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# Flexibility in forest management: managing uncertainty in Douglas-fir forests of the Pacific Northwest

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**Abstract**

Long planning horizons generate substantial uncertainty in forest management, making management flexibility, the ability to choose between multiple options or opportunities, a desirable attribute of managed forests. Flexibility in forest management reflects both the relative rigidity of intervention requirements and the potential range of development pathways for a stand. The wind stability of Pacific Northwest Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) plantations is used to demonstrate the concept of management flexibility. Dense Douglazs-fir plantations develop high height to diameter ratios (*H*/*D* same units) in the dominant trees making them unstable and prone to wind damage. The management of these plantations is inflexible, because without early and timely thinning, the stands do not contain stable trees that could be expected to survive long rotations or late thinnings. A combination of reduced planting densities and site-specific management reduces both the necessity and rigidity of intervention requirements (e.g., thinning) and expands the number of potential developmental pathways for these stands. The cost of greater management flexibility is reduced efficiency of wood volume production; however, greater adaptability to changing markets, labor conditions, and management objectives may be more important for many forest owners. While this approach to management is complex, it frees owners and managers from rigid management requirements and allows for a wider range of future stand conditions. Published by Elsevier Science B.V.

*Keywords:* Management flexibility; Douglas-fir; Wind stability; Management objectives

## 1. Introduction

Managing forest stands and landscapes are tasks made complex by long planning horizons. Multiple-decade time horizons generate substantial uncertainty concerning future markets, objectives, regulations, labor availability, and natural disturbances. The inherent uncertainty in forest management makes stands and landscapes that can be flexibly managed desirable. There are two closely related dimensions to the flexibility of stand management: operational; and developmental. Operational flexibility reflects the relative rigidity of intervention requirements, such as thinning to promote stability or reduce stagnation during particular stand development windows. The need for, and therefore intensity of, management declines as operational flexibility increases. Thinnings or other interventions are not excluded in stands that can be managed with operational flexibility. If timing for markets or labor availability is good, thinning can be pursued aggressively; however, if timing is poor, thinning can be postponed or eliminated without dramatic implications for future stand conditions. Developmental flexibility describes the range of potential

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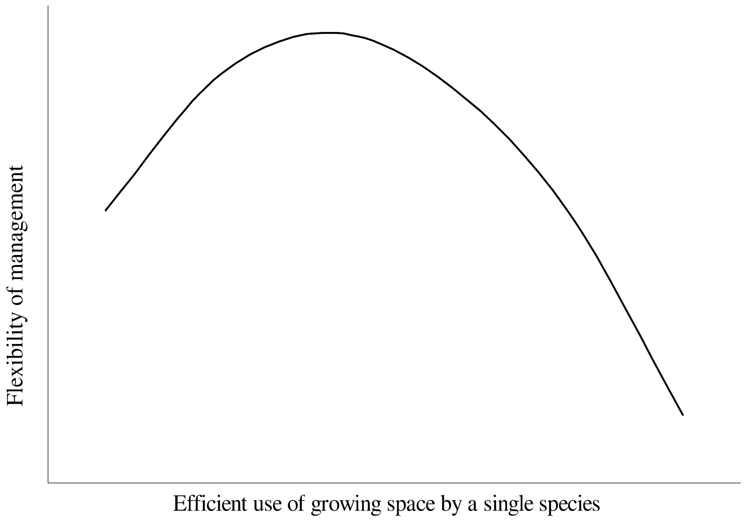


Fig. 1. Depiction of tradeoff between management flexibility and efficient use of growing space by a single tree species. Forest owners and managers must find an appropriate balance between how intensively they are willing to manage and how efficiently they wish growing space to be utilized by the planted species.

future stand conditions that are possible for a particular stand. Stands and landscapes with developmental flexibility are not limited to a single developmental path or end-point. For example, stands that contain wind-stable trees are developmentally flexible. The stable trees can be expected to survive late thinnings and extended rotations designed to create high quality wood, or can be used to develop and maintain older forest structure.

