Uneven-Aged Silviculture in Cedar-Hemlock-Grand-Fir Ecosystems of the Northern Rocky Mountains

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Abstract. Uneven-aged silviculture is used infrequently in the Northern Rocky Mountains. Because of wildlife, watershed, or scenic issues it is often preferred for managing many stands. While it has been applied in the ponderosa pine (*Pinus ponderosa*) forests it has had limited application in the grand fir (*Abies grandis*)-western redcedar (*Thuja plicata*)-western hemlock (*Tsuga heterophylla*) forests. To supply information for making more informed decisions on using uneven-aged silviculture in forests dominated by shade-tolerant species, a study was initiated in 1984 in northern Idaho. Twenty-seven stands were treated using classic uneven-aged diameter distributions defined by q-value (1.1, 1.3, 1.5), residual basal area (23, 26, and 35 m^2 ha^{-1}) and target tree size (50 cm). This replicated study was evaluated in 1989 and 1996. Grand fir and western hemlock regenerated profusely and suppressed the faster growing western white pine (*Pinus monticola*) and western larch (*Larix occidentalis*) that were planted. Even with the dense overstories created with the prescriptions, some natural regeneration of larch and white pine occurred. Both q-value and basal area had significant relationships with the height of white pine and larch. Because of grand fir regeneration, species composition changed little with the uneven-aged prescriptions. The stand structures and composition created by the prescriptions will perpetuate stands containing shade tolerant and disease prone species. Heart and root diseases are common in the stands making them prone to damage by wind, snow, and ice events. Also, because of disease and multiple canopies, the stands created are at high risk for stand replacing wildfires. Even with these concerns the structures created by the uneven-aged prescriptions likely fulfill many societal needs and desires.

Introduction

Silviculture is the art and science of managing forests to meet a variety of management objectives (Baker 1934, Smith 1962, Smith et al. 1997). These objectives can vary from

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producing forage and cover for animals, to providing transitory range for domestic livestock, to enhancing water flows for human consumption, to maintaining stream habitat for fish. In addition, an important component of many silvicultural prescriptions, particularly in the western United States, is the conservation and protection of soil resources. Management objectives are usually outlined by the landowner. This owner may be an individual, a government , or group of individuals or governments that control a particular forest landscape (Haynes et al. 1996, Nyland 1996). Historically, in the United States an important objective was to produce lumber, therefore, silvicultural prescriptions concentrated on producing timber crops. Silviculture systems were designed and refined to produce products such as high quality saw timber or fiber for news print and high quality paper.

Timber production prescriptions and treatments emphasized growth and yield of forest stands and the schedule of treatments for producing the desired amounts of timber and fiber. However, when these silvicultural systems were applied they produced a wide variety of forest structures. Often these forest structures and stand conditions met additional societal needs and desires. For example, in northern Idaho, newly regenerated stands provide forage for wild game and domestic livestock (Kingery and Graham 1994, Yeo and Peek 1994).

Although past silviculture systems concentrated on timber production, silvicultural prescriptions and treatments have been developed and used for other objectives. For example, the northern goshawk (*Accipiter gentalis*) is a forest dwelling hawk that requires a diverse set of forest structures to survive. These conditions range from mature trees for building nest platforms to more open areas that can provide prey and hunting opportunities (Reynolds et al. 1992). The recommended forest conditions and structures for the northern goshawk lend themselves to being created using a combination of group and individual tree selection systems.

For ponderosa pine (*Pinus ponderosa*) ecosystems, using these silviculture systems are very appropriate and reflect many of the ecological processes that evolved in these forests. However, these selection systems when applied to mixed conifer forests may have different responses than those observed in ponderosa pine forests. In the Northen Rocky mountains and interior United States, uneven-aged silviculture systems are infrequently applied to mixed conifer forests (Graham and Smith 1983; Graham 1989; Znerold 1989). Throughout the northwestern United states numerous areas have been harvested using various partial and selective cutting methods. Very often these cutting methods were termed uneven-aged systems and extolled as the answer to many of the environmental concerns associated with timber harvesting.

