Stocking control concepts in uneven-aged silviculture

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Summary

Stocking control refers to forest management operations that alter the number and arrangement of trees within a stand and is a central element of uneven-aged silviculture. Many alternative stocking control approaches have been developed for uneven-aged stands. Four methods are presented that represent a contrast in complexity and emphasis, but that conceptually build on each other. All are assumed to be tools for allocation of growing space. The BDq approach builds on a reverse-J diameter distribution that serves as a target stand structure. The Plenter system is similar to the BDq approach as it uses a diameter distribution to represent stand structure but provides more flexibility for structures with different growth patterns. Stand density index can be allocated among diameter classes to form a variety of structures. Similarly, leaf area index can be allocated among age classes or canopy strata without the constraints of a reverse-J diameter distribution. Other methods for controlling stocking in uneven-aged stands exist and many undoubtedly represent sound approaches to management. The trend in the four approaches described here is towards a better understanding of stand dynamics and greater flexibility for diverse structural goals.

Introduction

Stocking control concerns altering the number and arrangement of trees in a stand with forest management operations to meet management objectives. This definition applies equally to even-aged management and management to create and maintain uneven-aged stands that provide continuous cover. In either case, the stand structure is being altered. Stand structure is therefore integral to meeting management objectives because most forestry objectives are stand structure dependent. For example, wildlife habitat in forest systems is usually defined by stand structures. Aesthetics, hydrologic values, and timber production can be described with stand structure and influenced by manipulation of structure.

An uneven-aged silvicultural system maintains and regenerates a stand with three or more age classes (Helms, 1998). Uneven-aged or multi-aged (two or more age classes) silviculture are similar in concept to other terms used to describe similar forms of management such as continuous cover forestry (Garfitt, 1995; Mason *et al.*, 1999), close-to-nature forestry (Mlinsek, 1996), near-natural forestry (Benecke, 1996) and others (O'Hara, 1998). Uneven-aged silviculture is assumed to imply the presence of multiple age classes or a form of selection silviculture. However, the general objective of regenerating the stand while maintaining forest canopy can be achieved with other systems such as irregular shelterwoods and even more traditional even-aged shelterwoods. The study of forest stand dynamics also reveals that mixed-species, even-aged stands can form stratified mixtures and can therefore possess many of the structural attributes of uneven-aged stands (Oliver and Larson, 1996). The objective to increase within-stand variability may be achieved with systems that do not result in uneven-aged stands (O'Hara, 2001) and implementation of a particular system should be done after careful consideration of alternative treatments. Many of the justifications for uneven-aged silviculture are designed to meet objectives such as increasing within-stand variability that may also be achieved with even-aged systems (O'Hara, 2001). Regardless of the objective, the desired structure, or what the selected system is named, stocking control is an important consideration.

Stand structure has been defined as the horizontal and vertical distribution of components of a forest stand including the height, diameter, crown layers, and stems of trees, shrubs, herbaceous understorey, snags and coarse woody debris (Helms, 1998). Stand structure has been represented in a number of ways. It is a basic element of many landscape-level descriptions that utilize relatively coarse descriptions of stand structure. For stand-level management, measures of stand density and crown closure generally describe the horizontal structure. These measures of stand density are the most common measures of stand structure used in implementation of even-aged systems. In uneven-aged silviculture, diameter frequency distributions have been the most common technique for describing stand structure. Relative little attention is paid to vertical structure because it is thought to be represented by the diameter distribution or is deemed less important to stand management.

Stand density measures are quantitative descriptions of stocking or the degree of crowding commonly expressed by various growing space ratios (Helms, 1998). Growing space refers to the site resources utilized by a tree or stand. Stocking control can therefore be considered an exercise in growing space allocation. Allocating a limited amount of growing space among more or fewer trees results in a different stand structure. Likewise, allocating more growing space to certain species or certain age classes can be used to produce a particular structure. Therefore the concepts of growing space allocation and management to achieve a particular structure are closely linked.

Not only do different stand structures result when growing space is allocated in different amounts, but the efficiency in use of growing space is affected (O'Hara, 1988). This growing space efficiency is used to characterize the amount of volume or basal area growth per unit of occupied growing space. Occupied growing space is represented with leaf area, crown projection area, or through mathematical relationships of space occupancy, such as stand density index. When allocating growing space to different components of stand structure (i.e. species, age classes, canopy strata), variable rates of efficiency can result in different stand-level productivity. Forest managers can therefore affect stand productivity through the allocation of growing space, although total stand-level growing space occupancy may be constant. This reinforces the importance of stand structure and growing space allocations in affecting stand growth in ways beyond those typically represented by only total growing space occupancy. In complex stand structures, such as those created with uneven-aged silviculture, stocking control involves looking at both the total growing space occupancy and how growing space is allocated among structural components, such as species, cohorts or canopy strata.

