An Ecological Context for Regenerating Multi-cohort, Mixed-species Red Pine Forests

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ABSTRACT: Human disturbances have simplified the structure and composition of red pine forests, relative to historical conditions. A greater understanding of natural disturbances and their role in generating complex stand structures, and their associated benefits, has increased interest in managing for mixed-species, multi-aged stands. A useful framework for addressing issues of structural and compositional complexity in management is a conceptual model that arrays stands along axes of silvicultural actions, time since disturbance, and degree of complexity. We use this model to assess degree of structural and compositional disparity between benchmark and managed conditions. In practice, we are using overstory retention to add age and compositional complexity to red pine stands. We are managing for two-cohort structure and, potentially, multi-cohort structure. We are adding compositional complexity through planting and natural regeneration of multiple species. Moreover, we are experimentally altering spatial patterns of retention to favor regeneration of species differing in understory tolerance.

KEY WORDS: red pine, mixed-species silviculture, multi-cohort structure, overstory retention

Introduction

In many parts of the Great Lakes region, commercially managed red pine forests differ greatly in structure and composition from historical conditions. Many stands were regenerated artificially in even-aged plantations. In other instances, red pine regenerated naturally, after initial logging, on sites it occupied historically. However, even in these cases, structure and composition differ from the historical condition: for instance, single-cohort versus multi-cohort age structure and monospecific versus mixed-species composition. Still, these simplified stands are important biological templates that are closer to the historical condition of red pine growing on "red pine sites" than, for example, are white spruce plantations on northern hardwood sites.

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Where such stands exist, they provide opportunities to test silvicultural approaches for increasing structural and compositional complexity in managed forests. Here we discuss why adding structural and compositional complexity is an important consideration in forest management. We briefly examine red pine forests from an historical perspective, asking whether stands were more complex naturally. We examine the extent to which red pine management in the contemporary landscape incorporates complexity. Finally, we outline a conceptual approach for adding structural and compositional complexity into commercial red pine management and we illustrate application of the approach in an operational–scale management experiment.

A Landscape Perspective on Forest Management

It is important to frame our discussion of multi-species and multi-cohort red pine forests within the appropriate landscape perspective (Figure 1). This perspective, derived from the "triad model" (Hunter and Calhoun 1996), allocates the landscape into three distinct uses. These include intensive management, where fiber production is the top priority, reserve management, where sustainability of native biological diversity is the priority, and extensive management, where commodity production and sustainability of biological diversity are shared priorities, although the balance between the two will shift depending on the specific circumstances.

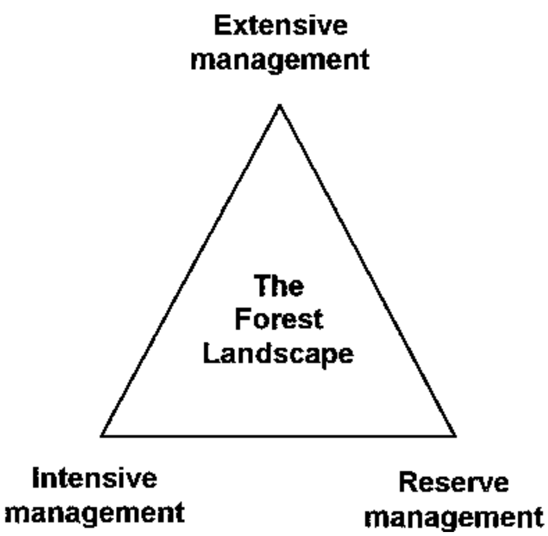

Figure 1. A conceptual zonation of the forest landscape based on tradeoffs between timber production and sustainability of biological complexity and diversity. Adapted from Hunter and Calhoun (1996).

Management for mixed-species forests and multi-age cohorts can certainly be an issue in ecological reserves, since for many forest-types this is, or was, a condition often found in the unmanaged, or natural system. In contrast, intensive management generally focuses on sustainability of fiber growth and yield, with only minor consideration given to other ecosystem goods and services. We argue that the greatest need for more consideration of complexity falls within the area of extensive management, where timber production is balanced against sustainability of a broad range of ecosystem goods and services, including biological diversity. It is within the realm of extensive management that our discussion is best considered.

Why Manage for Multiple Species and Multiple Age Cohorts?

