# Multiaged forest stands for protection forests: concepts and applications

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**Abstract**
Multiaged stands have two or more age classes that are the result of partial natural and anthropogenic disturbances that do not destroy all trees in a stand. Multiaged stands represent a more static structure than comparable even-aged stands because they fluctuate in a narrower range of variability in stand structure over time. For protection forests, potential benefits of multiaged stands are their resistance and resilience to disturbances. Resistance comes from the capacity to withstand or avoid disturbance effects. A variety of tree sizes might be desired for resistance depending on the specific protective function. Multiaged stands provide a range of tree sizes as well as developing trees to replace trees lost to disturbances. Resilience is the capacity to maintain or regain normal function after disturbance. Resilience may be higher in multiaged stands because of a smaller range of variation in structure over time that imparts a greater ability to quickly return to a pre-disturbance state. In the case of protection forests, the challenge is to establish and maintain a series of age classes of trees that maximize the resistance or resilience of the stand.

Keywords: multiaged forests, protection forests, silviculture, stand structure, hydrogeomorphic processes

## 1 Introduction

Protection forests are those designed to protect special resources, habitats, people, and others from disturbance (MATTHEWS 1989). Other, narrower, definitions include: forests "managed primarily to regulate stream flow, maintain water quality, minimize erosion, stabilize drifting sand, conserve ecosystems, or provide other benefits via protection" (HELMS 1998) or as forests "maintained on steep, unstable slopes to prevent accelerated erosion" (British Columbia Ministry of Forests). Other definitions exist and also emphasize the management of stands to reduce the detrimental effects of abiotic disturbances. This paper focuses on the potential of using multiaged silviculture to reduce negative affects of those disturbances associated with hydrogeomorphic processes such as landslides, flooding, debris flows, or snow avalanches. However, forests can be designed to protect from other abiotic disturbances such as fire and wind, and biotic disturbances such as insects, pathogens, the destructive effects of mammals, and human activities.

Silviculture is a means to modify forest stand structure thereby achieving management objectives including those associated with protection forests. Stand structure is the horizontal and vertical distribution of components of a forest including the height, diameter, crown layers, and stems of trees, shrubs, herbaceous understorey, snags and downed woody debris (HELMS 1998). It therefore represents the physical appearance of the stand and strongly influences a variety of ecosystem functions including those related to hydrologic processes, wildlife habitat, resistance and resilience to disturbance (O'HARA *et al.* 1994). The goals of silvicultural prescriptions can therefore be expressed in terms of stand structures, and stand structure becomes the principal element in assessing the efficacy of silvicultural treatments.

There are often a variety of means to achieve a silvicultural objective and silviculture can direct the development of a stand in a number of ways. OLIVER and O'Hara (2005) described "silvicultural pathways" as the changes in stand structure resulting from growth and silvicultural operations. For example, a stand might be thinned to develop along a pathway to a low density stand of large trees or the same stand might be unthinned to develop on a pathway towards a high density structure. If a certain (particular) element of a stand structure was desired, such as the presence of large stable trees, the silviculturist would design a pathway to develop this structural feature. The operations could involve a heavy thinning or simply planting a widely-spaced stand. For protection forests, there may be a variety of stand structures that can achieve the protection objective and there may be a variety of pathways and operations that can be used to achieve any of these structures.

The stand structural features that meet objectives related to protection provide resistance to disturbance or resilience from the effects of disturbance. Resistance is the ability of a stand or ecosystem to avoid alteration from a disturbance, and resilience is the capacity of a stand or ecosystem to maintain or regain normal function and development following a disturbance (HELMS 1998). In the case of protection forests, their protective function requires that they have resistance to a particular disturbance. However, they must also be resistant against other disturbances that can reduce or eliminate their ability to provide their protective function. In this paper, resilience (or elasticity; BRANG 2001) is used to describe the rate that a stand returns to its desired level of protective function. Both resistance and resilience are important features of protection forests, regardless of the type of protection forest.

There are a number of ways of classifying forests. These include the simple divisions based on number of age classes, canopy strata, species, development stages, or other structural features. This paper focuses on the relative importance and potential of multiaged stands to provide resistance and resilience to disturbances caused by hydrogeomorphic processes. Multiaged stands are defined as having two or more age classes (HELMS 1998) and include stands resulting from variable retention systems or other traditionally even-aged systems that leave residual or reserve trees. Although there is a recent surge in interest in multiaged systems in temperate and tropical forests around the world (O'HARA 1998), relatively little is known about their development, management, or the implications of multiaged management on resistance and resilience to hydrogeomorphic disturbances. This paper will:

1) introduce the relationship between stand structure and disturbances, particularly those that result in multiaged stands;
2) describe how multiaged stands impart resistance and resilience to abiotic disturbances in general and specifically hydrogeomorphic disturbances; and
3) present implications for management of multiaged protection forests.