The cost of greater management flexibility is less efficient use of growing space by desired species. To generate large future biomass yields, a single species of tree is typically planted at close spacings so as to usurp the available growing space as quickly as possible. The intense competition between trees in dense plantations necessitates early thinning to avoid stagnation and promote stand development beyond a narrow range of possibilities. Forest managers and owners must seek a comfortable balance between flexibility of management and efficient use of growing space. A graphical representation of the tradeoff between flexibility and efficiency is depicted in Fig. 1. High-density plantations efficiently capture available growing space for the desired species; however, operational requirements and developmental restrictions make them inflexible to manage. Flexibility peaks at moderate growing space efficiency because the range of potential developmental pathways is also reduced at very low initial densities.

This paper proposes that forest managers and owners consider the associated flexibility of management in the development of stand and landscape plans. An evaluation of wind stability for coastal Pacific Northwest Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) plantations illustrates the tradeoffs between management flexibility and efficient use of growing space.

## 2. Wind stability and management flexibility

Severe windstorms that damage forests have been common in the Pacific Northwest. Hurricane-force windstorms impact the coast of Washington and Oregon every 20 years on average (Wiley, 1965; Henderson et al., 1989). Severe storms in 1921 and 1962 are both estimated to have blown down over $25\times10^6$ $m^3$ of timber (Wiley, 1965; Lynott and Cramer, 1966; Henderson et al., 1989). Gusts in the 1962 storm exceeded 170 miles per hour at some locations (Wiley, 1965).

The impacts of stand stability on management flexibility are related to the current and future wind risk for a stand. Stands at high risk of wind damage are developmentally inflexible because they are unlikely to persist after thinnings or through long rotations. Thus, the range of possible future conditions in stands is limited when they do not contain windfirm trees. The risk of wind damage in a stand is typically estimated by three classes of factors: regional climate; stand characteristics; and site attributes (Alexander, 1987; Mitchell, 1995). Regional climate determines the potential for windstorms of sufficient intensity to damage forest stands. If damaging windstorms are rare, the wind risk of a stand or landscape may have minor implications for management flexibility; however, when rare storms impact trees and stands that are not preconditioned to high winds or to winds from particular directions, damage may be considerable (Kenworthy, 1998). Stand characteristics such as average height, tree taper, species composition, trees per unit area, average crown size, and characteristics of upwind neighbors are determined by the individual trees in the stand (Cremer et al., 1982; Becquey and Riou-Nivert, 1987; Lohmander and Helles, 1987; Foster, 1988; Ruel, 1995). Stand characteristics are responsive to manipulation. Site characteristics describe environmental conditions such as rooting depth, soil moisture, topographic exposure, site quality, and slope. These are characteristics that are not generally altered by forest management (Kennedy, 1974; Cremer et al., 1982; Mitchell, 1995; Quine, 1995). The implications of stand and site characteristics on wind risk and flexibility of managing Pacific Northwest Douglas-fir plantations are considered separately in the following sections.

### 2.1. Stand considerations

The wind risk literature identifies seven stand attributes that are associated with susceptibility to wind damage. These attributes are stand height, height to diameter ratio (*H*/*D*-both measurements in the same units), inter-tree spacing, species, prevalence of root and stem rot diseases, recent thinning, and recently exposed edges due to harvest of adjacent stands (see, Refs. Savill, 1983 and Wilson, 1998 for a review). Management can be used to alter any of these attributes, reducing susceptibility to wind damage. For simplicity, this section concentrates on evaluating the implications of a single attribute, *H*/*D* values, for wind risk and management flexibility. The impact of *H*/*D* values on wind risk is consistent and well documented. In addition, *H*/*D* values can be easily manipulated and reflect management flexibility more directly than the other attributes. For example, wind risk can be lowered by harvesting stands early, in effect limiting stand height; however, such short rotations accept restricted stand developmental options and timber outputs rather than promote greater flexibility of management.