A major consideration of any uneven-aged stocking procedure is achieving sustainability over time in volume production and residual structure. The emphasis has been on a consistent residual structure from one cutting cycle to the next because this is assumed to provide a constant level of volume production. Larger scale sustainability issues were not explicitly addressed in early research that focused almost exclusively at the stand-level. Nevertheless, the unstated assumption was that if a consistent production of wood was produced at the stand level, then larger scale sustainability issues were of no practical significance. Without the relatively sophisticated yield projection tools of recent years, sustainability could not be measured or predicted: it could only be addressed through a constancy of stand

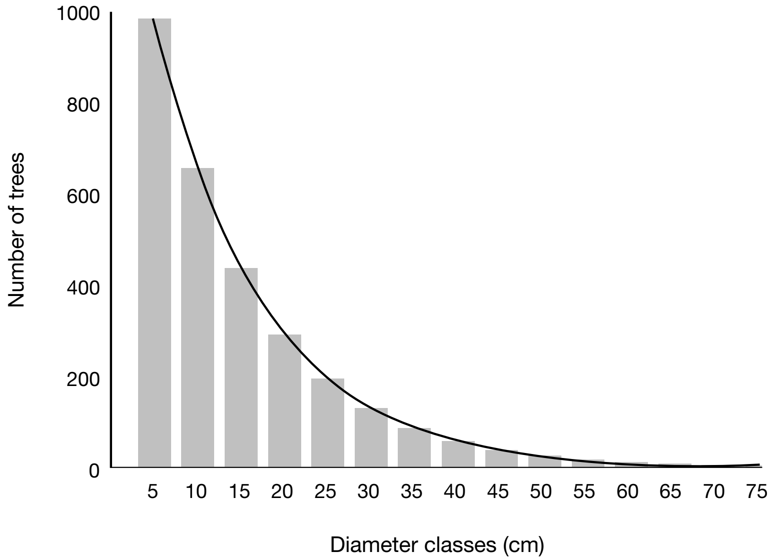

Figure 1. A negative exponential or reverse-J diameter distribution.

structure over a sequence of cutting cycles. Adams and Ek (1974), Hasse and Ek (1981) Haight *et al.* (1985) and others were the first to examine stocking in relation to various assumptions related to sustainability.

Stocking control techniques/approaches

Many approaches have been developed for controlling the stocking of trees in uneven-aged stands. In this paper we review four approaches, which differ in complexity and emphasis, but conceptually build on each other. Other approaches also exist and are available in the forestry literature. Many other undocumented approaches are probably used in practice. Our objective was to contrast the different approaches and to highlight their advantages and applicability so the reader would be able to judge which approach would be advisable for a given situation.

Q-factor approach

The most common approach for stocking control in North America describes the desirable stand structure with a negative exponential or reverse-J diameter distribution (Figure 1). The slope of this diameter distribution is described by the q-factor that is a ratio of trees in a diameter class to the number of trees in the next larger class. Total stocking is usually represented by basal area. The size of the tree of maximum diameter is used to define the endpoint of the distribution. Hence the method has evolved to become known as the BDq approach where 'B' represents basal area, 'D' the maximum diameter class, and 'q' the exponent of the decline function. The approach finds its roots in the work of de Liocourt (1898) and Meyer (1943), and more information on its application can be found in Alexander and Edminster (1977), Marquis *et al.* (1992) and Baker *et al.* (1996).

When using the q-factor approach, harvest and thinning treatments attempt to move the stand towards, or to maintain, a target diameter distribution. Ideally, sustainability is achieved by harvesting only those trees that exceed the target diameter distribution. The assumption is that the negative exponential distribution represents a sustainable structure with stable harvest levels. In practice, shortages in some diameter classes may require slight deviations from the target diameter distribution. Tree age is generally ignored with this procedure since tree size is assumed to be a suitable surrogate.