The forest ecosystems of the Northern Rocky Mountains are very diverse and productive. The tree and shrub species within these forests, particularly in the Northern Rocky Mountains, have many different shade tolerances, growth rates, fire resistance, and insect and disease resistance. The mixed conifer ecosystems of northern Idaho have a mixed and variable fire regime (Agee 1990, Arno 1980, 1988). In these coniferous forests, species evolved differently than they did in ponderosa pine ecosystems. In many stands surface fires historically occurred at intervals of 20 to 50 years and stand replacing fires occurred at longer intervals of 200 to 300 years. Western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), and Douglas-fir (*Pseudotsuga menziesii*) are the major late seral and climax trees species of the forests. Major early seral tree species include western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), and ponderosa pine (*Pinus ponderosa*). Depending on disturbance history and age, stands in these forests can contain one or all of these species with many different ages, diameters, and heights present (Foiles et al. 1990, Graham 1990).

Shrubs growing in concert with these tree species include alder (*Alnus* spp.) Rocky Mountain maple (*Acer glabrum*), ceanothus (*Ceanothus* spp.), nine bark (*Physocarpus malvaceous*), huckleberries (*Vaccinium* spp.) and currents (*Ribes* spp.). This suite of shrub species have a wide range of light requirements and they differ in their response to forest floor disturbance. These shrubs in combination with the range of tree species results in very diverse and highly productive forests.

The grand fir-western redcedar-western hemlock forests of the Northern Rocky Mountains are usually confined to elevations ranging from 500 to 1800 m in elevation. The topography of the area is typified by steep slopes and sharp v shaped valleys. Spodosols usually derived from loess or loessal like deposits are common with depths ranging from 25 to 230 cm. Summers are relatively dry with 710 to 1520 mm of precipitation annually with the majority falling during the fall and winters (Foiles et al. 1990, Graham 1990).

The structure and composition of stands in these forests are a product of their disturbance history and the seed available. The introduction of western white pine blister rust (*Cronartium* *ribicola*) has caused a major disturbance by increasing mortality of western white pine. Becaue of the loss of western white pine Douglas-fir and grand fir will dominate many stands. These species are much more susceptible to infestation by heart rotting fungi (*Echindontium tinctorium*) and root diseases (*Amillaria* spp.). Therefore, snags, downed logs, multiple canopies, standing trees with decay, and rich shrub and forb layers typify many stands in these forests today.

Throughout the western United States there are many objections to timber harvesting especially through the use of even-aged systems (clearcutting) although for mixed conifer forests, managed uneven-aged forest structures are uncommon. Goshawks, big game, water, scenery, and biodiversity are all issues that might be addressed using uneven-aged silviculture in these diverse muti-species stands of the Northern Rocky Mountains. But more information is needed to understand how these silviculture systems influence ecological processes that are compatible with these forest ecosystems in addition to addressing other forest management issues. With these complex issues of managing Northen Rocky Mountain forests as a setting, a study was designed to test the applicability of managing mixed conifer stands using uneven-aged silviculture. The objective was to produce a wide diversity of stand structures while still maintaining high forest cover.

Three questions were used to evaluate uneven-aged silviculture systems applied in grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) potential vegetation types located in the Northern Rocky Mountains.

Can uneven-aged stands be created and maintained in mixed conifer forests of the Northern Rocky Mountains?

How do the characteristics of uneven-aged stands influence the establishment and growth of regeneration?

How do uneven-aged prescriptions influence species composition?

Study Design

Twenty seven stands covering approximately 140 ha within the Deception Creek

Experimental Forest in northern Idaho were used in the study. A western hemlock potential vegetation type predominantly covered the area with smaller amounts of grand fir potential vegetation type (Cooper et al 1991). Stands were generally located on south facing aspects but some faced east and west. Slope angles of the stands ranged from 30 to 60 %. For its elevation (800 m), the Deception Creek Experimental Forest is one of the wettest places in Idaho with total precipitation exceeding 1300 mm.

During the 1930s and 1940s stands in the study received light "vigor" cuttings in the western white pine component with the objective of maintaining mature pine. These partial cuttings encouraged regeneration and the development of multiple age-classes and canopies in the stands. The species in the mixed conifer stands ranged from the shade tolerant western hemlock to seral western larch and lodgepole pine. The existing age (diameter) distributions tended to be uneven-aged with q-values ranging from 1.10 to 1.67 (Figure 1).

