Implementation and Interpretation
of
Management Recommendations for the Northern Goshawk

Version 2.1, December 2005

The Management Recommendations for the northern goshawk[1] (MRNG) are guidelines that were used to change Southwestern Region management philosophy from sustainable timber production to a sustainable ecosystem and have broad support both from within and on the outside of the Forest Service. As could be expected from any such publication there is room for interpretation. There have been a number of reviews of the MRNG and the understanding of what the guidelines are varies.[2]

The primary disagreements by critics of the MRNG seem to have been about the density of "old growth" at scales of several acres to landscapes. A number of large and intense wildfires have burned through occupied goshawk habitat since the MRNG was published, killing many and sometimes all of the large trees across hundreds to thousands of contiguous acres. With the increasing frequency and size of intense wildfires in (what may now be former) goshawk habitats the debate about forest density is subsiding as it becomes evident that high tree densities across large areas are not sustainable in most of the Southwestern forests. Other disagreements, particularly about the harm done to goshawk habitat by cutting some large trees when many are present are likely to become more focused.

This document presents our best current understanding and approach in implementing the Kaibab NF Land and Resource Management Plan (Plan) as amended in 1996 to meet the MRNG guidelines. In the early 1990s a group of professionals within the Kaibab National Forest (and to a lesser degree from outside of the Forest) studied the MRNG and provided interpretations based on the "intent" and sound biological concepts. These ideas simply represent a general consensus in an attempt to provide for consistent implementation across the Forest and from one project to the next.

Appendix A contains some concepts, ideas, and unique characteristics of the MRNG. We recommend these be reviewed as they are the basis for the implementation strategy discussion that follows. However, please recognize this not meant to be a total interpretation of all the recommendations.

Appendix B describes the principles behind the arrangement and residual tree densities recommended in this document.

Described is an implementation strategy for attaining the Desired Future Condition (DFC) outlined in the MRNG. To determine opportunities for treatment (management) it is critical to know (and be able to describe) the existing condition. In the past this has been done through an interpretation of the stand data that presents averages for a stand. These averages were again interpreted to derive a vegetative structural stage (VSS). This was mostly adequate when the DFC was a forest of even-aged stands and having stands of different ages across the landscape provided diversity. Large, old trees were provided only in deferred areas. That condition is no longer desired in the Plan. Table 6 (pg 17) in the MRNG describes interspersion of VSSs as one of the most important habitat attributes for most goshawk prey

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[1] Reynolds, R.T., et al. 1992. Management Recommendations for the Northern Goshawk in the Southwestern United States. GTR RM-217. FT. Collins, CO: USDA-FS, Rocky Mountain Forest and Range Experiment Station. 90 p.

[2] Az G&F Dept Review of USFS Strategy for Manging Northern Goshawk Habitat in the SW US. 1993. 90 p.

FS Goshawk Opinion Paper – A Response to Az G&F Dept Review of USFS Strategy for Manging Northern Goshawk Habitat in the SW US. 1994. 17 p.

Northern Goshawk and Forest Management in the SW US. 1996. The Wildlife Society Technical Review 96-2. 20 p.

Long, J.M. and F.W. Smith. 2000. Restructuring the Forest – Goshawks and the Restoration of Southwestern Ponderosa Pine. *Journal of Forestry* 98: 25-30.

species. Management on a group[1] basis (1/2 to 4 acres), featuring within stand (site) diversity should maximize interspersion. This poses unique problems of knowing and displaying the existing conditions down to ½-acre groups. Maps displaying stand averages (VSSs) are useful; however, they reveal little about the treatment needs of the individual groups. Mapping the spatial distribution of group VSSs would be cost-prohibitive. It is possible to map units based on the diversity (variation) or based on the departure from the DFC but we do not see GIS being utilized in a way we are all familiar with by creating maps of VSS distribution based on stand averages.

One approach the Kaibab has taken is to determine VSS based on the raw data collected at each sample point. Stand Density Index (SDI) is used to estimate occupancy and the canopy density classes (i.e., A, B, & C classes). The model for VSS calculation by point is described in Appendix B. VSSs can be calculated meaningfully when there are enough points. Generally a large area (a PFA, FA or "audit unit"[2]) will be reliably represented; however, there are not enough points at the stand (site) level to be confident of predictions.[3] An index of the variation between points (diversity) can be calculated and this variation could be mapped with a GIS system. This diversity (variation) is helpful in determining the priority of treatments.

