Multiaged Silviculture of Ponderosa Pine[1]

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Abstract

Ponderosa pine (*Pinus ponderosa* P. & C. Lawson) is highly suitable for management using multiaged systems. This suitability is primarily the result of a frequent, low severity disturbance regime, but also because it naturally occurs at low densities and has a long history of management to promote multiple age classes. Several different stocking control tools are available for ponderosa pine including the q-factor, allocation of stand density index, and allocation of growing space represented by leaf area. These methods are applicable to pure or mixed stands. The productivity of multiaged ponderosa pine is shown to be comparable to even-aged stands. Trends in multiaged management have included shorter cutting cycles and lighter harvest treatments. Multiaged silviculture in ponderosa pine is highly suitable for achieving a variety of objectives including timber production, aesthetics, and restoring presettlement stand structures.

Introduction

Ponderosa pine (*Pinus ponderosa* P. & C. Lawson) has a long history of management to retain multiple age classes within a single stand. This is primarily the result of the disturbance regimes that affect regeneration, mortality, stand density, and other ecosystem processes. The result – prior to European settlement – was an abundance of unmanaged stands with multiple age classes of trees. Much of the early management of this forest type perpetuated this structure and many of our multiaged stands today are more the result of previous management than prehistoric disturbance regimes. As a result there is an abundance of stand structures that are multiaged and an increasing desire to maintain this complex structure with future management. This paper will provide an overview of the silviculture of stands with two or more age classes. These stands will be referred to as multiaged in contrast to the term uneven-aged that has traditionally denoted stands with three or more age classes (Helms 1998).

Fire is the primary disturbance agent, but insects, wind, and pathogens are also important. Although fire regimes are highly variable across the entire range of ponderosa pine, a low severity, high frequency regime is common in most areas with pure pine. As species composition becomes more complex at higher elevations or on moister sites, the fire regime becomes one of higher severity and lower frequency. In pure stands, the disturbance regime often results in multiaged stands. These areas represent an ideal situation for multiaged silviculture. In the mixed stands, managing for multiaged ponderosa pine is more difficult because ponderosa pine is usually less

[1] An abbreviated version of this paper was presented at the symposium on Ponderosa Pine: Issues, Trends and Management, October 18-21 2004, Klamath Falls, Oregon.

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shade tolerant than its associates. In these situations, the conditions for regeneration and early growth favor other species and ponderosa pine may decline. In this paper, I will generally discuss mixtures and pure ponderosa pine stands separately.

Disturbance Ecology and Regeneration Patterns

Ponderosa pine may have the highest fire frequency of any tree species in western North America. Frequencies vary throughout the range: studies have documented fire return intervals as low as one year in pure stands and 40 or more years in mixtures (Arno 1980, Agee 1993, Weaver 1959). These fires had mixed effects: small trees were very susceptible whereas larger trees were largely unaffected. These events often gave rise to new age classes or cohorts of trees and resulted in highly variable multiaged stands. Patterns of regeneration were variable across the range of ponderosa pine. Some researchers have described groups of distinct age classes (Arno and others 1995, Cooper 1960, West 1969) while others have found heterogeneous patterns of age at the group level (White 1985). The former might resemble stands regenerated with a group selection system, the latter with single tree selection. Both patterns likely occurred at small scales. Generalizations are difficult at larger scales because the great heterogeneity over the entire range of ponderosa pine in soils, topography, elevation, associated species, and genetic variation in ponderosa pine. Another feature of older presettlement ponderosa pine forests was their open, park-like structure as was noted in many early descriptions of these forests. Later descriptions estimated crown closure at less than 30 percent (Covington and Moore 1994) and overstory tree densities of 40 – 60 stems ha^{-1} (Arno and others 1995, Covington and Moore 1994, Youngblood and others 2004).