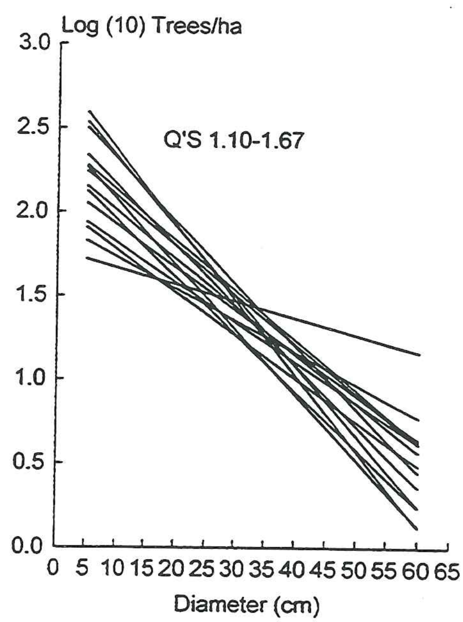

Figure 1. In 1983 prior to implementing uneven-aged silviculture prescriptions the stands in the study area had a broad range of diameter distributions.

In 1983 the 27 stands were inventoried and prescriptions prepared for diameter distributions with q-values of 1.1, 1.3, and 1.5 (Table 1). Maximum tree size of 24 inches and residual basal areas of 23, 26, and 35 m^2 ha^{-1} were planned. Existing diameter distributions were compared to actual distributions and the number of excess trees in each stand and diameter class (5 cm) were determined. The stands were marked using basal area as the first criterion and excess trees in each diameter class as the second criterion. If a stand contained excess trees, those with poor vigor, presence of disease, or poor form were chosen for removal. However, in many portions of the stands excess trees were not present, therefore many poor form, low vigor and/or disease infested trees were left to ensure that the desired stand structure (diameter distribution) could be maintained.

Table 1. Forest summary prior to harvest in 1983.

Tree[1] Species	Basal Area (sq m/ha)			Trees/ha			Tree Diameter (cm)			Tree Height (meters)			Tree Age		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
WWP	2	5	9	5	167	354	10	27	84	4	15	48	49	126	217
WL	1	1	2	2	5	10	53	56	60	35	42	48	164	188	203
DF	1	7	22	21	188	544	11	30	58	4	16	32	82	139	205
GF	16	30	56	391	2232	4176	7	15	28	2	7	18	65	96	129
WH	1	2	7	9	817	5373	4	16	52	1	8	35	66	84	119
LLP	6	9	18	113	224	383	18	23	26	14	19	24	84	85	87
ES	1	1	1	42	42	42	19	19	19	19	19	19	76	76	76

[1]Trees species are WWP = western white pine, WL = western larch, DF = Douglas-fir, GF = grand fir, WH = western hemlock, LLP = lodgepole pine, ES = Engelmann spruce.

In the western hemlock potential vegetation type after a disturbance abundant and species rich regeneration usually occurs. Western white pine and western larch regeneration are common in this type and the species are of commercial importance. Moreover, they could possibly play important ecological roles in these forest ecosystems. Because seed sources and quantity might be limited for western larch and blister rust resistant western white pine both species were planted to a density of approximately 740 trees ha^{-1} in 1991.

Steep slopes, dense forest canopies and cable harvesting systems were factors that prevented the desired stand structures from being created. In addition, because of the tremendous amount of natural regeneration occurring after harvesting the slopes (q-values) of the diameter distributions increased dramatically. Because of these conditions 18 stands of the original 27 were randomly chosen and arrayed into two factors, basal area and q-value. The basal area factor was defined as: low (less than 22 $m^2\ ha^{-1}$), medium (more than 22 and less than 27 $m^2\ ha^{-1}$), and high (greater than 27 $m^2\ ha^{-1}$) basal areas. The q-value factor was defined as: low (less than 2.14) and high (greater than 2.14). Each factor combination was replicated 3 times (stands) (Table 2).