## 2 Background

There is a natural connection between silvicultural operations and natural disturbances. However, it has only been recently articulated with OLIVER and LARSON's (1996) Forest Stand Dynamics book, the most recent edition of the Practice of Silviculture (SMITH *et al.* 1997), and a series of other publications (MITCHELL *et al.* 2002; FRANKLIN *et al.* 2002; LINDENMAYER and FRANKLIN 2002; PERERA *et al.* 2004). The connection involves the foundation of silviculture: an understanding of silvics and the ability to apply this knowledge to stand manipulation. An important silvical characteristic of any tree or community is the adaptability and resistance of trees and stands to disturbance. Trees have evolved under a set of environmental stresses including disturbances, and species vary in their ability to tolerate these stresses. Effective silviculture therefore builds upon tolerances to environmental stresses such as disturbances to favour certain species and to form desired stand structures.

Emulating natural disturbances with silviculture involves operations or sets of operations that favour or disfavour certain silvical characteristics in desired species. For example, even-aged silviculture generally favours species with low tolerance to shade, prescribed burning favours fire-adapted species, and mechanical site preparation favours species with low tolerance for non-mineral soil seedbeds. The arrangement of silvicultural operations in space and time also influences the ability to mimic the scale of natural disturbances. Whereas the practice of silviculture has traditionally recognized the link with natural disturbance, it has primarily been at the tree and stand level, not at larger spatial scales. Temporal issues of disturbance emulation are more commonly integrated into the design of silvicultural operations through rotation lengths, scheduling of thinnings, and multiaged cutting cycles. However the trend has been towards more uniform rotations and cutting cycles than occur with natural disturbances. Although the emulation of natural disturbances provides a valuable and desirable link between management and natural ecosystem processes, not all silvicultural operations closely mimic natural processes. Chemical treatments, removal of tree boles in timber harvesting, or compaction to soils in harvesting are examples.

The concept of designing stand structures that are resistant to disturbances is similar to designing structures that result from the emulation of disturbances because in either case the silvical characteristics of the tree species must be known and the operations used to form these structures may either emulate disturbances or may actually be forms of the disturbance agents as in the case of prescribed burning. The key questions involve determining the best structures for resistance and resilience to different disturbances or for a given suite of potential disturbances.

There is an expanding international interest in the retention and development of multiaged forest stands. Multiaged stands have two or more age classes and are more inclusive than uneven-aged stands with three or more age classes (O'Hara 1998). Other names for the systems to produce these stands and the structures that result include multicohort, continuous cover forestry, close-to-nature forestry, polycyclic, near-natural forestry, and others (O'Hara 1998). This expanding interest is primarily the result of environmental pressures such as demands for more natural structures, biases against even-aged management, and greater knowledge of multiaged stand dynamics and management.

Multiaged stands result from disturbances – whether by humans or natural causes – that leave some surviving trees. These disturbances may also occur on relatively frequent intervals. The primary distinction of multiaged from even-aged stands is therefore the occurrence of low-severity disturbances on relatively frequent intervals. For managed multiaged stands, these disturbances are partial cuttings and the intervals are termed cutting cycles. Unmanaged multiaged stands can result from the effects of many single types of disturbance events or combinations of disturbance events such as flooding, landslides, fire, wind, insects, pathogens, and others.

Although multiaged stand structures can be highly variable because the severity and frequency of disturbance events is variable, some key characteristics are common:

1) A diversity of tree sizes will be present that may or may not correspond to tree ages. In managed stands this diversity of size classes has often been represented with a negative exponential size frequency distribution with greater numbers of small than large trees. However, the negative exponential distribution is arbitrary and any distribution should be considered possible (O'Hara 1998).

2) At some spatial scale, age classes or cohorts of trees will be intermingled. At one extreme, age classes may be intermingled or, at the other, intermingled as patches of even-aged trees: the former is approximated by individual tree selection and the latter by group selection silvicultural systems.
3) Continuous presence over time of some stand structural elements including canopy cover, tree stems, or living root structures.