The most common management regime in coastal Oregon, Washington and British Columbia is to plant Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) following a clearcut harvest. Planting densities vary widely by ownership but typically range between 1000 and 3500 trees per hectare (tph). Planted stands generally develop less variation in tree sizes than the naturally regenerated stands they replace (Wilson, 1998). Limited variation of tree sizes within a stand increases the *H*/*D* of dominant trees (Wilson, 1998). Increasing *H*/*D* values reflect decreasing stability. *H*/*D* is a simple yet effective measure of tree stability under wind and snow loads. The value of *H*/*D* as a stability measure is supported by both mechanistic models of tree stability and empirical evidence (Petty and Worrell, 1981; Cremer et al., 1982; Becquey and Riou-Nivert, 1987; Lohmander and Helles, 1987; Peltola and Kellomaki, 1993; Slodicak, 1995).

Averaging the *H*/*D* for dominant trees (*H*/*D* for the largest 250 tph [$H/D_{\mathrm{L250}}$]) reflects stand-scale wind stability (Cremer et al., 1982). The trend of $H/D_{\mathrm{L250}}$ values for a stand through time typically follows a steep rise between 10 and 30 m of stand height followed by a slow decline (Cremer et al., 1982; Becquey and Riou-Nivert, 1987; Wilson, 1998). $H/D_{\mathrm{L250}}$ curves and peaks are higher for stands with greater initial tree densities. Only very early thinning provides substantial reductions in *H*/*D* values (Cremer et al., 1982; Slodicak, 1995; Wilson, 1998).

A theoretical comparison of allometric relationships in an individual Douglas-fir (Fig. 2) helps explain both the requirement for very early thinnings to reduce *H*/*D* ratios and the peaking of *H*/*D* ratios at 25–30 m. To maintain relatively stable *H*/*D* values between stand heights of 10–30 m requires substantial basal area increments (double and triple what they were at 5 m). Rapid height growth and basal area increments being a function of diameter-squared combine to assure rising *H*/*D* ratios between 10 and 30 m in all but open grown trees. Tree height–growth

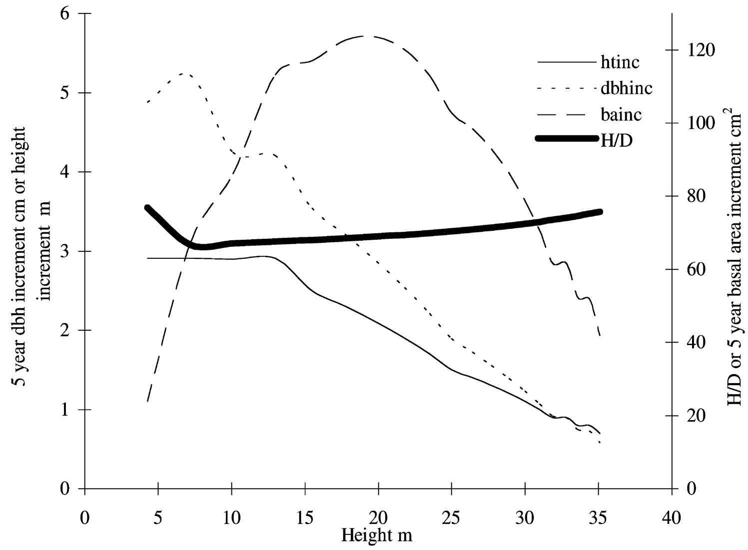


Fig. 2. Five-year height increment (Douglas-fir site index curves [Mitchell and Polsson, 1988]) and the theoretical diameter and basal area (BA) increments needed to maintain the *H*/*D* ratio shown. This figure shows the dramatic increase in BA increment required to keep the *H*/*D* ratio relatively constant in trees between 10 and 30 m tall.

increments decline beyond 25–30 m of stand height. The resulting reductions in basal area increment requirements suggest *H*/*D* values should peak in this height range.