It may also suffice to simply note needs during field reconnaissance, keeping the DFC in mind.

The end product of whatever process is used will be an estimate of the percent of each VSS for the assessment area and an indication of the areas where there are different degrees of within stand diversity. As discussed in Appendix A (#7), the VSSs thought to be critical to species diversity and numbers are the two ends of the spectrum (regeneration and VSS 5+). We will have estimates of the amount and whether we are deficit in regeneration, VSS 5+, or both.

For ponderosa pine, treatment will be to maintain and enhance within-stand diversity on a group basis (1/2 to 4 acres) by using group selection to create essentially even-aged groups with a "rotation" (200+ years) for each group of trees. For areas of one acre or more that are regenerated, reserve trees (3-5 per acre in pine) are to be retained that should effectively "escape" from the rotation, continuing to grow and become as old as physiology and natural disturbances permit.

One systematic approach to identify the need for change is to determine if there are shortages for the VSS ls and/or for the 5s and 6s. Based on this, the acres to be regenerated are estimated. If the VSS 5s and 6s compose less than 40%, then all sites fully occupied with 5s and 6s would be maintained. (An exception could be for treatment of dwarf mistletoe, but sites dominated by large trees – and even individual large trees - become increasingly important as their prevalence decreases). This does not mean that no groups of VSS 5or 6 nor individual large trees will be cut. All VSS 5s and 6s above an existing group of 2 through 4 VSS in excess of the 3 to 5 residual trees could be removed to release these groups but this would be uncommon when there are relatively few acres occupied by VSS 5s and 6s. More work by the Forest is needed to define what may be desirable in these situations.

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[1] For purposes of this paper, "clumps" range in size from two adjacent to perhaps ½-acre of similarly-sized trees, while "groups" are made up of clumps of similarly-sized trees up to two acres. "Patches" are made up of groups of similarly-sized trees from two to several acres.

[2] Audit units were developed by North Kaibab RD biologists to assign areas outside of PFAs to specific goshawk territories. Since the MRNG recommends assigning 5400 acres of FA to each goshawk PFA and the density of PFAs on the district precludes this, theissen polygons were set up to assign the actual available FA to each PFA. Conditions within each of these polygons are "audited" for existing conditions in planning treatment needs.

[3] Stand exams are usually designed to obtain an SE% of 20% (67% confidence) for trees per acre at the stand scale. Subdividing the tree profile into six classes raises the SE% considerably for trees per acre in each of the tree classes. Further, presence of trees in a particular diameter class do not make the corresponding VSS necessarily present. None-the-less, trees are arranged in a groupy pattern and a large number of plots are more likely to represent the true distribution of VSS than stand averages.

The definition of a "group" remains elusive. A clump within a stand where the individual trees are closer together than the individual trees around them is easily spotted. These are subgroups or variations within a group and are particularly important to recognize with VSS 4+. Residual basal areas within groups are described in a table in Appendix B for both the PFA and the FA. These are based on desirable occupancies measured by SDI. The DFC for these groups in the VSS 4+ consists of clumps with open interspaces. These open interspaces are necessary to allow room for developing root systems necessary to achieve the growth rates and achieve the desired size and canopy interlock within the clumps for the DFC. To retain this clumpiness within groups over time, it is important to thin by focusing cutting or leaving individual clumps rather than seeking optimal spacing for individual trees.

One way to gain an understanding of this concept is to observe the stocking of a group of mature to overmature ponderosa pines first hand in the forest. We recommend that this be done because most people will not recognize the group as one group but as a number of smaller (closed canopied) clumps. Inspecting the interspaces between these clumps will generally show little regeneration of robust trees and little herbaceous growth because these interspaces are fully occupied by the root systems of the clumps. The size of the individual stems is directly proportional to the amount of growing space. If the DFC is to have 24"+ trees then groups of VSS 1-3 must contain many interspaces and will probably be an A or low B VSS density. Moisture-limited ecosystems won't produce 24"+ trees with a continuous closed canopy across more than an acre or two. If there is doubt about what is required to grow large trees in a reasonable time frame, modeling may help. The growth and yield model in the Forest Vegetation Simulator for the Southwest is based upon research with a high coefficient of determination for diameter growth (98% in ten years).