In theory, the q-factor approach produces a 'balanced' stand where volume cut equals volume growth, and each size class occupies equal growing space (O'Hara, 1996; Smith *et al.*, 1997). Adjustments to the q-factor result in changes to the diameter distribution with more or fewer large or small trees and changes in growing space occupancy. Attempts to allocate additional growing space from one subset of trees to another apparently run counter to the assumptions of a balanced stand because the negative exponential distribution is assumed to represent equal growing space occupancy regardless of the slope of this distribution. In reality, this assumption is probably unfounded and is certainly untested: adjustments to the decline of the diameter distribution represented by the q-factor are a logical way to redistribute growing space. Adjustments to the basal area parameter allow the user to increase or decrease the total stocking in a stand. For example, increasing the basal area while keeping the q-factor constant will increase the number of trees in all diameter classes and theoretically add new diameter classes for large trees. The maximum diameter term can also be adjusted, but not without subsequent changes in total basal area. The basal area and maximum diameter are important parameters in affecting the structure and may override the importance of the q-factor, or having a continuous diameter distribution, in actual implementation (Baker *et al.*, 1996).

Advantages of the q-factor approach include the widespread experience with the approach and the foundations of the approach in area control forest regulation. The appeal of the method is the simplicity with which stand structure (diameter distribution), growing space allocation, and stocking control (max. diameter, deviation from target distribution) are connected in one simple function. Many users have found examples for the stocking parameters in natural stands (e.g. Meyer *et al.*, 1961). Disadvantages include the inflexibility of the approach for structures that do not have negative exponential diameter distributions but may be practical candidates for uneven-aged silviculture. The exponential decline assumes removal or mortality to be inversely proportional to size and makes no reference to growth of individual stand components. Ignoring age has led to attempts to implement the approach in even-aged stands where high-grading may result (O'Hara, 1998).

Plenter system

In central Europe, there is considerable experience with the plenter system, or plentering, as a form of uneven-aged silviculture. The plenter system is not only a stocking control tool. Instead, it is a broader concept or framework for the entire management of an uneven-aged stand. Because of the long-term experience and success with this system that exists in central Europe, it represents a viable option for forests in other regions. It is successful in forests where valuable species regenerate reliably in shade and can maintain a desirable stem form under suppressed conditions (Schütz, 1997a, 2001). Successful examples of the plenter system have also been demonstrated in stands with less-shade-tolerant species (Assmann, 1970).

The plenter system originated in the montane forests of central Europe where shade-tolerant silver fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.) as well as Norway spruce (*Picea abies* (L.) Karst) are the dominant tree species. These forests used to be managed for production of large diameter structural timber and firewood supply in small wood lots on very short return intervals. In theory the plenter system uses a negative exponential diameter distribution for stocking control to develop the plenter equilibrium. In reality, however, there exist countless variations of forests with plenter structure in which single tree selection is used for stocking control (Burschel and Huss, 1987). An equilibrium is achieved when standing volume remains constant from one cutting cycle to the next and when growth equals harvest, thus providing for long-term sustainability. The irregular structure that is the objective of a plenter system consists of trees of all sizes and ages. However, tree age is not considered an important variable because trees can remain in a state of suppression for many years. Wave-like deviations from the equilibrium diameter distribution seem to be most common, resulting in fluctuations of growing stock (Röhrig and Gussone, 1990).

Schütz (2001) argued that the plenter structure can only be maintained through constant control of the growing stock (standing volume) and that a growing stock in excess of the equilibrium stock will lead to reduced regeneration and recruitment into smaller diameter classes. The long-term effect is loss of plenter structure. Schütz (1975)