The answer to the question, W*hy manage for multiple species and multiple age cohorts*, reflects an evolving understanding of the forest stand. Traditionally, the stand as a silvicultural management unit embodied ideas of homogeneity and simplification of structure and composition within stands, and similarity among stands in the landscape. In practice, many management practices, overtly or inadvertently, lead to simplification of structure and composition and reduced variation in characteristics within and among stands.

More recently, there is increased interest in redefining stands to be more inclusive of heterogeneity and complexity of structure and composition (Franklin et al. 1997), as well as greater variation of characteristics among stands in the landscape. This interest stems largely from studies of structure and composition in natural forests and how such forests develop after natural disturbance. These studies point to the importance of biological legacies, that is, elements of forests such as residual trees, understory plants, dead wood, mycorrhizal fungi, etc., that survive disturbance and add complexity to the post-disturbance stand (Franklin et al. 1997). An important conclusion of this line of research is that most forest ecosystems, at all ages or stages of stand development, are naturally more complex then their managed counterparts. This complexity typically includes multiple age-cohorts and mixtures of overstory tree species.

An outgrowth of natural disturbance research is the premise that silviculture should be modeled after natural disturbance regimes and, more to the point, the structural and compositional outcomes of silviculture should reflect the outcomes of natural disturbance (Franklin et al. 1997; Palik et al. 2002a). The rationale behind this premise is that the ability to maintain genetic structure, species communities, and ecological processes in managed forests may reflect the degree that silviculture creates the same complexity and variety of structures and composition as natural disturbances.

The Benefits of Complexity

It is not sufficient to say that nature's way is the right way, as a justification for modeling silviculture after natural disturbance and adding complexity to managed forests. There must be demonstratable benefits. We believe that there are, although admittedly, some of these benefits are best considered working hypotheses. For instance, productivity of mixed-species forests may be greater than monospecific stands of the individual species (Kelty 1992). The hypothesized mechanism behind this effect is that diverse forests may be better at utilizing available resources if the component species complement each other in resource capturing capabilities. Moreover, diverse forests may be better able to recover from disturbance, i.e., they are resilient, because of differential susceptibility of component species to the disturbing agent. This has important implications for forest health in that mixed-species forests may be less susceptible to pathogen or insect disturbance than are monospecific forests of susceptible species. Structurally and compositionally complex forests provide a diversity of habitats for associated plant, animal, and microbe species and communities. As such, within stand diversity, or alpha diversity, of native species should be higher in complex forests than in their simplified counterparts.

Structurally and compositionally complex forests provide opportunities for pursuing diverse management objectives. Complex forests contain a greater diversity of marketable products, including multiple timber species, multiple timber products (e.g., sawlogs, veneer, pulp), and multiple nontimber products (e.g., bark, berries, roots, medicinal herbs, mushrooms, etc.). Structural and compositional complexity leads to greater within-stand and landscape-scale diversity of wildlife habitat (e.g., living and dead snags, vertical canopy structure) and greater recreational appeal. Heterogeneous growth environments in forests with complex age structure often result in periods of suppression and release, at least for some trees. This can result in higher wood density and narrow growth rings, which for some species and timber products can lead to higher quality and higher valued wood. Finally, compositionally diverse forests allow greater flexibility to pursue alternative management objectives, for instance, by altering successional pathways to favor different species if and when management objectives change.

Were Red Pine Forests Complex Naturally and Are They Now?

By most accounts, natural red pine ecosystems are more complex, compositionally and structurally, compared to their managed counterparts. Some evidence for this comes from examination of bearing tree data in General Land Office survey notes. Several studies from different areas in the northern Lake States suggest that on sites typical for red pine, a variety of other species had greater cumulative abundance in the overstory than did red pine (Figure 2). In contrast, contemporary inventory data for the same region (Miles et al. 1991; Leatherberry and Spencer 1994; Schmidt 1997) suggest that other species in the red pine type now contribute only 20 to 40% of total volume (Figure 3). Similarly, age structures of old-growth and mature red pine forests were more complex than contemporary managed stands. For instance, the age range of red pine in an old-growth stand in northeastern Minnesota approached two hundred years (Heinselman 1973). The age range for the stand approached three hundred years when additional species were considered. In contrast, most mature red pine stands in the Lake States are single-cohort stands planted in the 1930s and 1940s. Even in the best examples of naturally regenerated, managed red pine stands, age structures are likely to be less complex and less variable than the natural system. For instance, with the exception of scattered old individuals, red pine in mature stands on the Chippewa National Forest, Minnesota, fall within a 40-year age range when aged at breast height, and probably a narrower range when actual ages are considered (Figure 4).