Clumps and groups with a nearly closed canopy can and often do exist adjacent to what appear to be openings because their root mass can gather more moisture and nutrients in that circumstance. It is important to distinguish these interspaces from areas available for robust regeneration (VSS 1). In fact, intensive management (frequent disturbance) will have to occur to maintain these areas as openings. The DFC is to have at least the density described in Appendix B with as much "clumpiness" (with crowns growing together) as possible.

A rough example of this is in the Pearson Natural Area, Fort Valley Experimental Forest. There, groups of large ponderosa pine exist without regeneration directly under the group. But there is a sea of poles all around the groups well beyond their drip-line, pressing ever closer as each individual large tree dies. The interspaces needed by these trees are being lost to an encroachment of the regeneration and a higher rate of mortality is being induced due to the competition. Traditionally we would remove the overstory to release the poles, but the DFC described in the MRNG is to maintain 40% of the area dominated by VSS 5s and 6s. We would remove the poles away from the mature trees.

There will generally be four types of treatments: thinning; release; regeneration; and, tending. At the DFC, sites will consist of even-aged clumps making up groups and there will be less need for release.

In the interim, situations occur where releases are necessary, particularly where the number of large trees is not deficit in the landscape. Existing groups of VSS 2 through 4 will receive the needed management either through a thinning from below or a release through a removal (leaving the residual 3 to 5 trees per acre overstory). Existing clumps and groups of VSS 5 and 6 can be tended by either pushing back competing regeneration (generally poles) and/or by cutting out suppressed trees from within the group. Suppressed trees are generally few in number and are those that are deformed and are not very suitable for snags. If the VSS 5B+ presence is less than 40%, great care about the amount of release prescribed for existing regeneration should be taken: Is the highest value to release a group of 2s or is it to push back the 2s from a group of 5s? Again, it is important to have a firm grasp of what a group is: It is very easy to release a clump (less than ½ acre) of regeneration within a group of 5s when in fact the regeneration should be removed to maintain the 5s.

Assuring adequate regeneration exists (8%-10% of the area on a 20 year entry) is critical to establish a DFC that is sustainable over time. The first priority will be to identify and assure regeneration in existing openings. The primary treatment will be site preparation. The second priority will be where there is needed treatment for mistletoe. If after taking care of these two priorities regeneration is still needed then the location can be randomly chosen based on getting the regeneration areas evenly distributed across the landscape. Groups of VSS 5+ do not have to be cut down in order to provide for regeneration. When there is a deficit of VSS 5+, regeneration can be encouraged adjacent to an existing group of VSS 5+, perhaps in VSS 3 or 4, especially if they are surplus. The key is that an adequate number of acres are regenerated each entry to move the forest toward a balanced age-class distribution.

Following the 1996 Plan Amendment, the Kaibab's Plan no longer sets minimum thresholds for hiding or thermal cover in timbered areas. These habitat components are still considered to be important, although the need for thermal cover for both elk and deer has been called into question by research.[1] With irregular spacing and the maintenance of groupiness, thermal cover should not be a problem but hiding cover can be. The DFC is to grow seedlings and saplings in open conditions to maintain the full live crown. In many cases thinning has occurred too late and the crowns have already risen from the ground, loosing the characteristic needed for effective hiding cover. In addition to the use of commercial species, hiding cover can be supplied by noncommercial species such as aspen and oak and can be supplemented by broken topography and control of road access. The amount of hiding cover that must be maintained should be determined during project analysis. If hiding cover is barely being met or there is not enough hiding cover, then what ever is present may need to be maintained (even if this is in overstocked groups) until regeneration is in place to replace it.

Traditionally thinning has been on an individual tree basis with even spacing, reducing or removing clumpiness from the stand. The DFC is to have clumps with interlocking crowns in VSS 4+. To achieve the DFC it will be necessary to manage for the extremes by applying irregular spacing when the trees are approximately 8" dbh or larger (prior to this, tress may be evenly spaced). For trees less than 8" dbh, one approach that is being tried is to thin from below with an upper diameter limit. This favors the dominant trees and the clumpiness that is inherent in a natural stand. This is very site specific and prescriptions must be applied on a site-by-site basis using the existing condition. Another approach is to thin from below selecting individual stems until a desired BA is reached. Still another approach is to select the "dominants" and "co-dominants" for leave trees. What is important is to provide the needed management on every acre. Some acres may not need thinning at this time; others may be retained for hiding cover. But, it is important to look at every acre and do what is needed to achieve the DFC.