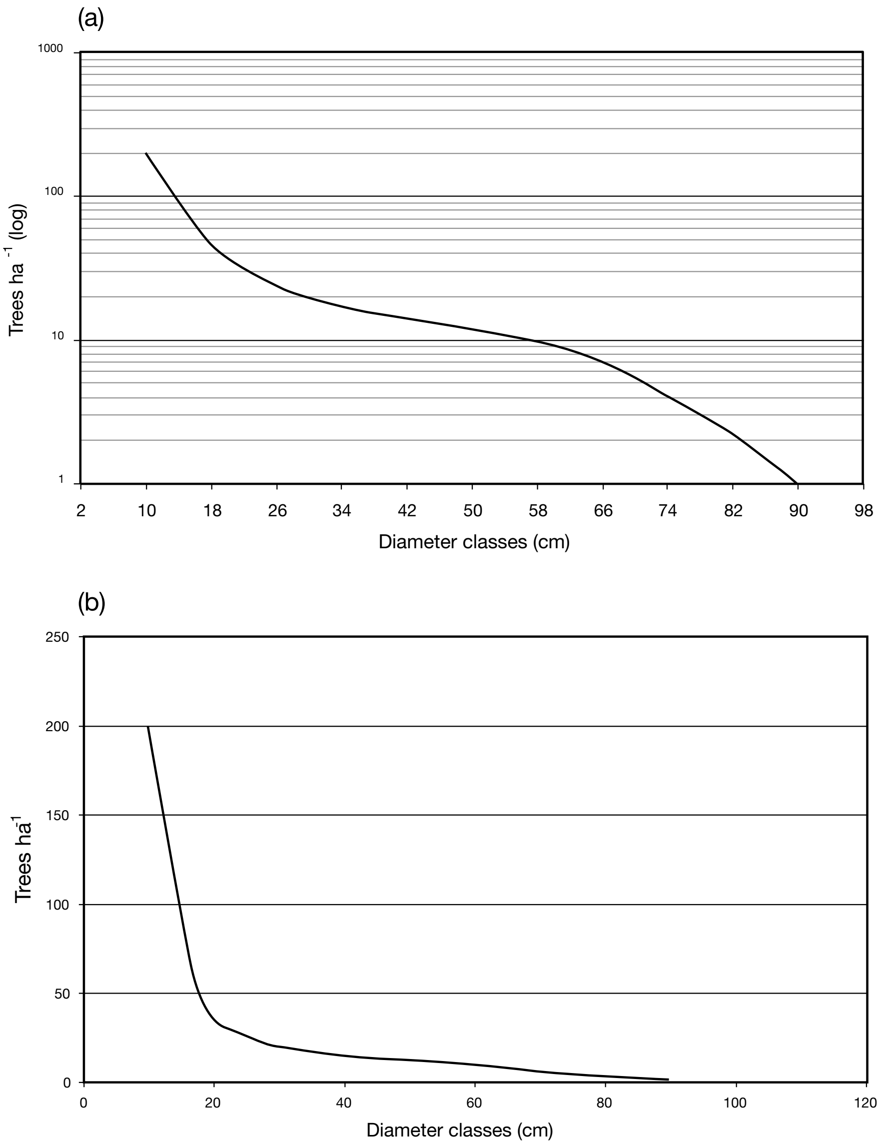

Figure 2. Equilibrium curve on semi-logarithmic scales (a) and linear scales (b) for silver fir/Norway spruce in Switzerland (modified from Schütz, 1975).

developed an equilibrium stocking relationship for Norway spruce/silver fir that varies from the negative exponential diameter distribution represented by the q-factor. This equilibrium relationship resembles a 'rotated sigmoid' curve (see Leak (1964) and Goff and West (1975) for more information on rotated sigmoid diameter distributions) that – when displayed on semi-logarithmic scales – has more trees in larger diameter classes than a negative exponential diameter distribution (Figure 2a). On linear scales, the relationship still approximates a 'reverse-J' curve (Figure 2b), but the additional larger trees are not readily apparent.

Schütz (1997b) justified the sigmoid shape as resulting from non-linear increase in periodic increment with tree size and the disproportional greater effect on the remaining stock when large diameter trees are removed. Increment in small diameter classes is relatively low and, therefore, is assumed to require a high number of stems to produce enough diameter class advancement, causing a steep decline in the diameter distribution in these size classes. As trees grow into larger diameter classes, mortality declines and diameter class advancement increases, causing a slower decline in stem number. Increased tree harvest in the larger diameter classes again causes a more rapid decline in the distribution. The equilibrium diameter distribution can be calculated from empirical values of diameter growth and harvesting of trees and tree mortality. The equilibrium stand basal area, or the total growing space occupancy, can be derived from growth and survival of regeneration depending on stand density. In theory we can construct a family of diameter distributions and calculate the corresponding standing volume. However, only a few curves will produce an equilibrium because of the negative effect of increased growing stock on regeneration and ingrowth. Realistic values for stem numbers in the lowest diameter classes are taken from observations in the field together with standing volume and ingrowth.

Different equilibrium diameter distributions can be developed for other forest types or other sites. These vary in shape due to differences in diameter increment and rates of removal. In silver fir-dominated forests at lower elevations the equilibrium distribution might have a more pronounced sigmoid shape, whereas a more consistently negative slope might be found in high elevation forests because of more uniform diameter increment across all size classes. These differences represent the relative diameter increment across the diameter distribution: equal diameter growth would result in a negative exponential relationship, whereas unequal diameter increment results in the rotated sigmoid form (assuming more rapid diameter increment in larger classes) (Schütz, 1997b). The advantage of this model is its flexibility in assigning diameter distributions and removal rates depending on growth rates and competition. Finally, the form of the diameter distribution is also a function of management objective in plenter forests. While different amounts of growing stock can be held at equilibrium through periodic inventory and stocking control, they result in varying yields of small, medium and large timber which will influence management decisions by the forest owner.