When considering the importance of complexity of structure and composition in natural forests, it is important to recognize the role of natural disturbance in generating variation in structure and composition (Landres et al. 1999). In the presettlement landscape, not all red

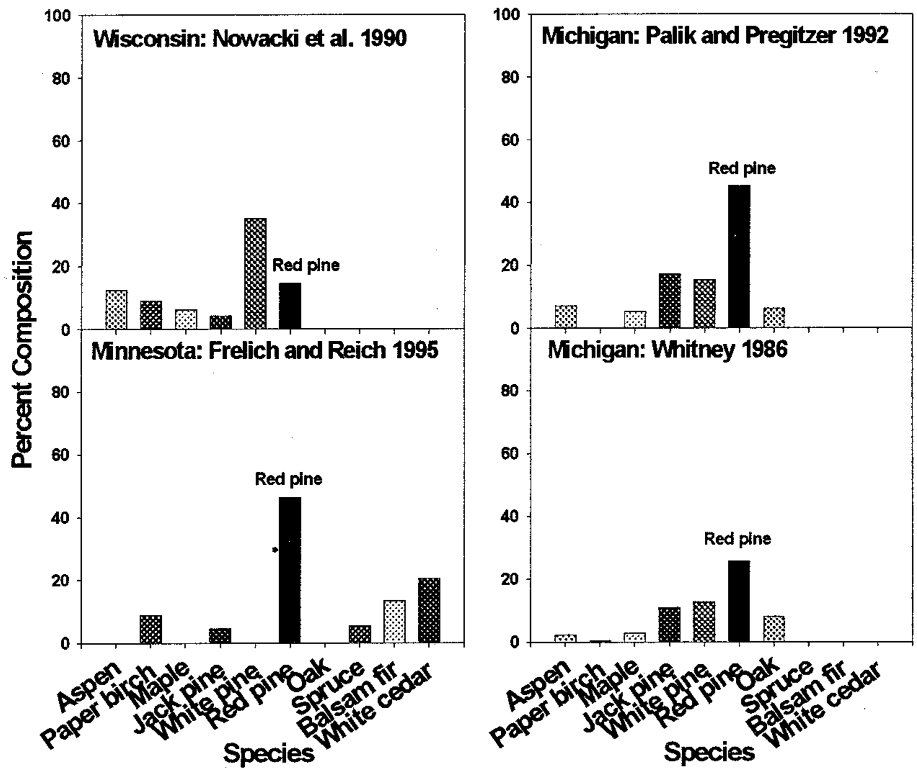

Figure 2. Species composition of bearing trees in presettlement pine forests in the northern Lakes States.

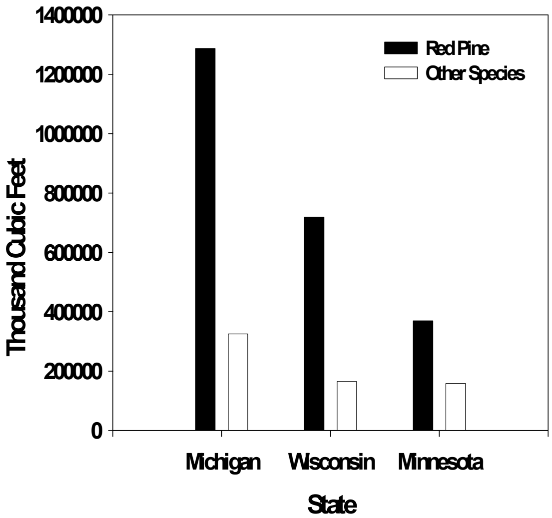

Figure 3. Volume of red pine and other species in the contemporary red pine forest type in the northern Lakes States.

pine forests likely were as structurally and compositionally complex as the examples we give. As such, single-cohort age structures and dominance of a single species, as are common for contemporary red pine stands, may well fall within the range of natural variation for the system. However, potential problems exist when simplified systems dominate the managed landscape, such that the range of variability in structure and compositional complexity is greatly reduced, as in the contemporary landscape, relative to the conditions generated by natural disturbance.