Table 2. Stand characteristics of randomly selected stands after harvest in 1989.

Tree[1] Species	Basal Area (sq m/ha)			Trees/ha			Tree Diameter (cm)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
WWP	0	2	5	2	81	568	2	42	92
WL	0	1	2	2	65	247	1	54	93
DF	0	2	5	2	192	618	1	30	72
GF	9	20	39	36	2414	7914	5	14	66
WH	0	2	5	3	906	4816	1	13	73
LLP	0	2	5	110	179	247	1	12	23
PP	0	0	0	124	124	124	2	2	2

[1]Trees species are WWP = western white pine, WL = western larch, DF = Douglas-fir, GF = grand fir, WH = western hemlock, LLP = lodgepole pine, ES = Engelmann spruce, PP = ponderosa pine.

In 1996, the study was inventoried using 13.5 m^2 plots and stand summaries were prepared. An analysis of variance for a completely random 2 by 3 factorial design, analysis of variance for generalized complete block design, and regression were used to analyzed the data (Kirk 1995). The independent variables in the factor analysis were the initial (1989) classes of q-value and basal area classes. The response variables included amount of regeneration, amount of lower vegetation (shrubs, grasses, and forbs), seedling height, seedling growth, and q-values occurring in 1996. For the height and height growth dependent variables initial tree density (trees ha^{-1}) was used as a covariate in the analysis. All 27 of the stands in the study area were used in a regression analysis displaying the relationship diameter distributions (q-value) and residual basal area to the height of western larch and western white pine. The generalized randomized block analysis was used to detect species composition changes. Year (1983, 1989, 1996) represented treatment levels, and all 27 stands were groups. The analysis was conducted by species and trees ha^{-1} and basal area ha^{-1} were the response variables.

Results

From the initial cuttings in 1984 through 1996 regeneration continued to occur in the study area. Even though soil disturbance was minimal and no intentional site preparation occurred, the abundant regeneration caused the slopes of diameter distributions in all of the stands in the study area to increase compared to the 1983 slopes (q-values as high as 2.78) (Figure 2). No matter the target basal area or the target q-value the resulting q-values in 1996 were similar (Figure 3). The reason for the similar q-values in 1996 among the three levels of basal area and two different target q-levels was the large amount of regeneration that occurred in the harvested stands. The most common species less than 12 cm in diameter was grand fir. In stands with low target q-values and high basal area over 4,000 grand fir stems ha^{-1} existed (Table 3). It appears that the initial openings in the stands with the planned low q-values were excellent sites for grand fir regeneration. In contrast, stands with initial high q-values had less room for additional regeneration and the number of grand fir did not exceed 3,000 stems ha^{-1}.

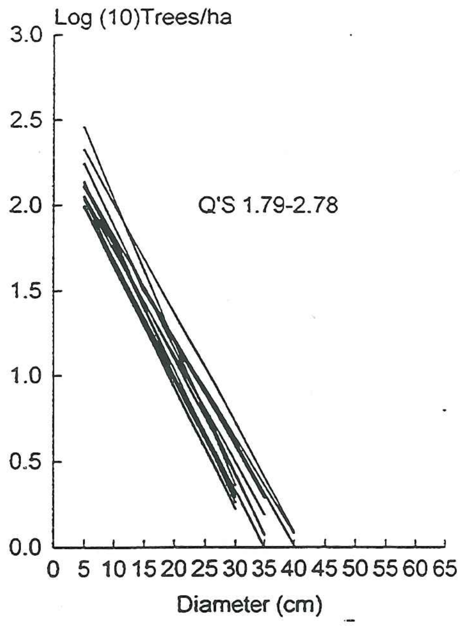

Figure 2. In 1996 7 years after implementing uneven-aged silviculture prescriptions the decrease in high forest canopy cover encouraged regeneration, thus increasing q-values and changing the diameter distributions.