The structure of VSS 4 is critical to achieve the DFC essential for mycorrhizae and for squirrel nesting cover. The DFC is to grow trees with as much live crown as possible and then to close up the canopy of clumps (sub-groups up to 1/10 acre in size) within the group. In an FA the group would have an average residual BA of 62; however, it would contain clumps that will maintain a closed canopy with a much higher stocking. Space between the clumps will be open, maintaining most of the live crown on the outside of the clump. Markers can key on clumps and use a BA guideline for the trees that are around the clumps. The number of clumps is based on a spacing interval of approximately twice the diameter of the clump. These clumps can occur in roundish groups or in stringers determined by the conditions found at the sight. Using basal area as a guide to marking is difficult because of the variation

[1] Duncan, Sally. 2000. Why Do Elk Seek Shelter? The Case Against the Need for Thermal Cover. USDA-FS, Pacific Northwest Research Station. *Science Findings* 22:1-5.
Freddy, D.J. 1984-1986. Quantifying capacity of winter ranges to support deer—evaluation of thermal cover used by deer. Denver, CO: Colorado Division of Wildlife; Wildlife research report.

being created and the small size of the clump. It is better not to use BA but rather to look for and select the desired number of dense clumps and thin everything around them to approximately 30 BA. Stocking within the clumps may be controlled by simply spacing individual trees approximately 10 to 12 feet apart or by removing only suppressed and intermediate stems. Clumps of approximately 7 to 10 large trees found on the Fort Valley Experimental Forest that have never been thinned have a spacing of around 20 to 25 feet with lots of variation. An additional thinning at the VSS of 5 will approximate this condition at VSS 6.

There are several terms that should require less specific management emphasis now with the MRNG-based management (or relatively recent research findings) than they did in even-aged management (with 120-year rotations and evenly-spaced residual trees) because of the inherent characteristics of this approach. These include:

- stand (site) adjacency requirements;
- cover;
- interior dwelling species;
- old growth;
- migration corridors;
- snag recruitment;
- wildlife trees;
- visual quality objectives; and,
- various stand characteristics that were averaged over the stand.

Adjacency requirements assured that adjacent stands would not be given the same treatment (e.g., shelterwood seed cut) essentially enlarging stands and reducing diversity. Under the MRNG guidelines the DFC is to obtain within stand diversity by managing on a clump/group basis.

A common term that is often used with old growth is "interior dwelling species". Interior dwelling species require large areas of closed canopy forests. An example would be the temperate rain forests of the Northwest where fire occurred infrequently. In the Southwest most forests evolved where fires occurred frequently and forests seldom, if ever, grew in this arrangement across large areas with the likely exceptions of spruce-fir and the higher elevation mixed conifer forests. Fire adapted forests are more open with clumps or groups of trees with a closed canopy. No native wildlife species should require these types of conditions except in upper-elevation mixed conifer and spruce-fir. The management indicator species for old growth for the Kaibab is the northern goshawk. These guidelines were specifically developed for the goshawk and its prey species.

The traditional view of old growth as a continuous closed canopied forest of large old trees simply is not sustainable in the Southwest where most forests evolved with frequent fires. Old growth as directed under these guidelines is to maintain a "flow" of large old trees across the landscape both spatially and temporally. It mimics (but does not replicate) forest conditions that occurred prior to European settlement where large old trees occurred in small clumps/groups across the landscape. The Plan requires a minimum of 20% of the landscape to be in old growth, although the guidelines require 40% of the landscape to be in large trees (18"+ dbh). These fully stocked groups of large trees meet the needs for all "old growth dependent" wildlife species, providing old growth on 40% of the landscape.

Migration corridors are common term used in landscape analyses for wildlife. In order for wildlife species to occupy a landscape they must have the habitat components that enable them to move across the landscape. Since some species cannot move across large openings these could "fragment" the habitat, limiting movement. The intent of the MRNG is to limit fragmentation by managing for diversity on a very small scale by managing openings or stocked groups of trees on a group basis where all components are to be represented in each small landscape unit. Therefore, at the DFC, there is little need for specific vegetative management for "migration corridors". What may be much more important to fragmentation for many wildlife species could be the presence and frequent mechanized use of open roads or cross-country travel.