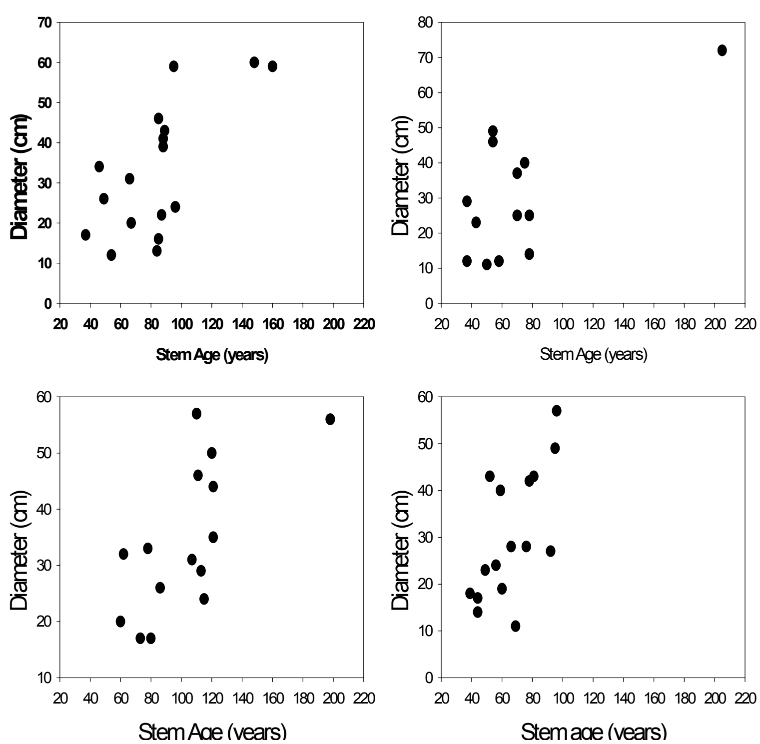

Figure 4. Age structure of four naturally established red pine stands on the Chippewa National Forest, Minnesota (John Zasada, unpublished data).

Adding Complexity into Managed Red Pine Forests

A Conceptual Model

A useful framework for addressing issues of structural and compositional complexity in management is a conceptual model that portrays an array of stands along a gradient of management intensity and desired future conditions (Figure 5). On the right end of the gradient is the unmanaged, benchmark condition, characterized by diverse composition and structural complexity. This may be the condition of choice if management of ecological reserves is the primary objective. On the left end of the gradient is the intensively-managed condition. An extreme example is a short-rotation, single-cohort plantation of an exotic species, where maximization of fiber production is the objective. There is a wide array of conditions between the endpoints, falling within the region of the model we call extensive management. These conditions could include extended rotation, single-cohort red pine plantations and multi-aged, mixed-species stands managed with overstory retention. It is important to consider the differences and disparities between intensively managed stands and ecological benchmarks for two reasons. First, it is important to determine the size of the disparity between the benchmark and managed conditions and take steps to reduce the disparity, if that is a management goal or desired future condition. It is equally important to understand the size of the disparity from the intensively-manged end of the gradient. In other words, it is important to understand not only how far management has to go to reduce disparity with the benchmark condition, but also to judge success in adding complexity to stand structure and composition.

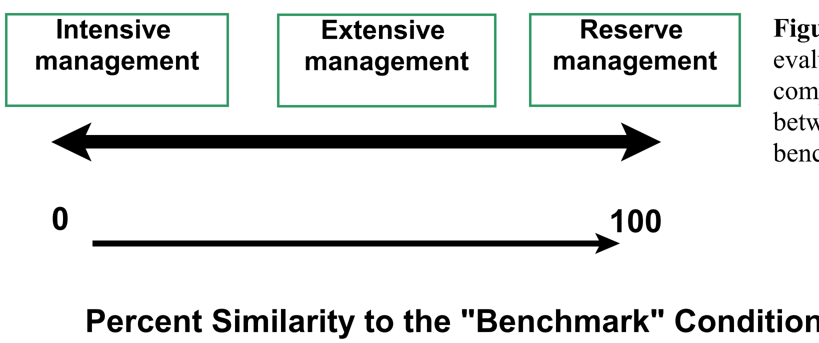

Figure 5. Linear conceptual model for evaluating the degree of disparity in compositional and structural complexity between managed red pine systems and the benchmark condition.