Historical Management of Multiaged Stands

Much of the early history of timber harvest in ponderosa pine forests consisted of partial harvests that perpetuated multiaged stand structures. Initially these harvests were to support mines, railroads, farms, and towns. Later, as commercial harvests began in the late 1800s, they focused on private lands. These early cuttings were primarily heavy partial cuts that removed 75 to 90 percent of the volume but generally did not have a silvicultural objective (Mowat 1961). Following formation of the national forests, cutting of ponderosa pine on these lands followed similar patterns. One of the first published references to multiaged silviculture in ponderosa pine on national forests was by Clapp (1912). He described systems of very heavy removals of approximately two-thirds of the volume and cutting cycles from 40 to 60 years. Dunning (1928) developed tree classifications to aid in selecting trees that were overmature or low in vigor. Keen (1943) developed a more detailed tree classification system specific to ponderosa pine that became a key component of many multiaged systems for decades. Meyer's (1934) yield tables for selectively cut stands in the Pacific Northwest were one of the first references to quantitative criteria for multiaged management of ponderosa pine. Meyer proposed periodic cuttings of up to about 85 percent of board foot volume at intervals of greater than 40 years. Munger et al. (1936) developed a "maturity selection system" in the interior Pacific Northwest that emphasized the financial maturity of individual trees. This differed from diameter-limit cutting or zero-margin selection cutting (Smith et al. 1997) by also considering the tree's biological maturity in assessing whether to leave or cut. In the southwest, Pearson (1942) developed a procedure called "improvement selection" that attempted to upgrade the amount and quality of the growing stock.

Munger and Pearson debated the relative merits of "maturity selection" and "improvement selection" in the Journal of Forestry (see letters and responses following Pearson 1942). O'Hara (2002) concluded that the differences between the approaches were likely the result of differences in the current state of ponderosa pine forests of the interior Northwest and the southwest US: the forests of the southwest were probably more degraded from heavy cutting, grazing, an abundance of stocking from the 1919 regeneration year, and had a greater need for improvement than the forests of the interior Northwest.

Another trend in these early treatments that has carried forward to more recent multiaged silviculture is the decline in severity of harvest over time. Mowat (1961) noted this trend and described current practices around 1960 as removing 25-65 percent of volume. There are a number of factors that have contributed to this trend including greater stumpage values and the availability of the crawler tractor that made less severe harvest economically and operationally feasible. There was also a developing recognition that lighter cuttings produced greater yields (Brandstrom 1937, Roe 1947) because the stand response to partial harvests was greatest in the first decade or two after cutting (Mowat 1961, Roe 1952). Later descriptions of multiaged silviculture in ponderosa pine described cutting cycles of 20 to 30 years (Alexander and Edminster 1977, Shepperd and Battaglia 2002).

Contemporary Stocking Procedures

Stocking control is central to multiaged systems because through stocking the silviculturist affects stand structure, the potential for regeneration, and the sustainability of the stand. There are a variety of stocking control procedures for multiaged stands managed with single tree selection systems. O'Hara and Gersonde (2004) discussed the development of these systems over time. The most common stocking control procedure for ponderosa pine has been the q-factor approach that uses a reverse-J diameter frequency distribution. The traditional interpretation of the q-factor was as a constant diminution quotient where the number of trees in a diameter class is a constant ratio of the tree number in the next larger class (*fig. 1*). For example, a q-factor of 1.2 applied to a 25-30 cm diameter class with 50 trees ha^{-1} would result in 60 trees ha^{-1} in the 20-25 trees ha^{-1}cm class and 72 trees ha^{-1} in the 15-20 cm class. This diameter distribution may represent the post-harvest stand target. Using this method, a stand is marked to conform to the target diameter distribution at the end of each cutting cycle. During each cutting cycle the stand will experience growth in most diameter classes and the diameter distribution moves away from the target. Alexander (1986) and Fiedler and others (1988) provide more details on this approach. This approach has also been described as the BDq approach where B represents the total basal area, D the maximum diameter class, and q the q-factor of the target structure (see Guldin 1991).

Stand regulation with the q-factor approach is achieved through harvest or thinning treatments that reset the stand to the target structure at the end of each cutting cycle. Stands managed to meet a particular q-factor diameter distribution have been described as "balanced" (Meyer 1943, 1952, Nyland 2002, Smith et al. 1997) because they were assumed to have constant volume production over time and equal space occupancy by each size and age class. The balanced stand therefore resembles a forest under area control regulation but at a smaller scale. O'Hara (1996) questioned these assumptions and concluded that management to maintain these "balanced" stands resulted in lower yields for ponderosa pine and didn't guarantee sustainability. In practice, segmented q-factors can be used so some parts of the diameter distribution have a different q-factor than other parts. This helps avoid the common drawback of this approach where large numbers of small trees occupy a greater share of growing space than necessary for most management objectives.