Allocation of stand density index

Stand density index (SDI) is a relative stand density measure originally developed by Reineke (1933). As a measure of relative density, it attempts to represent competition and growing space occupancy. Although SDI was originally developed for even-aged stands, Long and Daniel (1990) proposed using it as a tool for stocking control in uneven-aged stands. They examined how structures designed with the q-factor varied in terms of distribution of SDI among diameter classes. Figure 3 shows a diameter distribution for a ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws) stand with a q-factor of 1.5. In this stand, neither basal area nor SDI is equally distributed among diameter classes, or among the broader diameter class groups. These results show that structures that are considered sustainable do not necessarily have equal growing space allocation nor do they need to have a balanced diameter structure. These results are contrary to the assumption of a balanced structure having equal growing space distribution across size classes.

As an alternative to the stocking regime shown in Figure 3, Long and Daniel (1990) offered the regime in Figure 4. It has fewer small trees, more large trees, and fewer trees in total. Despite these differences, total growing space occupancy is similar in the two stands. Although the diameter class distribution depicted in Figure 4 resembles a negative exponential curve, it ranges in slope as represented by the q-factor from 1.15 to 1.42. These two examples demonstrate how different structures can result from similar levels of total growing space occupancy. The rational for this alternative scenario is similar to deriving the standing volume of equilibrium conditions in plenter forests where regeneration and growth of small diameter classes is a function of stocking in larger diameter classes. However, the reduction in understorey growth due to overstorey competition cannot be derived from stand density index.

Long (1998) outlined some basic steps to allocation of SDI among different size classes. This

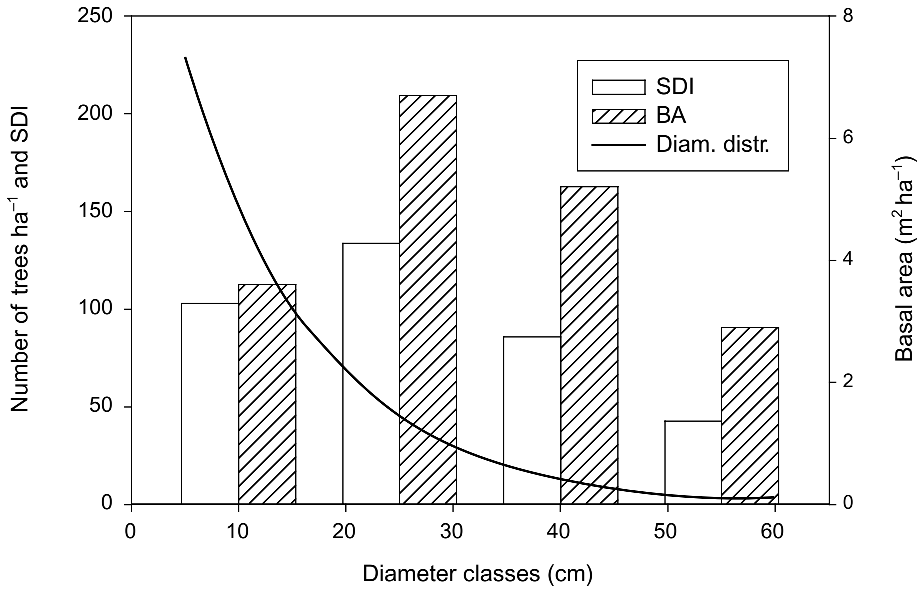

Figure 3. Stand density index, basal area and diameter distribution for a ponderosa pine stand with q-factor 1.5; using data from Long and Daniel (1990).