The DFC is to have a flow of habitat components (such as snags) across the landscape both spatially and temporally. Some trees with defect are deliberately retained; live green trees with spiked tops, lightening strikes, and other defects that are suitable for cavity nesting species across the landscape. In addition, a set number of large trees (i.e., 3-5 trees in ponderosa pine) are retained during regeneration treatments and these will remain outside (and in addition to) the 40% of the landscape that is fully stocked by large trees. So not only are snags retained, but their recruitment is assured across the landscape. It may be that most of the functions that snags currently provide were present in green trees with defect prior to logging.[1]

Visual quality objectives often conflicted with even-aged timber management, especially in "retention" areas that were in the foreground. However, the MRNG emphasis on interspersion of small groups (and openings) with lots of variety at human scales across the landscape, matches the desired stand structures in the Plan with "Retention" visual quality objectives.

[1] Ganey, J. L. 1999. Snag density and composition of snag populations on two National Forests in northern Arizona. Forest Ecology and Management 117: 169-178.

APPENDIX A

1. The recommendations are on a landscape approach. The recommendations are applied to all our forested ecosystems except where Mexican spotted owl habitat requirements or site-specific species requirements take precedence. There are basically three types of management areas: Nest stands/replacement nest stands, post-fledging family areas and foraging areas.
2. The recommendations require intensive management that should be applied, based on the potential of the site, as a management strategy throughout the ecosystem (including areas outside of the suitable timber base).
3. The intent is to maintain a flow of large old trees across the landscape both spatially and temporally. "Large" is not completely defined but will depend on the site. Most pine sites are capable of growing trees over 24" dbh in less than 200 years at the stocking levels shown in Appendix B.
4. In order to maintain the acres of large old trees the forest will become "regulated" (i.e., vegetation manipulation will be necessary to ensure enough acres of each age class are present at all times to maintain the oldest age class).
5. The sole reason for regeneration is to grow large old trees. Regulation will be accomplished through a constant recruitment of seedlings over time with each entry. Planned entries within an assessment area for timber harvest should be at 20 year or greater intervals. This includes all treatments. Exceptions would be for small-scale operations to catch latent infections of dwarf mistletoe, burning, planting, etc.
6. Any reduction (i.e., does not regenerate, maintain overstocked stands, etc.) in growth will reduce the amount (acreage) of large old trees that will be possible.
7. The structural stages with the greatest importance for prey habitat are: the early stages (1 & 2) where a herbaceous and/or shrub layer and hiding cover are present; and, the later structural stages (4+). VSS 3 has little biological importance and is necessary primarily as an intermediate stage as VSS 2s grow to 4s. The time that a given area is in VSS 3 should be minimized by maintaining the maximum growth rates.
8. Live crowns are important for hiding cover, diversity, cone production, and tree vigor. The maintenance of most of the live crowns is essential for the DFC.
9. It is important to have a robust herbaceous-shrub layer present.
10. Interlocking crowns are important in the older age classes (large VSS 3s and larger).
11. It will be necessary to have open grown trees from seedlings to the middle of the VSS 3 class (8" DBH) to develop an herbaceous-shrub layer and live interlocking crowns in the VSS 4 class. . How thinning is carried out in the VSS 3s is critical to the eventual development of interlocking crowns in the older age classes. Irregular spacing of trees beginning with mid-VSS 3 is critical to developing groups with interlocking crowns in the VSS 4+ classes.
12. To further develop the size desired for the VSS 6s, trees in VSS 4/5 groups will have to be released. Release (thinning) will be on a clump basis (having fewer clumps), maintaining the interlocking crown condition in the remaining clumps within the group.
13. Stand Density Index (SDI), a relative measure of stocking, will be used to regulate tree densities. It is assumed that there is a reasonable correlation between given SDI values and canopy density by species at the group level. Maximum SDI is independent of site (soils) where light is limiting.

It is assumed in the southwest where moisture is limiting that SDI may not be completely independent.

14. It is the intent of the recommendations to achieve and maintain healthy forest conditions. Insect and disease problems will be dealt with based on current forest conditions. Treatments in the short term may depart from the described recommendations to deal with high infestations of dwarf mistletoe.