A family of $H/D_{L250}$ curves for a range of initial Douglas-fir densities developed from Pacific Northwest experimental plot data is presented in Fig. 3. This plantation data does not contain stands old enough to show the slow declines in $H/D_{L250}$ values beyond 25–30 m of height found in previous studies. Thinning stands after they reach 10 m of height produces only very moderate declines in $H/D_{L250}$ levels. Thinning plantations by 20% of their basal area from below at an average height of 15 m only reduced $H/D_{L250}$ levels by 2.5 at heights of 30 m (Wilson, 1998).

There is an early and dramatic divergence of *H*/*D* values for trees growing in different competitive environments (Fig. 4). Rising *H*/*D* values in all plantations between 10 and 30 m of height make their early development crucial to future stability (i.e. height<10 m). To keep plantations from exceeding modestly stable *H*/*D* values (e.g. $H/D_{L250}<80$) requires thinning prior to the onset of competition between trees and rising *H*/*D* levels. The higher the initial plantation density the earlier *H*/*D* values start to rise, restricting the effective thinning window even further (Figs. 3 and 4).

Two options for maintaining relatively low $H/D_{L250}$ values are available. One, initial densities of Douglas-fir can be reduced, either through planting at wide spacings (<1000 tph) or early thinning. The higher the initial density the earlier stands must be thinned to remain stable. Two, plantations or thinnings could be designed to generate greater variation in tree sizes to more closely mimic naturally regenerated stands. This could be achieved by planting seedlings of different ages or using irregular planting patterns. If $H/D_{L250}$ values continue to rise throughout a stand's development, the second approach provides the more flexible option for long rotations. Strong differentiation of tree sizes reflects a hierarchy that persists through the life of stands. Fortunately, $H/D_{L250}$ values in Douglas-fir stands tend to decline beyond 25–30 m as the height growth increments decrease relative to diameter growth increments; consequently, controlling initial densities can promote stability throughout the development of a stand. An approximate maximum $H/D_{L250}$ value can be anticipated through planting design or early thinning. The advantage of controlling early densities rather than developing greater tree size

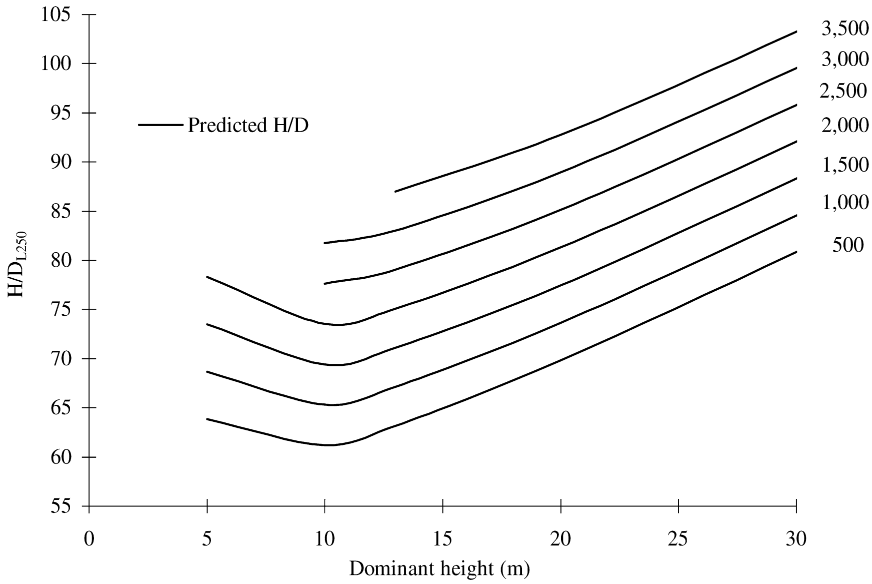


Fig. 3. Predicted $H/D_{L250}$ vs. dominant height of unthinned plantations ((ht-bh)/$d$=63.72588+1.20446*(ht-bh-19.06629)+0.00715*(iddf), adj. $r^2$=0.771, $p$<0.0000) Line labels (numbers on far right) correspond to initial Douglas-fir density. The British Columbia Ministry of Forests Research Branch (EP703), Stand Management Cooperative (SMC), and USDA Forest Service, PNW Research Station (LOGS) provided data for this study (Wilson, 1998).