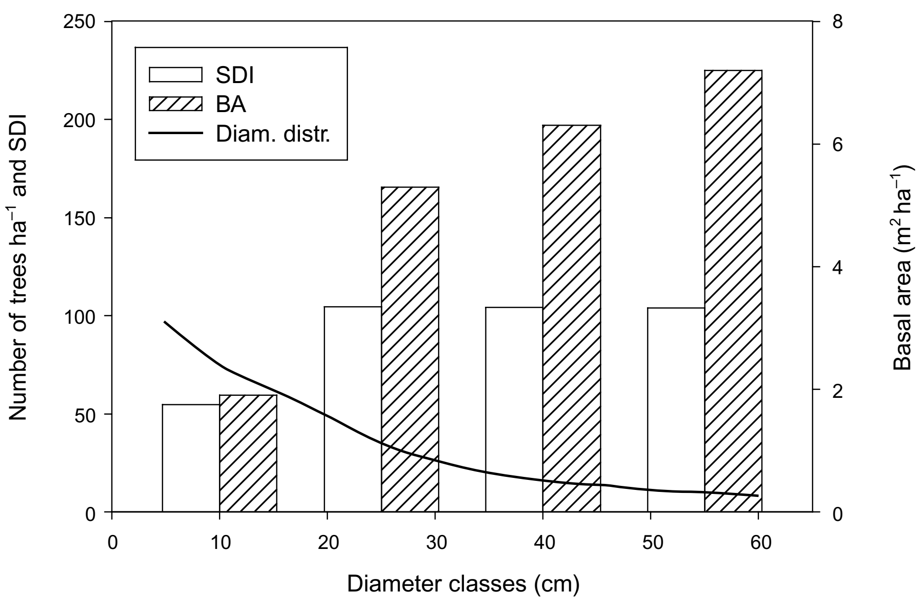

Figure 4. Stand density index, basal area and diameter distribution for a ponderosa pine stand with variable q-factor; using data from Long and Daniel (1990).

generally involves identifying the SDI required for one size class and then dividing the remainder among other classes, as needed. The total amount of SDI, or growing space occupancy, can often be obtained from even-aged stand data, growth and yield models, or even-aged stocking guides. More information on application of this procedure is available in Cochran (1992) or Long (1996).

Leaf area allocation

Leaf area is an expression of the total leaf surface area of an individual plant, stand or ecosystem. When expressed per unit of ground surface area it becomes 'leaf area index' or LAI. O'Hara (1988) proposed using LAI as a measure of occupied growing space because it generally increases early in even-aged stand development and attains a maximum that is related to the quality of the site. Leaf area can be allocated among stand components (age classes, species, canopy strata) to achieve a desired structure (O'Hara, 1996; O'Hara and Valappil, 1999). Using this 'top-down' approach, structures are not necessarily balanced, at equilibrium, or sustainable but they will give the manager a guideline for what understorey densities are possible given the structure of the overstorey.

This approach moves stocking control away from creating particular diameter distributions and towards designing structures using features that are directly related to productivity and growing space occupancy. O'Hara and Valappil (1999) therefore described it as a 'first principles' approach to stand density management and stocking control. The model takes into account differential growth rates depending on relative canopy position (cohort) as well as maximum growing space occupancy (max LAI).

The leaf area allocation approach uses a model called MASAM, or Multi-Aged Stocking Assessment Model (O'Hara and Valappil, 1999). This model provides estimates of stand growth, average tree vigour, and other stand parameters for a single cutting cycle, or period between harvest treatments. The user designs the desired stand structure by selecting the maximum total level of growing space occupancy, the number of components and how growing space is allocated among these components. In the example in Table 1, cohorts or age classes are the stand component used in this stocking regime for ponderosa pine. The model is constructed so that the oldest age class, or cohort, is removed at the end of a cutting cycle. Then the second oldest cohort becomes the oldest and a new cohort is regenerated. If canopy strata are used instead of cohorts, the model assumes the tallest stratum is removed at the end of the cutting cycle. Cutting cycles are assumed to be repeated over time; however, the user can change the stocking parameters to design a series of consecutive structures that might be useful for transforming a stand from even-aged to a stand with two or more age classes.

The model takes a different approach in that it does not provide the user with diameter distributions, but with estimates of a variety of details about the structure being designed under 'Diagnostic Information' (Table 1). This includes information at the beginning (BCC) and end of each cutting cycle (ECC) for LAI, basal area and SDI. End-of-cutting cycle values are provided for stand increment and average tree vigour.

In the example stand structures in Tables 1 and 2, two different ponderosa pine structures are presented. They have identical levels of total growing space occupancy (LAI), but Table 1 shows a stand with four cohorts and Table 2 shows a stand with only three cohorts. The three-cohort stand might be easier to maintain than the four-cohort stand, and has virtually the same total productivity. Both stands have a linear decline in number of trees with increasing age and an increasing allocation of LAI with increasing age.

Table 3 shows MASAM output for a structure consisting of a mixture of Scots pine (*Pinus sylvestris* L.) and Norway spruce. This stand favours Scots pine over spruce but assumes that some spruce, particularly in the understorey, is unavoidable. The model requires a separate LAI allocation for each species and, unlike the ponderosa pine models in Tables 1 and 2, this model uses canopy strata rather than cohorts. Only two canopy strata are used so the model is not appropriate for stands with more strata.