For forests susceptible to hydrogeomorphic processes, the continuous presence of structure provides both resistance and resilience. For other disturbances, multiaged stands may provide greater resilience but less resistance. For example, the heterogeneous canopy of a multiaged stand may provide vertical fuel ladders but also some trees that survive a fire and hasten recovery.

## 3 Resistance and resilience

### 3.1 Trees

An individual tree imparts resistance by being able to survive a disturbance. Whereas many species are assumed to have coevolved and developed resistance mechanisms to disturbances such as fire and insects, few documented cases of coevolved resistance to hydrogeomorphic processes exist.

The strength of the stem is a critical form of resistance to a variety of disturbances. Although species vary in their inherent wood density and strength, stem resistance to wind stress is generally expressed as a ratio of tree height to stem diameter at breast height. Higher ratios imply less resistance and threshold ratios typically vary from 80 to 100 for most conifers (CREMER *et al.* 1982; STATHERS *et al.* 1994; NYKÄNEN *et al.* 1997; WONN and O'HARA 2001). Differences are due to variation in root structure, deciduousness, wood strength, branch flexibility, and others. MASON's (2002) review of stand structure and tree stability found some evidence of greater stability in more irregular stands indicating multiaged stands may have greater resistance to disturbances related to stem strength. These include wind and hydrogeomorphic events like landslides, snow avalanches, and debris flows.

Root systems are another important form of resistance to disturbances. Root system structures are apparently an adaptation to aid nutrient and water uptake and provide stability to the tree. Species therefore vary in their root system structure: spruces (*Picea* spp.) are typically shallow-rooted species that are prone to windthrow whereas pines (*Pinus* spp.) often form taproots that make them more stable. Root systems also provide a network of overlapping and sometimes interconnected below-ground structure to enhance soil stability. Hence a fully stocked stand with mature trees provides resistance to mass wasting, and other forms of erosion. A mixed-species stand would likely have species pursuing different rooting strategies and possibly forming a more cohesive and synergistic root system structure (STOUT 1956). Single-species, multiaged stands might also have individual trees occupying different rooting strata but this has not been measured. Once a stand is cut or receives some other form of stand replacement disturbance, the root system provides stability that declines as this root system decays. Another important factor is the ability of roots to anchor a soil to bedrock. Multiaged stands therefore have an advantage as their "continuous root system structure" over time provides increased stability to steep slopes.

Bark serves an important role in protecting trees from some disturbance agents. Thicker bark provides greater protection and bark thickness is usually linearly related to tree diameter (HUSCH *et al.* 2003). Hence larger trees have greater resistance to fire and some insects, and greater resilience to fire disturbances. Bark thickness is probably of little consequence for resistance to hydrogeomorphic disturbances except as a form of insulation from stem injury and decay or when they occur in combinations with other disturbances such as insects and fire.

Resilience to disturbance comes from two types of reactions: the ability of trees to survive a disturbance and recover post-disturbance, and through regeneration of post-disturbance replacement trees. The function of protection forests is often met through the presence of standing trees (or the accumulation of living biomass), so live trees that may not be vigorous may be functional. In cases where the protective function is met through large woody debris (LWD), resilience is the result of having living trees present that may form future LWD and larger trees that may form more effective debris barriers. Trees that withstand a debris flow, for example, are immediately present to serve in a protection role as LWD for future events.

Following any type of forest disturbance, trees will usually invade through a variety of regeneration mechanisms (OLIVER and LARSON 1996). Disturbances favour different regeneration mechanisms and therefore certain species in much the same way silviculture attempts to favour species. For example, advance regeneration are favoured by windthrow where only the overstorey is destroyed, but windblown seeds are favoured when a disturbance, such as a stand-replacing fire, kills all standing trees and prepares a seedbed. If disturbances occur frequently, species that sprout have an advantage over species that rely on seed production. Resilience is therefore highly dependent on the type of disturbance through determining which species survive, the frequency of the disturbance because of interactions with when trees reach sexual maturity and can reproduce, and the species present because non-present species cannot regenerate regardless of the disturbance type or frequency.

### 3.2 Stands

WILFORD *et al.* (2005) characterized hydrogeomorphic disturbances as ranging from low-power events with limited stand damage to high-power events that might completely remove all trees. Stands provide resistance to these disturbances through the presence and arrangement of individual trees or obstacles and resilience through the potential to replace these trees. Because stands are dynamic, levels of resistance and resilience vary over time. The resistance to many hydrogeomorphic processes is dependent upon having large trees present. For example, debris flows and rock falls may be slowed and their extent of damage or run can be reduced. Other structures – including the presence of small trees or LWD – may provide resistance to other disturbances. For many hydrogeomorphic disturbances, the mere presence of trees and down wood debris provides some resistance to flow of water and debris. Resilience may be provided by having advance regeneration that survives a disturbance to form replacement trees or by having trees that can survive a disturbance such as sediment deposition.