15. Hiding cover will be provided by growing seedlings and saplings in an open grown condition (full live crown development) and letting the crowns grow together in late VSS 3s, along with other practices such as road closures, which can relieve some of the need for (security) cover.

16. Thermal cover will be provided with the interlocking crowns in tree groups in VSS 4+ and in groups of noncommercial trees, such as aspen and oak.

17. Group sizes are defined in the recommendations from 1/2 to 2 acres. The exception to this would be for mistletoe treatment which may emphasize a larger group or may require an even-aged stand (site) prescription. Openings up to 4 acres are consistent with the MRNG but are considered an even-aged treatment, by definition.

18. Regulation will be attempted at the stand (site) level based on the existing condition at the assessment level (i.e., the DFC will be to have a regulated forest at the stand level, however, this cannot be achieved in the short term at the expense of the conditions in the overall assessment area). Due to the high variation we seek to create in each site it will only be practical to analytically monitor progress toward DFC at the landscape scale (about 10,000 acres). We can subjectively monitor progress at smaller scales.

19. Forty percent of the area is to be fully stocked (occupied) with VSS 5 and 6. The remainder of the area (60%) will be occupied with VSS 1 - 4 with a residual overstory of 3 to 5 trees per acre (in a clumpy fashion) of 5s and 6s.

20. Skid trails may not be classified as "permanent" but the locations should be permanent. Consider integrating skid trail layout into group boundary definition. If skid trails follow/define group boundaries, costs of control lines for prescribed burns could be reduced over the alternative and problems with felling or skidding large trees through seedlings and sapling groups can be minimized. In any case, skid trails must be planned as part of the permanent transportation system to avoid proliferation of soil compaction over time.

21. The thresholds between the A, B, & C class for VSS are based on SDI and are explained in detail in Appendix B. The Region has been basing these on a threshold of canopy density (0-40%, 40-60%, & 60%+) when we do not have this type of data available. Rather than base them on canopy density, we have based them on "function" (what it is we want to achieve). For the A class the objective is the amount of sunlight that can get to the ground allowing herbaceous plants and shrubs to grow. This would equate to total canopy density for all forest layers. For the C class the objective is to have adjacent or interlocking crowns of the upper (dominant) forest layer and should not contain all forest layers.

22. Presently our VSS model (Appendix B) will classify a group as multiple storied based on diameter size classes and not on tree height (upper layer of forest canopy based on the dominant trees). This will lead to a classification of some groups as multi-storied which are actually single storied, especially when the mean diameter is close to the division between two VSS classes. In practice, the short-term management will be to blend the size classes and manage for a single storied group. In the long term groups will be close to even-aged groups.

APPENDIX B

The Problem

The Management Recommendations for the Northern Goshawk in the Southwestern United States (MRNG) and many other sources identify "extremes" of vegetative composition or structure as being important to wildlife species. These include very dense and very open tree conditions as well as regeneration and old growth areas. Functions identified include thermal cover, foraging habitat on the ground as well as in tree canopies, hiding cover, large snag production and regeneration of trees. If biodiversity is important, a wide range of vegetative composition and structure must be present at scales appropriate to the needs of plants, animals and fungi.

The Kaibab NF uses vegetative structural stage (VSS) extensively in the modelling process. In checking some of the stand densities associated with the "A" and "B" density levels, we became concerned that the Region 3 thresholds set in this classification were not serving the purposes we would like them to serve. For example, in the Region 3 VSS scheme, our sites classified as "5A" average about 60 basal area and some are as high as 90.

We would like "A" densities to be indicative of sites capable of producing a relatively large amount of forage or of regenerating robust seedlings. We would like the "B" densities to indicate sites that are higher than "A" densities but are still not completely occupied with trees. This would leave fully occupied sites in the "C" category. We therefore developed our own VSS thresholds for project analyses which are more indicative of function, at least for the Kaibab NF, than those in the Region 3 model.

We also found analyzing VSS on a point basis rather than a site average basis is much more indicative of site condition relative to the desired condition in the MRNG. (See endnote [i].)