Stand density index (SDI) can also be allocated among diameter classes or groups of classes as a means of allocating growing space in multiaged stands. Long and Daniel (1990) demonstrated this approach with examples for ponderosa pine (*fig. 1*). SDI can be calculated for groups of diameter classes and then added to obtain a stand-level total. Their assumption was that even-aged density management zones for even-aged stands could also be applied to multiaged stands. Long and Daniel (1990) demonstrated how the approach could be applied to design stands that deviated from the traditional reverse-J diameter distribution with a constant diminution coefficient. This approach has also been applied to ponderosa pine stands with presettlement structures (Cochran 1992) and two-aged stands (Long 1996).

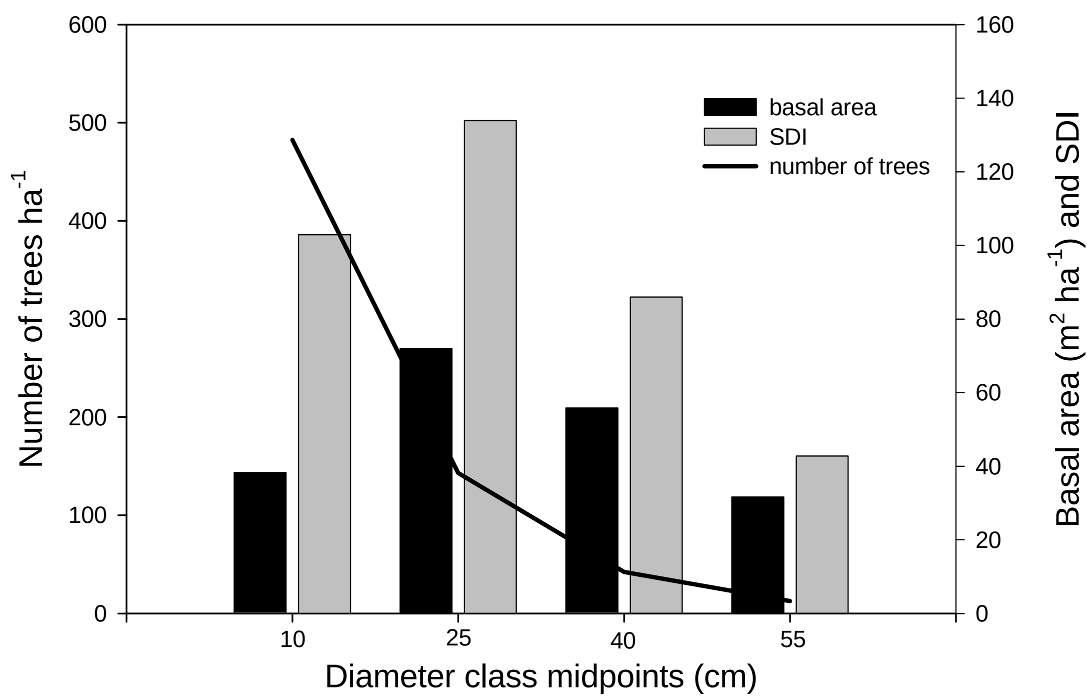

Figure 1— A diameter distribution, stand density index, and basal area for a ponderosa pine stand with a q-factor of 1.5 using metric units. Note the unequal distribution of SDI and basal area on a diameter distribution that was assumed to be "balanced" (Modified from Long and Daniel 1990 and O'Hara and Gersonde 2004).

All stocking control procedures are essentially tools for allocating growing space. This was explicit in the leaf area or growing space allocation tool developed for multiaged ponderosa pine (O'Hara 1996, 1998; O'Hara and others 2003; O'Hara and Nagel 2004). The growing space allocation method is distinguished from other methods because: 1) trees are divided into two to four stand components such as canopy strata or age classes rather than diameter size classes; and 2) growing space occupancy is represented by leaf area index (LAI - ratio of leaf surface area per unit of ground area covered). A user of the system divides growing space among components so as to meet management objectives. The target structure might therefore have the most growing space allocated to larger trees or perhaps to smaller trees. This flexibility is an asset of this method and allows the design of stand structures such as two-aged stands and presettlement structures with large or old trees.

A spreadsheet-based model is used for growing space allocation in this procedure. This model, called PP-MASAM, has been calibrated for pure ponderosa pine stands from three regions: central Oregon, western Montana, and the Black Hills in South Dakota and Wyoming (O'Hara and others 2003; O'Hara and Nagel 2004) and is available online at cnr.berkeley.edu/~ohara/downloads/. *Table 1* shows a three-age ponderosa pine stand using the Montana version of PP-MASAM. A four-age stand is described in *Table 2* using the PP-MASAM from Montana. The model projects volume increment, and calculates estimates of basal area, tree vigor, and SDI. It is flexible for designing stands that are two-aged, stands with high or low stand densities, or designing stand structures where harvest of presettlement trees above a certain diameter is avoided.