This conceptual approach for considering management outcomes is more instructive when dimensions of time and spatial variability of complexity are added to the model (Figure 6). In this expanded model, the area in gray represents the domain of natural variability of the system, as defined by combinations of time since disturbance and degree of complexity of age structure and composition. Thus, the gray area represents the array of benchmark conditions for the system. It is important to recognize that the domain of natural variability includes not only old-growth red pine systems, having varying degree of complexity, but also young post-natural disturbance systems. The point being that even immediately after a catastrophic natural disturbance, young stands do contain high levels of complexity of structure and composition.

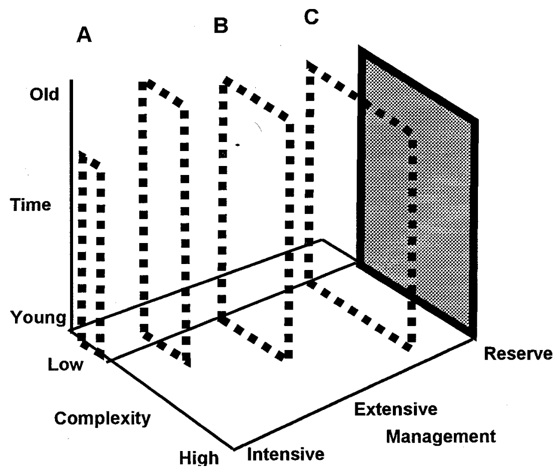

Figure 6. Multidimensional conceptual model for judging disparity in compositional and structural complexity between managed red pine systems and benchmark conditions. The area in gray represents the domain of natural variation in complexity of the benchmark condition, as a function of time since disturbance. The dashed rectangles represent domains of variability in complexity, as a function of time since disturbance, for a variety of management scenarios.

The dashed rectangles are domains of variability in age structure and composition for management scenarios differing in the degree to which they achieve multiple objectives, for instance wood production and sustainability of native species. Domain A might represent a plantation of an exotic species, established on a former red pine site, managed intensively for fiber production. Notice that range of variability in complexity is not only narrow, it is outside the range of natural variability. Domain B might include red pine systems managed for large diameter sawlogs and structural complexity by developing two-cohort stands. Notice the range of variability is narrow, relative to the benchmark condition, but still within the domain of natural variability. Domain C might represent systems managed for maximum similarity to a benchmark condition, for instance, with limited harvesting of naturally-killed trees.

In the model, we focus on outcomes of silvicultural actions and desired future conditions. However, the actions themselves can be overlain on the model. For instance, various activities, including site preparation, artificial and natural regeneration, and competition control, can be arrayed along the management axis depending on the extent to which and how the action is applied, e.g., more or less depending on intensity of management. This is important to consider because, ultimately, silvicultural actions influence the age structure and composition of the forest.

An important question for managers, when considering a gradient analysis like the one described, is to determine how close to the benchmark condition is close enough. The answer is objective driven. When managing ecological reserves, the goal probably will be to get as close to the benchmark condition as possible. When managing for maximum fiber yield, reducing the disparity with the benchmark condition is probably not a consideration. When managing for outcomes within the region of extensive management, reducing the disparity to the benchmark condition is an important consideration, but in many instances it will be done in ways that also consider constraints of meeting other objectives. With extensive management, the goal often will be to model the benchmark condition as close as possible, within the real-world constraints of managing for wood production. In this case, the objective is to shift stands to the right on the management axis (Figure 6) through innovative incorporation of complexity, while still maintaining timber production as a primary objective.

A Working Hypothesis

As a working example of our ideas, we are using overstory retention during regeneration harvests to add size, age, and compositional complexity to what are largely single-cohort, monotypic red pine stands (see Fig. 4), dominated by hazel in the understory. We are managing these stands initially for two-cohort structure and, potentially, for multi-cohort structure by retaining the residual overstory through a second rotation, along with a new cohort of planted trees. We are adding compositional complexity by planting eastern white pine, red pine, and jack pine. Overstory retention is combined with different levels of hazel control to provide better opportunities for tree recruitment and development of more species rich herbaceous and shrub layers.

While not as structurally complex as a multi-cohort benchmark condition for red pine ecosystems, our approach adds substantially more structural complexity to red pine stands than traditional single-cohort, single-species management approaches. Operationally, we are moving stands to the right on the management gradient (Figure 6), by restoring structural complexity, along with species and habitat diversity, to managed red pine stands, while still pursuing opportunities for sawtimber production.