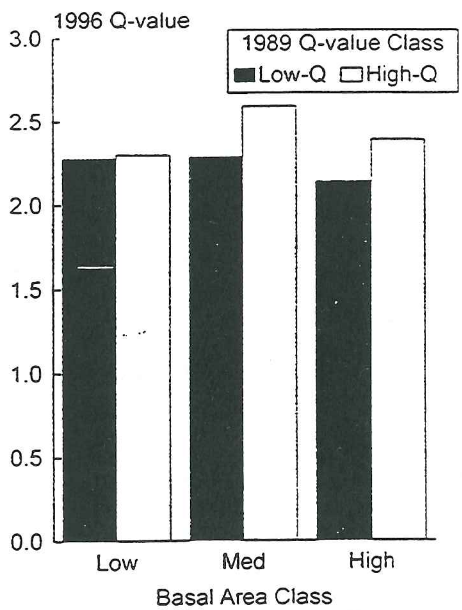

Figure 3. There were no differences in q-values in 1996 among 1989 basal area classes or q-value classes. The reason for detecting no differences was the vast amount of grand fir and western hemlock regeneration.

Numbers of western white pine regeneration increased in the study from the initial planting of 740 trees ha^{-1} with the exception of areas that had an initial low q-value and medium basal area. Even in the high basal areas (greater than 27 m^2 ha^{-1}), western white pine numbers increased (1480 trees ha^{-1}) from the initial planting density (740 trees ha^{-1}) indicating that without a threat of blister rust natural regeneration would adequately stock these stands with western white pine (Table 3.).

Western larch is far more shade intolerant compared to western white pine and its numbers decreased from the initial planting in 4 of the 6 q-level and basal area combinations (Table 3). In stands with the initial low q-values with the large amount of grand fir regeneration western larch numbers decreased from the initial planting across all basal areas. There appeared to be some limited amount of natural regeneration of larch occurring in stands with the high basal areas and with the high q-values. Only in these stands where the initial stocking of small trees was low was there apparently enough growing space for western larch. In contrast to western white pine, the establishment of western larch in these uneven-aged stands with high forest cover does not appear to be a silvicultural option.

In these forest types shrubs also responded aggressively to additional growing space and in doing so they can interfere with the establishment of conifers. Shrub presence in the stands with different q-values for the most part was the opposite of the trend for western white pine and western larch. For example, in the stands with the low q-values and medium basal areas over 40% of the soil surface was covered with shrubs resulting in the fewest numbers of western white pine. Similarly, in stands with high q-values and low basal areas 50 % of the soil surface was covered with shrubs and little or no regeneration of western white pine occurred.

Table 3. Trees per hectare, adjusted height, and adjusted 5 year height growth among basal area classes and between diameter distribution classes (Q)[1].

	White Pine		Western Larch		Grand Fir		Western Hemlock	
	Low Q[2]	High Q	Low Q	High Q	Low Q	High Q	Low Q	High Q
Trees/ha								
Low Basal Area[3]	1055	793	788	316	2272	1304	643	192
Medium Basal Area	714	971	390	677	3033	2895	859	1005
High Basal Area	1480	1396	457	1203	4313	2211	1215	417
Adjusted Height (cm)								
Low Basal Area	50	43	64	72	76	109	175	84
Medium Basal Area	50	33	56	82	70	99	146	74
High Basal Area	25*	25*	58	73	76	146	89	105
Adjusted 5 Year Growth (cm)								
Low Basal Area	39	38	64	67	18+	48+	76	53
Medium Basal Area	42	30	49	46	24+	44+	77	46
High Basal Area	25*	20*	24	44	27+	60+	47	46

[1] Height and 5 year growth are adjusted means using 1989 trees ha^{-1}.

[2]Low Q class was less then 2.14 and high Q class was greater then 2.14.

[3]Low basal area class was less then 22 $m^2\ ha^{-1}$, medium basal area class was 22 to 27 $m^2\ ha^{-1}$, and high basal area class was greater then 27 $m^2\ ha^{-1}$.

*Significant difference ($p = .05$) among basal area classes.

+Significant difference ($p = .05$) in Q classes.