Table 1 — *Three-aged ponderosa pine stand designed with the PP-MASAM model from Montana (from O'Hara et al. 2003). Bold text are values provided by the user: the others are model output.*

	USER-SPECIFIED VARIABLES				
TOTAL Leaf Area Index (LAI)	6				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL
Number of Trees/Cohort/Hectare	60	100	140	0	300
Percent of LAI/Cohort	50	35	15	0	100
	DIAGNOSTIC INFORMATION				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL
Leaf Area Index/Cohort ECC	3.0	2.1	0.9	0.0	6.0
Leaf Area Index/Cohort BCC	1.3	0.6	0.0		1.9
Leaf Area/Tree (m^2) ECC	500.0	210.0	64.3	0.0	
BA/Cohort (m^2/ha) ECC	15.0	9.7	3.8	0.0	28.5
BA/Cohort (m^2/ac) BCC	5.8	2.7	0.0		8.5
Avg. Vol. Increment/Tree (m^3/yr) ECC	0.04	0.01	0.01	0.00	
Avg. Vol. Increment/CC (m^3/ha/yr)	1.7	1.0	0.4	0.0	3.1
Quadratic Mean DBH/Cohort (cm) ECC	50.1	31.1	16.5	0.0	
Tree Vigor (cm^3/m^2/yr)	76.988	79.069	91.604	0.000	
Stand Density Index ECC	182.2	141.9	72.3	0.0	396.3
Stand Density Index BCC	85.1	51.6	0.0		136.8

Table 2 — *A four-aged ponderosa pine stand designed with the PP-MASAM model from Montana. Bold text are values provided by the user: the others are model output. The PP-MASAM model is also available in English units (from O'Hara et al. 2003).*

			USER-SPECIFIED VARIABLES		
TOTAL Leaf Area Index (LAI)	**6**				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL
Number of Trees/Cohort/Hectare	**45**	**60**	**74**	**89**	268
Percent of LAI/Cohort	**40**	**30**	**20**	**10**	100
			DIAGNOSTIC INFORMATION		
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL
Leaf Area Index/Cohort ECC	2.4	1.8	1.2	0.6	6.0
Leaf Area Index/Cohort BCC	1.4	1.0	0.5		2.8
Leaf Area/Tree (m^2) ECC	533.3	300.0	162.2	67.4	
BA/Cohort (m^2/ha) ECC	12.1	8.3	5.1	2.5	28.1
BA/Cohort (m^2/ac) BCC	6.3	4.2	2.1		12.5
Avg. Vol. Increment/Tree (m^3/yr) ECC	0.05	0.02	0.02	0.00	
Avg. Vol. Increment/CC (m^3/ha/yr)	1.5	1.1	0.7	0.1	3.4
Quadratic Mean DBH/Cohort (cm) ECC	51.8	37.3	26.3	16.8	
Tree Vigor (cm^3/m^2/yr)	77.885	80.591	71.188	46.368	
Stand Density Index ECC	144.4	113.8	80.4	47.2	385.8
Stand Density Index BCC	85.4	65.2	39.3		189.8

Group Selection

Another highly appropriate form of multiaged silviculture for ponderosa pine is group selection. These groups provide openings with sufficient light to allow shade intolerant species to germinate and be competitive in mixed-species stands. Another advantage of group selection is the operational efficiencies that arise from harvesting in larger gaps than single tree selection systems.

For stand regulation, group selection operates on an "area control" basis where openings are moved throughout a stand and each opening cycles back for a second treatment after a period of time analogous to an even-aged rotation. In one of these "rotations", the entire stand would be treated with equal areas harvested in each cutting cycle. Although there is very little experience with more than one "rotation" with group selection systems, a number of areas in the ponderosa pine region are through several cutting cycles. A key planning strategy when first establishing a group selection system is to organize openings so that all are accessible through all cutting cycles. There are also advantages to how openings are oriented with respect to shading each other. For example, there may be significant advantages to having a younger and shorter group of trees on the south side of a new opening to maximize light availability.