Even-aged stands will often range from having few if any living trees initially to having many large trees at end-of-rotation. Their ability to serve as protection forests to hydrogeomorphic processes therefore varies with stand age (Fig. 1). After a clearcut, or other stand replacement disturbance, resistance is provided only by stumps, snags and LWD. Any residual structure – such as that provided by seed tree, shelterwood, or variable retention systems –

would increase resistance. Resilience is provided by the ability to replace lost trees quickly. Since even-aged stands may only provide a protective function with the presence of mature trees, they alternate between serving as protection forests or growing into functioning protection forests, but not both simultaneously. If large trees are required, they can never be both functioning and have much resilience because by definition the entire process of even-aged stand development lacks regeneration trees to replace mature trees (Fig. 2). If, for example, a stand provides the protective function for the last 20 % of a 100-year rotation and experiences a stand-replacement disturbance at age 80, the stand would require another 80 years to reach the protective function and a full 160 years would pass without providing that function. If small trees are required, the protective function is met early in the rotation when reproductive maturity has not yet occurred. In these situations, coppice systems may be most appropriate.

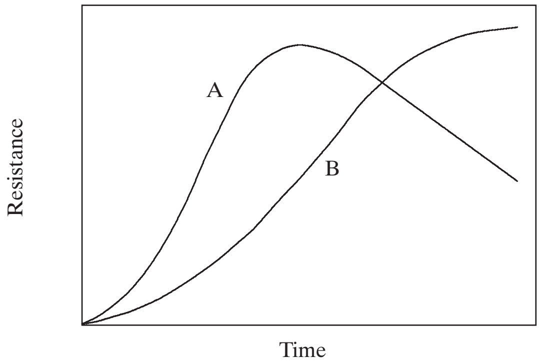


Fig. 1. Hypothetical resistance regimes for even-aged stands. Regime A represents a disturbance where medium-sized trees provide the protective function and Regime B where larger trees provide the protective function.

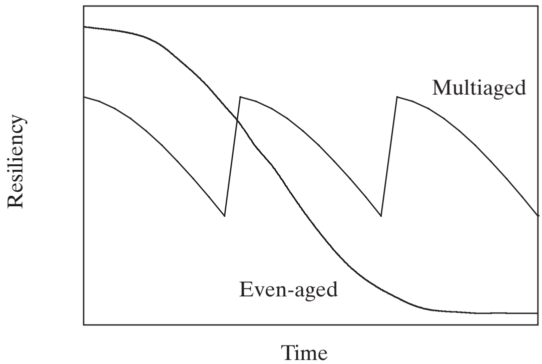


Fig. 2. Hypothetical resilience of even-aged and multiaged stands over one even-aged rotation or three multiaged cutting cycles. Diagram assumes that resilience is provided by regenerating trees that are generally not present late in the even-aged rotation but always present in varying amounts in the multi-aged stand.

Multiaged stands provide resistance continuously but at a level lower than the maximum of the even-aged stand (Fig. 3). Multiaged stand structures fluctuate within a narrow range from the beginning to end of a cutting cycle. Some protective function is therefore always provided. In addition to the variable number and distribution of age classes, multiaged stands also vary in the spatial arrangement of age classes from intermingled to patchy. These different spatial patterns may also affect the protective function of these structures. Differences in spatial pattern may be insignificant if the area serving as protection forest is sufficiently large as to accommodate a patchy structure with all age classes represented. For smaller areas, only the "fine scale" structure would provide the protective function. Alternatively, for some disturbances such as debris avalanches, the important protective function may be provided by the edge of the stand and resilience may come from a sufficiently large stand that always has some edge available.

The periodic development of new age classes of trees in multiaged stands provides the resilience to replace larger trees. The effect of any disturbance – whether hydrogeomorphic or otherwise – that destroys larger trees would be relatively short-lived because younger trees would immediately benefit from the available growing space. However, if a multiaged stand was completely destroyed, it would not have greater resilience to disturbance than an even-aged stand. Greater resilience is only an advantage for multiaged stands when disturbances do not kill all trees. An even-aged forest where large trees provided the protective function may be most resilient only in the short-term case of a partial disturbance in mature stands that did not kill larger trees.

