecosystem types must be developed. The definitions should not be based on arbitrary numbers. The rationale for any definitions and any uncertainties need to be clearly stated.
- Natural disturbances and the role of individual site factors in determining these disturbance regimes must be recognized.
- In areas that are more contentious or ecologically sensitive, time and money should be allocated for the development of more accurate and detailed forest inventories and for more locally adapted natural disturbance pattern research.
- Further research should be conducted on the feasibility of developing a regional scoring scheme or index for measuring old-growth attributes. This would be especially useful in determining the quality of the forests following widespread insect infestations (e.g., the current bark beetle problem in central British Columbia) or fires.
- A top-down approach should be emphasized. This requires establishing old-growth landscape-level objectives prior to exploring old-growth management on a local or stand level. In the context of adaptive management, a monitoring plan should be established to determine the effectiveness of any established objectives.

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Test Your Knowledge . . .

Old-growth definitions and management: A literature review

How well can you recall some of the main messages in the preceding Discussion Paper? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Which of these is an attribute that would not be used in a structural definition of old growth?
   A) Complex food webs and associated animals
   B) Age of the canopy
   C) Amount of large dead woody material

2. What is the rationale for developing indices, scoring schemes, or other continuous measures of "old-growthness"?
   A) The need to incorporate social perceptions of old-growth into definitions
   B) No clear ecological thresholds have been developed to distinguish between old growth and other forest development phases
   C) The need to focus on the way forests develop and function rather than the way they appear at particular stages

3. What is a common criticism of using natural disturbance pattern concepts to manage old growth?
   A) It is too difficult to accurately determine historical landscape patterns
   B) It does not consider the traditional role of fire on the landscape
   C) It favours social and economic values over ecological values

Answers

1. A 2. B 3. A