Although group selection openings provide open growing conditions for developing trees, this open condition occurs primarily in the center or north side of openings in the ponderosa pine region and declines toward the group edges. In mixed-species forests – that often have greater crown closure and higher LAI – group sizes must therefore be sufficiently large to provide conditions where ponderosa pine has an advantage. York and others (2004) documented the edge effect for six conifer species in the Sierra Nevada where the greatest growth was from seedlings in the center and north of center within group openings. For ponderosa pine, mean height of seedlings after five years was greatest in the largest opening sampled (1 ha). They also measured growth of trees outside but bordering the group opening and found increased growth after group establishment suggesting a positive productivity effect that might compensate for the growth losses of edge seedlings in the opening.

Mixed-Species Applications

Mixed stands that include ponderosa pine also have the potential for management with multiaged systems. However, with the exception of western larch (*Larix occidentalis* Nutt.) in the inland Northwest and the Northern Rocky Mountains, ponderosa pine is less shade tolerant than all of its major competitors in mixed-species stands. This provides a competitive disadvantage for ponderosa pine in multiaged systems in these mixed species types. Without management intervention, the regeneration success of ponderosa pine will decline leading to greater dominance by more shade tolerant species. Whereas these mixed-species stands are desirable for a variety of management objectives, the decline in numbers of shade intolerant species like ponderosa pine often leads to a number of insect and pathogen problems and may leave the stand more susceptible to fire.

Several studies have examined multiaged stand management in the Sierra Nevada. Lilieholm et al. (1990) documented trends in diameter distributions and species composition after several decades of selection harvests in stands that were even-aged but with irregular stocking. They found all five major conifer species – including ponderosa pine – were able to regenerate although the more shade tolerant species comprised the bulk of the regeneration. They also noted that the diameter distributions after 20-28 years of harvest treatments were moving towards the target reverse-J distributions. Guldin (1991) applied the BDq method to the Sierra Nevada mixed-conifer forests. He concluded that a form of group selection was needed to insure regeneration of shade intolerant species and advocated the BDq procedure for these stands. Gersonde and others (2004) used a light model to identify locations where shade intolerant species were most likely to be successful in mixed-conifer stands in the Sierra Nevada.

In other parts of the ponderosa pine range, similar problems exist. For example, interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Mirb.) Franco) and several other species compete with ponderosa pine on many sites in the inland Northwest and northern Rocky Mountains. In these forests, mechanical control of Douglas-fir or use of understory burning are necessary to give ponderosa pine an advantage and maintain its presence.

Other Issues with Multiaged Stands

The Cutting Cycle

In a fully regulated multiaged system, the length of the cutting cycle is a function of the severity of the harvests (O'Hara and Valappil 1999). Heavy harvest treatments would necessitate longer cutting cycles to rebuild pretreatment stocking levels. Lighter harvest treatments would have the opposite effect: shorter cutting cycles. Many of the earliest multiaged systems in ponderosa pine used very heavy removals (Meyer 1934) whereas more recent systems used light cuttings and short cutting cycles (Becker 1995, Shepperd and Battaglia 2002). O'Hara and Valappil (1999) described a tradeoff between the probability of obtaining regeneration and volume increment with shorter cutting cycles/lighter harvests resulting in greater volume increment and a lower probability of obtaining natural regeneration because of heavier competition. The opposite would be true for longer cutting cycles/heavier harvests. The trend to shorter cutting cycles and with lighter harvests in ponderosa pine may favor greater stand growth but less regeneration. In mixed stands, longer cutting cycles would be more likely to produce ponderosa pine regeneration and give this species a competitive advantage.

Theoretically the target multiaged stand is best met at only one point in time during a cutting cycle. Otherwise, the stand is either growing towards or away from the target. Longer cutting cycles would therefore deviate more from the target than shorter cutting cycles. Another consideration is the q-factor and SDI approaches generally design target structures for the beginning of the cutting cycle. The PP-MASAM designs end-of-cutting cycle structures but also provides data on stand characteristics at the beginning of the cutting cycle. When designing a cutting cycle it is more important to recognize the tradeoffs between cutting cycle length and harvest levels and how to achieve the target stand structure for as long as possible.

Productivity

The relative productivity of multiaged stands to other stand structures, particularly even-aged stands, is a point of great interest for most foresters. There is no empirical evidence for ponderosa pine that indicates multiaged stands are more or less productive than other structures. O'Hara (1996) compared increment in even-aged and multiaged ponderosa pine stands in central Oregon and western Montana. Cubic volume increment was slightly higher for multiaged stands in both study areas but differences were not significant (Table 3). Since LAI was slightly higher in even-aged stands, these results suggest higher efficiencies of growing space occupancy in the multiaged stands. Similar results were obtained in the Black Hills although only one even-aged stand was sampled (Table 3 – O'Hara and Nagel 2004). Additional studies found greater water pressure deficits in even-aged stands during the growing season suggesting differences in water availability may contribute to lower productivity in even-aged stands (Nagel and O'Hara 2002). A review on multiaged productivity[3] concluded that any productivity differences that might exist between even-aged and multiaged stands were small and probably less significant than differences in operational effects on growth and volume recovery [(O'Hara and Nagel 2006)].