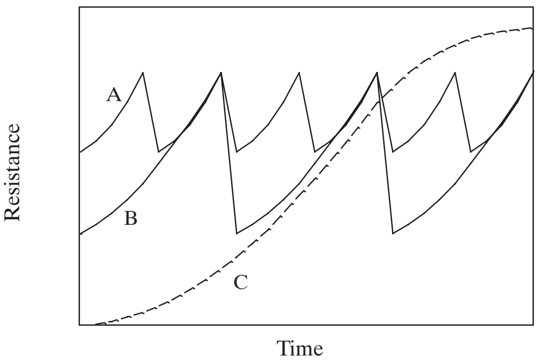


Fig. 3. Hypothetical resistance of two multiaged regimes and an even-aged regime assuming the protective function is provided by large trees. Regime A has more frequent harvest treatments and shorter cutting cycles than regime B. If resistance were provided by large trees, then regime A would appear to be superior in this example but neither reach the maximum resistance provided by the even-aged stand (C).

## 3.3 Broad areas

The spatial variability and spatial extent of multiaged protection forests is also critical to their function. Large areas may function as protection forests for alluvial deposition whereas a snow avalanche protection forest may be relatively small. Multiaged stands, particularly those managed with a patch or group selection pattern, can resemble a regulated forest of even-aged stands but at a much smaller scale. Scale is therefore important in how it affects the arrangement of structural elements in a stand. A small stand will require the protective structure element be present continuously whereas a large stand might have the protective structural element shifting in time and place within the stand. Some protective functions can also be described as direct where the structure at a given location is critical, whereas indirect protection would be provided by having a certain portion of a broader area in a protective structure (BRANG and SCHÖNENBERGER this issue).

Similar concepts apply to larger areas. In general, there is less structural heterogeneity in multiaged stands over time than in comparable even-aged stands. The protective function – assuming it is met with a multiaged structure – is provided continuously and at a higher level by the multiaged structure. At larger scales, a forest of multiaged stands would form a much more homogeneous canopy and provide less variability in the level of protective function. If the protective function was provided at a high level, then this structure would be more desirable than a large area of even-aged stands. In either case, protective functions at the larger scale may take precedence over stand-level concerns.

# 4 Management of multiaged protection forests – Implications

## 4.1 Management approaches

Multiaged stands, by definition, include two or more age classes. The conversion of an even-aged stand to the most basic multiaged stand therefore requires a significant time period and the development of a protective function that includes larger trees requires even greater time (O'HARA 2001). On an unforested site, the process of developing a multiaged stand will also require a considerable time commitment, particularly on harsh sites.

Stocking control is central to implementation and design of multiaged silviculture. A variety of approaches are used: O'HARA and GERSONDE (2004) described four stocking control approaches that are among the most common worldwide. Stocking control has traditionally consisted of implementation of a diameter frequency distribution that serves as both a representation of stocking and stand structure. However, there has generally been very little flexibility in varying the form of this diameter distribution from a negative exponential form. An alternative approach based on leaf area allocation to age classes or canopy strata provides more flexibility for alternative structures (O'HARA and VALAPPIL 1999).

Multiaged protection stands will need to assume a variety of structures and will be most effective if the constraints of more regulated and traditional multiaged or uneven-aged systems are discarded. Since the protective function may be provided by the presence of large trees in some cases, the high concentration of small trees characteristic of traditional systems may be unnecessary and undesirable because this growing space can be allocated to larger trees. For protective forests where the presence of small trees is critical, structures with only enough large trees to provide seed with the rest of the growing space allocated to regeneration and sapling-sized trees may be most effective.

The number of age classes or cohorts present is related to the cutting cycle length: longer cutting cycles will require fewer age classes for equivalent lengths of the multiaged "rotation". This has important implications for regeneration and productivity: longer cutting cycles require lower stocking at the beginning of the cutting cycle thereby providing more resources for regeneration, particularly of shade intolerant species, but shorter cutting cycles allow for higher overall stocking leading to greater productivity (O'HARA and VALAPPIL 1999). To maximize the protective function, short cutting cycles with light cuttings at high stocking levels could provide greater numbers of large trees (Fig. 3), but might make regeneration more difficult.