Applications of the approach for Scots pine/Norway spruce mixtures are available in O'Hara *et al.* (1999, 2001), for ponderosa pine in O'Hara *et al.* (2003) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm) (O'Hara and Kollenberg,

Table 1: Multi-aged stocking assessment model (MASAM) for ponderosa pine in Montana

Ponderosa pine MASAM – Montana					
	User-specified variables				
Total Leaf Area Index (LAI)	**6**				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Total
Number of trees/cohort/hectare	**50**	**75**	**100**	**125**	350
Percentage 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	1.2	0.9	0.5		2.6
Leaf area/tree (m^2) ECC	480.0	240.0	120.0	48.0	
BA/cohort (m^2 ha^{-1}) ECC	12.1	8.3	5.1	2.5	28.1
BA/cohort (m^2 $acre^{-1}$) BCC	5.6	3.8	2.0		11.4
Av. vol. increment/tree (m^3 a^{-1}) ECC	0.04	0.02	0.01	0.00	
Av. vol. increment/CC (m^3 ha^{-1} a^{-1})	1.4	1.0	0.7	0.1	3.3
Quadratic mean d.b.h./cohort (cm) ECC	49.2	33.4	22.6	14.2	
Tree vigour (cm^3 m^{-2} a^{-1})	75.8	80.5	70.8	46.6	
Stand Density Index ECC	147.5	119.0	85.4	50.5	402.4
Stand Density Index BCC	79.3	64.0	40.4		183.8

Data in bold font are values entered by user. Remaining information is provided by model as an aid to designing a multi-aged structure. This structure has four cohorts and would produce an estimated 3.3 m^2 ha^{-1} a^{-1} over a cutting cycle. The cutting cycle might be as long as 30 years.

2003). Additionally, the MASAM models can be downloaded from the following website: www.nature.berkeley.edu/~ohara/downloads

Other approaches

The four stocking control approaches presented here are well documented and well recognized in the scientific community because of their publication histories. Other procedures exist but may have relatively minor representation in the scientific literature or may be neither published nor widely known outside their local region. It has also been common for high grading of forest stands to occur under the guise of uneven-aged silviculture. A typical sequence of events may have been the removal of the largest trees – thereby perpetuating an uneven-aged structure – under the untested assumption that these trees were older and the stand was uneven-aged. Other procedures may be quite sound in their ecological and economic approach, but exist with little documentation: instead relying on the experience of the practitioner. Although evidence is scarce, diameter limit cuttings may have also been successful if sufficient quality growing stock was left but long-term studies are still needed (Sendak *et al.*, 2003). Variable limits for different species maybe effective for favouring certain species and altering the stand structure.

Examples of more formal approaches include the ‘volume/guiding diameter limit’ (VGDL) approach that was used for decades on the Crossett study in southern pines (Reynolds *et al.*, 1984; Baker *et al.*, 1996). VGDL sets harvest volume equal to growth over a cutting cycle and uses a flexible upper diameter limit to guide tree

Table 2: Multi-aged stocking assessment model (MASAM) for ponderosa pine in Montana

Ponderosa pine MASAM – Montana					
	User-specified variables				
Total Leaf Area Index (LAI)	**6**				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Total
Total					
Number of trees/cohort/hectare	**75**	**115**	**150**	**0**	340
Percent of LAI/cohort	**60**	**30**	**10**	**0**	100
	Diagnostic information				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Total
Leaf Area Index/cohort ECC	3.6	1.8	0.6	0.0	6.0
Leaf Area Index/cohort BCC	1.2	0.5	0.0		1.6
Leaf Area/tree (m^2) ECC	480.0	156.5	40.0	0.0	
BA/cohort (m^2 ha^{-1}) ECC	18.0	8.3	2.5	0.0	28.9
BA/cohort (m^2 $acre^{-1}$) BCC	5.4	1.9	0.0		7.4
Av. vol. increment/tree (m^3 a^{-1}) ECC	0.04	0.01	0.00	0.00	
Av. vol. increment/CC (m^3 ha^{-1} a^{-1})	1.9	0.8	0.3	0.0	3.0
Quadratic mean d.b.h./cohort (cm) ECC	49.0	26.9	13.0	0.0	
Tree vigour (cm^3 m^{-2} a^{-1})	76.8	77.6	87.2	0.000	
Stand Density Index ECC	220.0	129.6	52.4	0.0	402.0
Stand Density Index BCC	84.5	40.2	0.0		124.7

Data in bold font are values entered by user. Remaining information is provided by model as an aid to designing a multi-aged structure. This structure has three cohorts and would produce an estimated 3.0 m^2 ha^{-1} a^{-1} over a cutting cycle. The cutting cycle might be as long as 40 years.

selections towards minimum residual stand volume. Hallin's (1959) 'unit area control' treated homogeneous areas within a stand as harvest areas thereby perpetuating an uneven-aged structure through a form of group selection. The 'maturity selection' system for ponderosa pine evaluated the financial and biological maturity of individual trees (Munger *et al.*, 1936). The 'improvement selection' system, also for ponderosa pine, focused more on improvement of growing stock (Pearson, 1942).