[3] O'Hara, K.L. and L.M. Nagel. 2006. A functional comparison of productivity in even-aged and multiaged stands: A synthesis for *Pinus ponderosa*. Forest Science (in press).

Table 3 — *Mean (± SE) volume increment, leaf area index (LAI), and growing space efficiency (GSE) for even-aged and multiaged ponderosa from three study areas. Only the GSE means for central Oregon were significantly different of these results. Data are from O'Hara (1996) and O'Hara and Nagel (2004).*

Location	Age Structure	Vol. Increment ±SE $m^3\ ha^{-1}\ yr^{-1}$	LAI ±SE	Stand GSE ±SE $m^3\ m^{-2}$
Western Montana	Even-aged	5.0 ±0.3	7.2 ±0.47	0.72 ±0.04
Western Montana	Multiaged	5.4 ±0.3	6.8 ±0.31	0.80 ±0.03
Central Oregon	Even-aged	4.8 ±0.4	6.9 ±0.41	0.70 ±0.04
Central Oregon	Multiaged	4.7 ±0.3	6.1 ±0.29	0.81 ±0.03
South Dakota[1]	Even-aged	5.8	7.8	0.73
South Dakota	Multiaged	5.2 ±0.2	6.9 ±0.043	0.77 ±0.04

[1]One even-aged stand was sampled in South Dakota so a comparison of means was not possible for these data.

Slash and Fuel Treatments

The variation in tree sizes in multiaged stands has the potential to form fuel ladders that increase the potential for crown fire development. In pure ponderosa pine, stands can be maintained at low densities so fuels are not continuous. In mixtures, this problem is more significant and may preclude multiaged stands in some locations such as fuel breaks or near structures. Prescribed understory burning may also be more difficult in multiaged stands because some small trees would always be present. Slash disposal may also be problematic as broadcast burning is not possible and residual trees may limit equipment options for piling. These are additional limitations on operations beyond those related to the removal of trees from multiaged stands and may require additional expenses to provide comparable fire protection as in older even-aged stands.

Site Quality

A long-standing shortcoming of multiaged systems is the inability to estimate site quality using site index. Because a requirement of site trees is that they be free growing trees throughout their development, any tree developing in a multiaged system is unsuitable. Managers are therefore forced towards finding similar sites with free-growing even-aged trees, using soil-site relationships, or vegetation analyses such as plant associations. These latter methods often provide only wide ranges of site productivity values and are ultimately tied to site index relationships from even-aged stands. There have been attempts to determine site index from the free-growing period of development for a multiaged tree, but this is an area that could use more research.

Summary

Ponderosa pine has a rich history in both the research and practice of multiaged silviculture. A variety of different methods have been used and many have had some success. Much of this success is because ponderosa pine, particularly when growing in pure stands, is a highly suitable species for multiaged management. This is due to several factors including the low stand densities of many ponderosa pine stands that can permit regeneration and development of several age classes. Another important factor is the disturbance regime dominated by high frequency, low intensity fire in much of the ponderosa pine range. These disturbances often produce new age classes resulting in multiage stands that can be easily emulated by management. On moister sites, where ponderosa pine often grows with more shade tolerant species, multiaged silviculture can be more difficult, particularly on sites where fire exclusion has already altered the species composition of these stands. On these sites, multiaged silviculture can also be successful, but will required additional treatments to control undesirable species and to reduce fire hazards.

One of the truly great assets of the pure ponderosa pine ecosystem is the wide range of management practices that can be successful. This includes multiaged as well as even-aged silviculture. For multiaged systems, land managers can usually choose between regimes with short or long cutting cycles, high or low levels of residual stocking, and many to just a few age classes or cohorts. Flexibility to accommodate a wide variety of regimes is therefore an important component of any management tool. Multiaged silviculture can therefore be used to meet a wide variety of objectives in an ecosystem management context. These objectives can include providing stand structures for wildlife habitat, timber production, enhancing aesthetics, or restoration of presettlement stand structures.

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