The Approach

The MRNG recommends management of mid-aged and old-aged groups of trees at canopy cover percent (CC%) minimums of 40 to 70, depending upon species and intended function. Functions include providing site amelioration, protection for fledglings and squirrel foraging habitat. Unfortunately, most of our data has not been collected in a way which allows us to directly measure CC%. There are several measures of relative stand density which can make a fairly good estimate of CC% and we have appropriate data available. In the early 1990s, the Kaibab NF collected canopy density (CD) with a densiometer at plot centers along with our usual stand examination data on approximately 4000 points. We have drawn a correlation between CD and Reineke's stand density index (SDI) (See endnote [ii].) from these points.

There is a lot of variance between these two measures of density for a couple of reasons:

> a) The size of the plot measured with stand exams (fixed and variable plot) and the densiometer (vertically projected cone) are not the same;
>
> b) Interpretation of stand exam data using SDI can give an estimate of the occupancy of the site relative to its biologic potential for the species in question. It is not clear what biologic parameter, if any, is being measured with the densiometer.

Nonetheless, this is the data we have available to work with and some reasonable conclusions consistent with SDI thresholds have been drawn from the data.

Setting the "A/B" Threshold

Several studies have been done in northern Arizona and elsewhere correlating absolute density measures (such as basal area) with forage production. We wished to develop a correlation with SDI.

Also a recent study (Deiter, 1991) on the North Kaibab Ranger District indicates relative measures of density (such as SDI) have better correlations to forage production than absolute measures, including CD as measured with a densiometer, when other factors are equal.

For “A” densities, we assume a site should be unoccupied by trees at least to the extent it is available to produce 1/3 to 1/2 of its potential in forage. (On fescue sites, this would obviously be much higher absolute production than on a blue gramma site but the amount of the each site's potential going into forage production should be about the same.) This is consistent with our view that "openings" should fulfill that function rather than just have an absence of tree canopy. eg. Cinder pits, rock piles and gaps between tree groups are open but are not openings if they do not produce forage in amounts comparable to what a productive local site would be capable of. By thinking of "A"s in this way, rather than as just an absence of a certain CD, their true function becomes more clear.

Pearson (1964) studied forage production on sites near Fort Valley that were quite similar to those at Taylor Woods in 1967. Since he correlated forage with basal area but not with dbh or trees per acre, some reasonable assumptions need to be made about these to correlate SDI with forage production.

With Pearson predicting about 490#/ac of forage in an un-timbered (but capable of growing trees) site, we felt 200#/ac would be a good break between the "A" and "B" densities for this site. Using the Taylor Woods data for 1967 (Ronco, et.al, 1985) to derive SDI by basal area, a connection was made to forage production by SDI. A basal area of 40 correlates with about 200#/ac of forage production. Basal area 40 areas in the Taylor Woods data had an average dbh of 6.8" and 159 trees per acre in 1967. SDI for 200#/ac is therefore calculated as 86 or 19.1% of SDI Max. For simplicity sake, the "A/B" threshold is set at SDI 90, or 20% of SDI Max.

This seems consistent with SDI theory since trees are thought to begin competing for space (and crowns begin to lift even in young trees) at 25% of SDI Max.

Setting the "B/C" Threshold

In theory, a site is fully occupied at or above 35% of the maximum SDI for a species. Adding another tree to the site results in a corresponding and proportional loss of growth from the rest of the trees on the site. Foliar biomass is also near its maximum at this point. Adding another tree to the site results in a corresponding and proportional loss of live crown from the rest of the trees on the site. Since the MRNG sets the objective of growing as many very large trees as possible for a site (at least in the PFA) while also seeking to have a lot of canopy density in the medium to large trees, it is reasonable to manage these groups near an SDI of 35%.

For ponderosa pine sites, we found a CD of 60 corresponded with an SDI of about 158, which is close to 35% of the maximum SDI of 450[1] for ponderosa pine. This indicates it is probably unreasonable to expect canopy densities much higher than 60% over the extent of any group of large ponderosa pine, when the area occupied by its roots is included. Therefore, we have set the "C" density of our vegetative structural stage (VSS) classifier as SDI 35%+. A point or a site with at least an SDI of 35% of the dominant species' maximum will be considered to be in the "C" density.

End Notes

[1] Work done by Edminster (1988) sets an average maximum density for ponderosa pine sites at 407. However, this maximum was calculated differently than done by Reineke and others. Edminster plotted an average maximum density line through the top 2 percent of observations from Regions 2 and 3. Others plot an SDI maximum line which includes virtually all observations rather than just the top 99%. Indeed, the densest site in Edminster's data set is 492; any difference between the two methods may have nothing to do with the "actual" SDI maximum.