In this project, we also are examining ways to manage takeoffs between restoration of biological complexity and growth and yield of timber species. Our approach tests different spatial distributions of overstory retention for their effects on resource availability and growth and survival of planted pine (Figure 7). In this research, overstory basal area is reduced to a similar low level in all treatments (e.g., ~ 60 ft^2/ac), but the spatial distribution of residual basal area differs from dispersed to small aggregate retention to large aggregate retention. We hypothesize, based on plant competition research in other pine systems (Palik et al. 1997, 2002b), that maximum resource availability and seedling growth of intolerant species at the whole stand-scale occurs with large aggregate retention, rather than dispersed or small aggregate retention, despite the fact that all three treatments have the same low residual basal area per unit area.

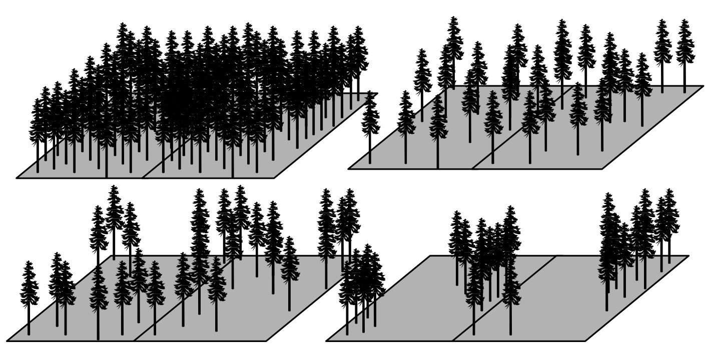

Figure 7. Conceptual representation of spatially variable overstory retention ranging from uncut forest (top left), to dispersed retention (top right), to small aggregate retention (lower left) to large aggregate retention (lower right). The three harvest treatments have the same amount of residual basal area.

Moreover, we hypothesize that by experimentally altering the spatial pattern of the residual overstory, from dispersed to large aggregates, we will alter the resource environment in the understory so as to favor different species with different retention treatments. For instance, assuming appropriate seedbed and forest floor conditions, eastern white pine may grow best with dispersed or small aggregate retention, whereas red pine and jack pine should grow best with large aggregate retention. Ultimately, our interest is in evaluating approaches for establishing mixed-species forests using variable retention (*sensu* Franklin et al. 1997), by incorporating dispersed and aggregate retention within the same stand to favor different species in different locations.

The primary goal of this research is to determine if we can minimize competitive inhibition of the new cohort of trees, relative to that which occurs under an intact overstory, while still adding structural complexity to the stand. However, we expect that spatial distribution of overstory red pine will influence other ecosystem characteristics, goods, and services (Table 1). For instance, the incidence of *Sirococcus* and *Diplodia* shoot blights in red pine seedlings, a concern when they are grown under a residual overstory, may vary with retention pattern. Similar to competitive inhibition of regeneration, we expect that the likelihood of *Sirococcus* and *Diplodia* infection will be minimized with large aggregate retention, because of greater spatial disassociation of overstory trees and seedlings. Abundance and production of competitive shrubs, as well as economically important nontimber plants, may also respond to retention pattern. For example, hazel and wild blueberries would likely have higher production with dispersed and aggregate retention, respectively, requiring more aggressive control for the former and providing more harvesting opportunities for the latter.

Table 1. Hypothesized effects of retention pattern on red pine ecosystem characteristics.

Characteristic	Dispersed	Aggregate
Regeneration growth (intolerant species)	Lower	Higher
Regeneration growth (tolerant species)	Higher	Lower
Hazel production	Higher	Lower
Blueberry production	Lower	Higher
Red pine needle blight	Higher	Lower
Logging efficiency	Lower	Higher
Residual tree damage	Higher	Lower
Campground quality	Lower	Higher
Fuels distribution	Uniform	Aggregated
Tree form and geometry	Uniform	Variable

Summary

We suggest the following points to consider when developing red pine management options:

1. Natural disturbance generates complexity in structure and composition of red pine systems, often, but not always, resulting in mixed-species, multi-cohort stands.

2. Great opportunities and need exists to incorporate increased complexity of structure and composition as a desired future condition for red pine management.

3. Overstory retention, to create two- or multi-cohort red pine stands, is a conceptually straightforward approach for increasing structural complexity while still managing for wood.

4. Variable retention, from dispersed to large aggregates, may favor species differing in understory tolerance.

5. Consider how spatial pattern of retention and different levels of complexity influence other ecosystem characteristics, including incidence of disease, understory shrubs, wildlife habitat, etc.

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