## 4.2 Other disturbances

Protection forests are intended to protect other resources from certain disturbance events. However, an important consideration is the vulnerability of the protection forest to other disturbances. If the protection forest is damaged by another disturbance then it may fail to meet its protective function. The structure of a given stand is a primary variable in determining its susceptibility to disturbances and disturbance effects will vary with structure. The greater structural diversity of multiaged stands makes them more susceptible than even-aged stands to some disturbances and less susceptible to others. For example, in dense stands, multiage structures may form fuel ladders that enhance spread of surface fires to the crowns, causing greater damage. Dwarf mistletoes (*Arceuthobium* spp.) spread more easily when seeds can fall vertically to other susceptible species making pure species, multiaged stands among the most vulnerable structures. Some insects, such as western spruce budworm (*Choristoneura occidentalis* Freeman), benefit from a vertically diverse canopy of susceptible species. Alternatively, other insects that require a certain minimum tree size to breed successfully, such as the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), may have more difficulty reaching outbreak levels in multiaged stands. Multiaged stands may also be more resistant to windthrow damage (MASON 2002). It is likely that every stand structure has a unique set of vulnerabilities and resistances with regard to disturbances and managers should consider these in designing structures for protection and managing these structures. Multiaged stands may be an effective protection structure in some cases and not in others. There may be ways of modifying multiaged stand structures to separate canopy strata either vertically or horizontally to alleviate risks. Mixed-species stands will also enhance resistance to many insect and pathogens.

### 4.3 Implications

The optimal stand structure for protection forests will vary with the disturbance agent and the severity or power (e.g. WILFORD *et al.* 2005) of that disturbance. LWD may be critical for protection from sediment movement and deposition. Small trees may provide greater protection to snow avalanches while large trees may be most effective with debris avalanches (BRANG 2001). Protection forests consisting of multiaged stand structures will therefore be highly variable. With variations in forest type and site productivity, the organization of management operations will also be highly variable.

A central element of multiaged systems is the cutting cycle. If natural disturbance patterns are used to guide silviculture, then the frequency of disturbance can guide cutting cycle lengths in multiaged stands. The protection forest objective may be quite dissimilar to the natural processes for a given site. Many forests, particularly in light-limited environments, develop through extended periods of stem exclusion where regeneration of new cohorts does not occur (OLIVER and LARSON 1996). Periodic operations to open the canopy will be necessary to maintain multiaged stands. The time of these operations will depend on the need for new cohorts. For example, on a poor site where growth is slow, operations can be very infrequent as short cutting cycles would only have a minor effect on tree-size diversity.

Thinnings can also be used to reduce the density of multiaged stands without also having a regeneration objective. These operations may be designed to reduce the density within a cohort or to provide growing space to another cohort. Regeneration may occur at any time during a cutting cycle. Planted seedlings can be used to target certain areas of a stand and to accelerate the process of tree development.

Although the objectives of protection forests may not include revenue production, they may have the potential to produce revenue from timber harvests to offset management costs. This will require sufficient wood volumes and a road network to permit access. Roads, whether temporary or permanent, must not exacerbate disturbance hazards by decreasing soil stability or providing pathways for water or debris concentration. Roads may actually contribute to the protective function if strategically placed. The high costs of road construction and maintenance may make commercial operations unfeasible and force all operations to be non-commercial where undesired trees are cut and left on the ground or simply killed and left standing. This may create fire hazards in addition to being regular hazard trees if stands are near recreation sites, buildings, roads, etc. In any case, protection forests may require considerable public investment with limited or non-existent revenue generation.

Future research might address relationships between disturbance frequency and severity as a basis for designing silvicultural regimes. Short disturbance cycles might justify multiaged stands where cutting cycles correspond to disturbance frequencies. Or conversely, severe and infrequent disturbances may warrant short cutting cycles that maintain high levels of stand structure to maximize the protective function.

## 5 Conclusions

Multiaged stands have potential to provide protective functions in many different forest types against a variety of hydrogeomorphic disturbance agents. Whereas this potential may provide advantages for multiaged stands in many situations, the structure of these stands will be highly variable and some situations will exist where even-aged stands are most suitable. The resistance of protection forests to other disturbances will also determine the efficacy of these forests beyond providing only their protective function. Management of these multiaged stands can vary the allocation of growing space to stand components, by varying species composition or by varying the length of the cutting cycle to modify stand structures to meeting specific goals. Desirable stand structures may include a preponderance of large or small trees, certain species, or spatial patterns. The design and management of protection forests may also range from the intensive care and modification of structures to structures than require only monitoring over time.

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