Synthesis

When we alter the structure of a multi-aged stand, or any stand, we assume management objectives can be met by intervening on what would happen without management. Since a primary objective of uneven-aged silviculture is often to promote a higher degree of naturalness, then our assumption in managing these stands is, in part, that we can improve on nature and achieve our management objective. Whereas stands might naturally have a great amount of heterogeneity, management has tended to homogenize stand structures. Even-aged plantations are an example of this trend as are efforts to force multi-aged stands into a balanced standard structure. Hence an evolving trend in uneven-aged stocking control has been greater flexibility to accommodate a diversity of structures that are desired for management objectives that may range from maximizing timber volumes to promoting naturalness in all its forms.

All of these stocking approaches are tools to guide the design of appropriate stand structures for multi-aged stands. Since an appropriate

Table 3. Multi-aged stocking assessment model (MASAM) for Scots pine and Norway spruce mixtures in Finland

	User specified variables			
Scots pine LAI	**1.5**			
Norway spruce LAI	**0.5**			
Total LAI	2			
	Scots pine		Norway spruce	
	Upper strata	Lower strata	Upper strata	Lower strata
Percentage growing space (LAI)	**70**	**30**	**25**	**75**
Trees/ha by component	**750**	**1000**	**20**	**500**
	Diagnostic information			
Sapwood area/tree (cm^2)	109	35	148	18
Volume increment/tree (dm^3 a^{-1})	11.4	2.2	13.3	0.8
Av. tree GSE (dm$^{3\ cm-2}$)	0.11	0.06	0.09	0.04
Basal area/tree (cm^2)	347.5	66.6	306.1	44.0
Basal area/component (m^2 ha^{-1})	26.1	6.7	0.6	2.2
Cohort increment (m^3 ha^{-1} a^{-1})	8.6	2.2	0.3	0.4
Stand increment (m^3 ha^{-1} a^{-1})	11.5			
Stand basal area (m^2 ha^{-1})	35.5			

Data in bold font are values entered by user. Remaining information is provided by model as an aid to designing a multi-strata structure. This structure has both species present and two canopy strata.

structure is dependent upon management objectives, a stocking approach should be flexible for design of a variety of objectives and structures. The relative rigidity of the original q-factor approach to a constant declining number of trees with increasing diameter has evolved towards methods that recognize alternative distributions that may be more productive and consistent with stand-specific objectives.

Sustainability is an underlying objective of all multi-aged stocking control tools. It is achieved by allocating growing space such that the stand structure is maintained over time, volume growth balances removals, and/or sufficient and timely regeneration is obtained. Achieving these 'criteria' of sustainability in multi-aged stands under a diverse array of management objectives is achieved through allocation of growing space or stocking control. A stocking control approach with greater flexibility to accommodate the diverse objectives will have greater overall utility. Additionally, for a given forest type and site conditions, there is little evidence that only one uneven-aged structure will be sustainable. Alternative arrangements of growing stock can be sustainable but at different levels of volume productivity (O'Hara, 1996).

Any stocking prescription is an attempt to balance management objectives with the ecological limitations of the species present. This is true whether the objective is an even-aged or an uneven-aged structure. The procedures for guiding stocking control in uneven-aged systems therefore need to accommodate the silvics of desired species and also be sufficiently flexible to meet objectives. There are undoubtedly many different ways that stocking can be controlled in even-aged or uneven-aged stands while still meeting management objectives. The choice of the method used should depend on local experience and applicability of the approach to a given forest type.

The stocking control methods vary considerably in their flexibility to control stocking in stands with unusual structural features or simply irregular structures. These might include old-growth relics, unusual age classes, or species requirements. Few applications of uneven-aged silviculture in the future will resemble classical textbook examples and adaptability to highly variable structures is important. Also critical to the successful implementation of any uneven-aged stocking prescription, is the potential of any stocking control approach to be translated into field guidelines for tree marking. Ultimately, the true measure of effectiveness of a stocking control tool are the results of whether the stand is marked to the specifications of the prescription. Finally, stocking control tools are only one aspect of uneven-aged silviculture. Because they are a key variable in affecting yields, regeneration, timing of operations, and stand health, they are a fundamental component of uneven-aged silviculture.

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