Grand fir growing in stands with high basal area and high q-values were over 140 cm tall (Table 3). In contrast, in these same stands western white pine was just over 20 cm tall. In stands with either an initial high or low q-value western white pine height decreased as basal area increased. Western larch height growth appeared to be less sensitive to the changes in basal area or the changes in q-value. The height of both western white pine and western larch might be responding to the tall and heavy amount of grand fir regeneration more than the residual overstory stand conditions. Western larch was the fastest growing species with grand fir and western white pine having similar growth rates depending on the forest conditions. Even with the better growth rates, the western larch numbers were decreasing. During the examination of the stands it appeared that western larch was growing in height rapidly but diameter growth was poor making the trees susceptible to weather and mechanical damage.

Basal area and q-value had a significant relationship with the height of both western white pine and western larch regeneration. In general, the lower the q-value and the lower the basal area the taller the pine or larch (Figure 4 and 5). When residual over story basal areas approached shelter wood levels (10 m^2 ha^{-1}) and q-values approached 1.0 heights of both species exceeded 70 cm. In contrast, when q-values were over 2.0 and basal areas approached 60 m^2 ha^{-1} the height of both species did not exceed 20 cm. Knowing this relationship will help silviculturists and forest managers design stand strictures that can meet a variety of objectives and determine the level of western white pine or western height that would be acceptable.

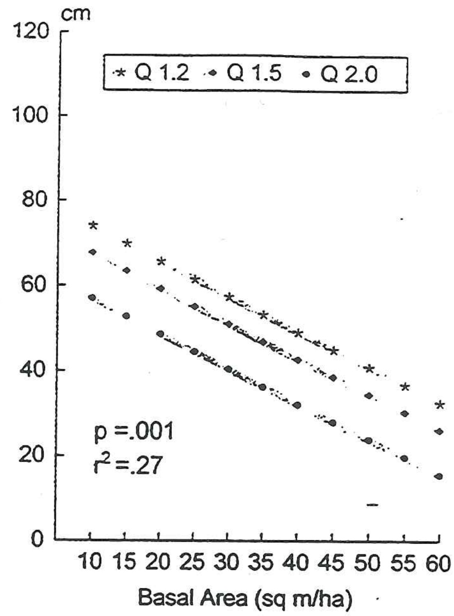

Figure 4. Western white pine height had a negative relationship with increasing basal areas and q-values.

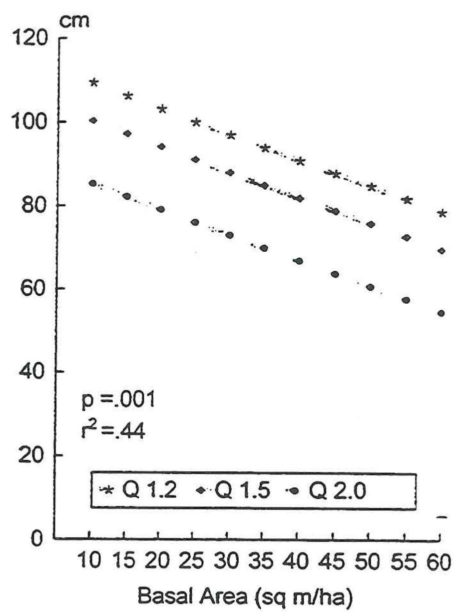

Figure 5. Western larch had similar results to western white pine (Figure 4). Western larch also had a negative relationship with increasing basal areas and q-values.

Applying the uneven-aged prescriptions did not readily change the stand composition. Grand fir dominated the stands prior to harvest, after harvest, after cleaning, and after planting. As the stands age grand fir will probably become even more dominant. Western larch will likely have a small presence in future stands and western white pine will be a minor component.

Discussion

Creating and maintaining stands with diameter distributions having the classic reverse "J" shape appears to be difficult in the grand fir-western redcedar- western hemlock forests of the Northern Rocky Mountains. Steep slopes, multi-species stands with a wide range of silvical characteristics, difficult logging conditions, and variable markets for wood products all contribute to the difficulty of executing uneven-aged prescriptions. Their success in maintaining desired diameter distributions is confounded by the tremendous numbers of grand fir and western hemlock regeneration that occurs with any amount of canopy opening. After disturbance all species in these forest types will regenerate. It is common in these forests for old (100 year plus) western hemlock with diameters less than 5 cm in diameter to exist producing stands with multiple diameter classes but not multiple ages. Therefore, uneven diameter distributions do not necessarily equate to uneven-aged distributions. But a strong characteristic of grand fir, western redcedar, and western hemlock is their ability to respond to release at an advanced age making them excellent species for uneven-aged silviculture (McCaughey and Ferguson 1988).