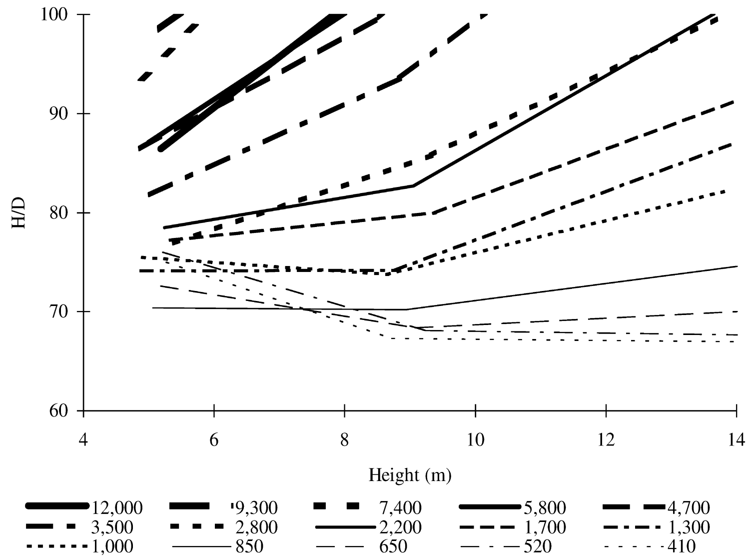


Fig. 4. Early $H/D$ trends from Haney, BC Nelder plot data. Numbers to the right of legend lines represent initial Douglas-fir density (tph) in particular arcs (data from Smith, 1983; Reukema and Smith, 1987).

variation is the ease of implementation compared to planting seedlings with a range of ages or developing complex planting patterns.

Developing mixed species plantations could combine the two options described previously. Relatively low initial Douglas-fir densities could be augmented by planting more shade tolerant species that Douglas-fir generally overtops (Wierman and Oliver, 1979). Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western red cedar (*Thuja plicata* D. Don ex Lambert) are two species that appear to have minimal impacts on future Douglas-fir $H/D_{L250}$ values (Wilson, 1998). In this approach, mixed-species crown and size stratification replace size variation within a single species caused by age differences or spatial aggregation. One advantage of the mixed-species alternative is that it addresses concerns that wider spacings reduce wood quality (e.g. large branches, juvenile wood core, and weed competition). In addition, this approach increases species diversity. Diversity of tree species enhances habitat value and provides a greater range of timber products from a stand. A range of products provides some insurance against downturns in specific markets. In addition, a stand with multiple tree species is less likely to be completely decimated by insects or pathogens.

The management of Douglas-fir stands planted at high densities is less flexible from both an operational and a developmental perspective. High initial densities restrict the thinning window during which future $H/D_{L250}$ values can effectively be lowered. If thinning has not been accomplished within the narrow window, potential developmental pathways and endpoints for high density stand are curtailed. Stands that develop high $H/D_{L250}$ values do not have suitable trees to leave after late thinning or for extended rotations. Options for the stand are primarily restricted to harvesting after a short rotation. If the objectives and expectations for a stand focus on high volume production during a short rotation, efficient use of growing space represents a high priority — making planting Douglas-fir at high densities a reasonable management approach. When objectives are less clearly defined or future markets are somewhat uncertain, the value of stands that can be managed flexibly increases. Stands that cannot be managed flexibly lock the owner/manager into a strict treatment schedule or a limited product mix that may prove costly if conditions change. Flexibility in management may be most critical for forestland controlled by public agencies. Even basic objectives for public agency forestland may swing widely with conflicting political pressures. Developing stands that, with minimal intervention, can provide outputs ranging from timber production to older forest habitat is critical when future goals and management options are uncertain.