The canopy gaps created by executing uneven-aged prescriptions might be similar to the gaps created by low intensity surface fires that frequent many of these forests at 30 to 40 year intervals. These small canopy gaps provide sufficient growing space for shade tolerant western hemlock or grand fir to become established. These species are so adapted to regenerating and developing in shaded conditions they suppress faster growing western white pine and western larch. Even though western white pine and western larch can become established in these conditions, it would be difficult to maintain these species in stands using individual tree selection silvicultural systems without considerable cost in frequent cleanings. From a positive stand point, stands with abundant high forest cover suppress *Ribes* spp. shrubs, the alternate host for western white pine blister rust. Under these conditions blister rust hazard would be much lower in these stand structures than in stands created by even-aged systems.

Without the presence of heart and root disease resistant western white pine and western larch, the grand fir and western hemlock dominated stands would have high amounts of stem and root diseases. In addition, this situation is exacerbated by wounding of trees during frequent yarding operations that must be conducted when using uneven-aged silviculture. The exception is western redcedar which is somewhat resistant to disease infection caused by wounding. The high amount of disease present in these kinds stands make them prone to damage by wind, ice, and snow events. As with logging damage, these events increase the amount of disease in the stand and also make the stand more susceptible to stand replacing wildfires.

Stand replacing wildfires in these forests occur relatively infrequently (200 to 400 years) but the conditions of multiple canopies and ladder fuels caused by the uneven-aged distribution would make them a high candidate compared to 1 or 2 canopied stands that historically occurred. Because of these stand replacing events, large amounts of western white pine and western larch dominated the stands early and only later were they dominated by grand fir and western hemlock. Because of the propensity for uneven-aged stands that are dominated by grand fir and western hemlock to have large amounts of disease, high susceptibility to wildfire, and prone to damage by weather events their long-term sustainability is not likely. Moreover, these kinds of stands will have a minimal component of western white pine and western larch two species that might have unique ecological roles in these forests.

Therefore, other diameter distributions than the reverse "J" may be appropriate in these forest types. Possibly 3 or 4 age classes could be maintained especially if they were differentiated by shade tolerance or different q-values for different portions of the stand (see Nyland 1996 for discussion of defining residual stand structures). Stands could be developed consisting of large amounts of western white pine and western larch in the overstory and large amounts of grand fir and other shade tolerant species in the intermediate and codominant classes. These stand structures might be better achieved using some type of group selection silvicultural system.

The use of individual tree selection systems in the grand fir-western redcedar-western hemlock forests does present many challenges but they also offer some opportunities and produce desired forest conditions that meet many desires and wants of society. The conditions created by these silvicultural prescriptions would be excellent habitat for big game. They would provide both cover and forage for ungulates. The high basal area stands would provide excellent nest areas for birds and small mammals and the stands with the lower basal areas would provide excellent forage areas. The decadence found in the stand would provide habitat for many of the cavity nesting birds and the high shrub component would provide cover for small animals

Another approach for maintaining high forest cover in these kinds of stands might be a form of free selection in which each area of a stand is evaluated on the premise of species composition, growth, vigor, disease, and other attributes. At each location the removal or keeping individual stems would be evaluated using a set of biophysical characteristics and how the present stand condition would meet a set of objectives. This type of selection system would take highly skilled people in making the decision as to which tree to leave and which tree to be removed. This selection system would use the "art" portion of silviculture and integrate all of the knowledge possessed by a siviculturist.

The grand fir-western redcedar-western hemlock forest ecosystems evolved under mixed and variable fire regimes that tended to create even-aged stands of seral dominated species early in the succession cycle. As these forests aged they often became more multi-aged through weather, disease, or fire events. The use of uneven-aged silvicuture in these forests may be possible for a short period of time (100 to 200 years) but the stand conditions created by these prescriptions probably are not sustainable. However, in this short period of time the characteristics of these stands will probably meet a variety of societal desires and needs.

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