### 2.2. Site considerations

Exposure, soils, and site quality all interact with stand conditions to determine the risk of wind damage. Risk in turn has important implications for how flexibly a stand can be managed. Stands in topographically protected areas can be managed more flexibly since the site reduces risk of wind damage; however, topographically protected sites may be exposed if winds come from unexpected directions (Rebertus et al., 1997). As landscape-scale silvicultural approaches are developed and modified, tradeoffs between risk from expected and unexpected storm directions should be considered (Wilson, 1998). Deeper well-drained soils that are less prone to windthrow increase management flexibility in much the same way as exposure. The interaction of management flexibility with site quality is slightly more complicated. Stands developing on sites that are more productive grow more quickly in height, achieving high heights and $H/D_{L250}$ values sooner. More rapid height growth also results in temporally narrowed thinning windows for effective reduction of $H/D$ values. In some cases site quality, soils, and exposure may have confounding effects on wind risk and management flexibility. For example, stands on deep soils may be relatively productive, narrowing potential thinning windows and generating risk sooner (Rebertus et al., 1997).

The risk of wind damage changes dramatically across a landscape. A management approach that is not modified according to the spatial position of stands within a landscape does not account for these inherent differences in risk of wind damage. The balance between efficiency and flexibility changes when a single management approach is implemented on different landscape positions (Fig. 5a). Wind risk in Fig. 5a is composed of equal contributions from site and stand risks. The importance of efficiency

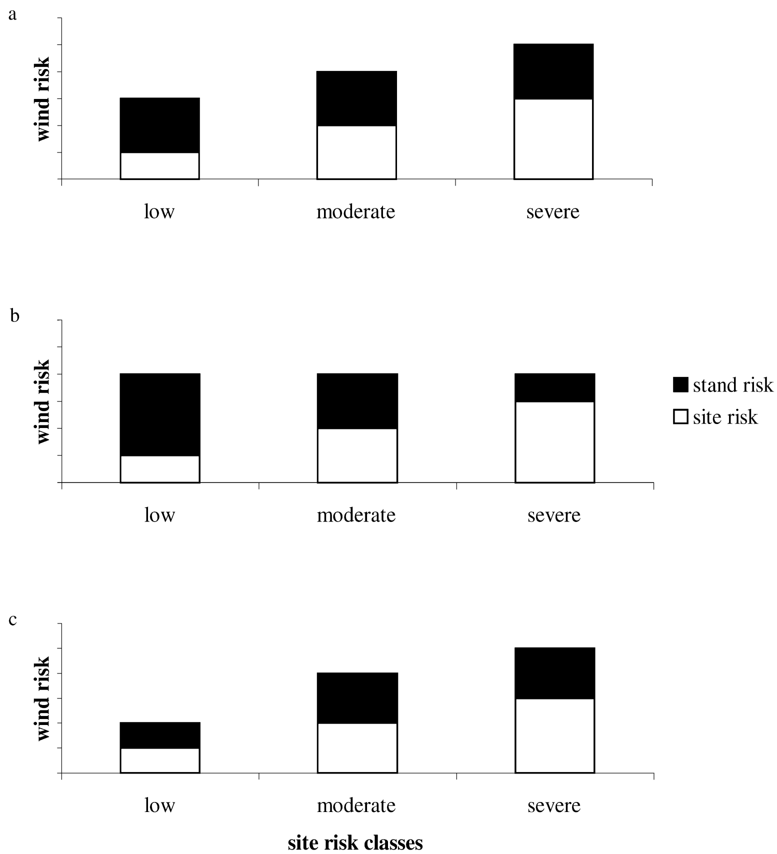


Fig. 5. Conceptual comparison of wind risk rankings: (a) when a single silvicultural approach is used across a landscape; (b) when management prescriptions are altered to account for inherent site risk; and (c) low site and stand risk are combined to provide very low risk stands that are more suitable for long rotations. Overall wind risk is composed of equal parts site and stand risk.

increases relative to flexibility if sites with high risk are managed in the same manner as those with low risk.

An alternative approach is to adapt management to site conditions so that the balance between efficiency and flexibility is applied more consistently across the landscape. In a simplified example that does not consider productivity differences between sites, planting density could be increased in stands with lower inherent site risk levels. Protected sites would be planted at high densities; exposed sites would be planted at lower densities or thinned earlier. The increased risk associated with stand attributes would be balanced by low site risk (Fig. 5b). Conversely, if it is desirable for some proportion of the landscape to be in older forest structure, flexibility could be weighted more heavily in stands with low inherent wind risk (Fig. 5c). Low-density plantations on low-risk sites are capable of producing older forest structure that is likely to persist on the landscape. If older forest structure needs to be created rapidly, low risk, high quality sites could be preferentially chosen.

These simplified examples reveal the complexities associated with forest management when relatively subtle tradeoffs such as management flexibility and efficient use of growing space are considered. Tools that facilitate evaluations of complex management tradeoffs, such as a landscape wind risk rating system based on inventory information and growth model projections, have been proposed and developed (Mitchell, 1995; Mitchell, 1998; McCarter et al., 1998; Wilson, 1998).

## 3. Conclusion

The range of owner objectives and landscape conditions in the coastal Pacific Northwest suggests that no one silvicultural approach can achieve the appropriate balance between efficiency and flexibility. The intensive management required for high-density plantations may be acceptable for some owners, managers, or sites. For others, temporally restrictive thinning windows and limited developmental pathways may be a burden that overwhelms any resulting gains in the efficiency of growing space utilization. Within an ownership, the range of site conditions over a landscape makes the balance between efficient use of growing space and management flexibility variable and generally inconsistent if a single silvicultural approach is employed uniformly across the landscape. Sites with low wind risk provide opportunities for increasing efficiency or for providing older forest structure and high-quality forest products. Where operational constraints such as limited access exist, the importance of management flexibility increases. The more difficult it is to access or conductoperations in a stand, the more burdensome timely treatment requirements or windthrow salvage become.

The increased emphasis on partial harvests, riparian buffer zones, and older forest habitat throughout the Pacific Northwest and many other forested regions heightens the value of stands that are developmentally flexible. Stands containing stable trees can provide residual green trees, riparian buffers, and older forest structures with a high probability of surviving future windstorms.

Wind hazard is only one of many factors impacting flexibility of management; however, it provides a clear example of how tradeoffs need to be evaluated. Other factors include fire and insect hazards, growth stagnation, wood quality, and stand structural constraints. Interestingly, extreme silvicultural approaches typically generate the most inflexible stands. Planting single-species stands at high densities for high volume production requires timely interventions to maintain stand stability and avoid growth stagnation. Similarly, establishing and maintaining multi-cohort stands requires multiple and timely interventions to establish regeneration, prevent mortality, and maintain wood quality (i.e., straight stems).

A combination of stand-scale (e.g., low density or mixed-species plantations) and landscape-scale (e.g., adjusting management according to site) approaches could be used to increase the flexibility of Pacific Northwest forest management. Stands and landscapes that can be flexibly managed provide multiple options or opportunities allowing owners and managers to take advantage of the uncertainty inherent in forest management. The type of approach described in this paper, where operational and developmental flexibility are factored into decision-making, may provide a more sensible combination of timber outputs, stand structures, risk levels, management requirements, and range of future possibilities than current forest management practices offer.

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