[1] We calculated VSS by point using the following steps from stand exam data:

a. Determine the forest type for the point.

b. Break out all trees on each point into the 6 diameter classes in the MRNG (for commercial forest types).

c. Calculate the number of trees per acre and basal area represented by each sample tree for each of the six classes. (See formulae in endnote 2.)

d. Calculate SDI for each class. The class with the highest SDI is the VSS size class.

e. Sum the SDI for all classes and divide by the maximum for the forest type. If the ratio is < 0.2, the density class is "A". If the ratio is 0.2 to 0.35, the density class is "B". If the ratio is >= 0.35, the density class is "C". (It is not entirely correct mathematically to add SDIs across size classes in this manner. This yields somewhat lower densities than their true values. However, this is also the method used by the Regional Office program.)

f. Determine if any one size class is >= 60% of the total SDI for the point. If so, the point is single-storied ("SS"). Otherwise, it is multi-storied ("MS").

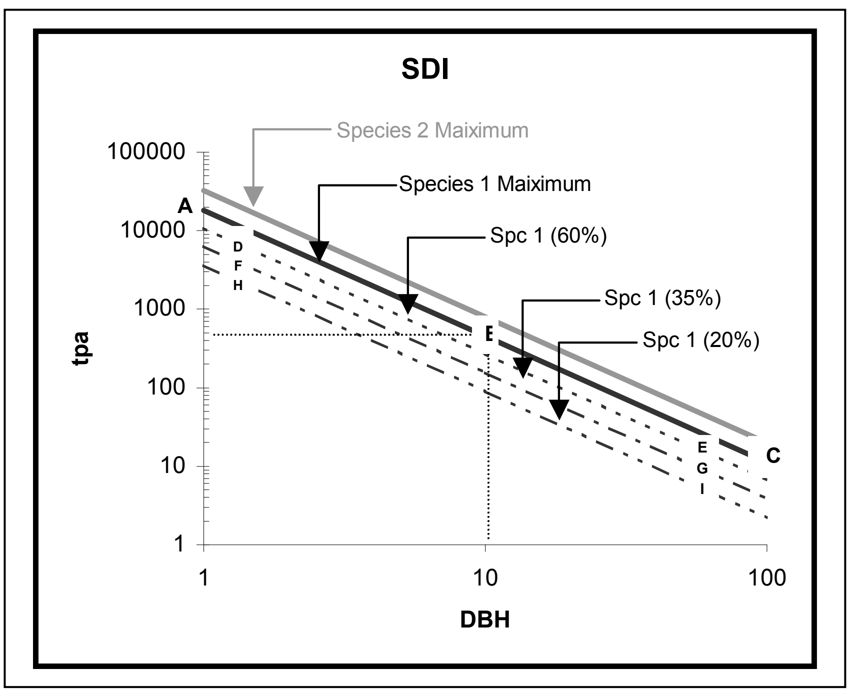
[2] There are two basic tools we have in density management to meet objectives, be they primarily for certain types of wildlife habitat, fiber production economics or visual quality. They are:

a. Size-density relationships (and indices derived from them, such as SDI; and

b. Growth-growing stock relationships.

Size-density relationships using SDI

SDI "has the potential of being a most useful tool when intensive stand management requires a refined method for regulating stand density to fit prescribed goals." (Principles of Silviculture, Daniel, Helms & Baker. 1979 pg.262)



The principle of SDI comes from a discovery by Reineke that a single-species, fully stocked (self-thinning), even-aged stand of a given average stand diameter (Dq) has about the same number of trees per acre (tpa) as any other stand with the same four conditions. Reineke found this relationship to be independent of site quality or age over a wide range.

By observing several stands that were self-thinning (e.g. growing at their maximum biological density) across a range of average stand diameters, a curve of maximum number of tpa by diameter class was obtained for a given species. (When plotted on log-log paper, this curve becomes a straight line.) After plotting maximum lines for several species, Reineke found most of these lines had the same slope, although the y-intercept was different for most species. Since these maximum lines have the same slope (-1.605 for a plot of tpa over Dq), their location on a graph can be defined by the location of only one point on the graph. In a plot of tpa over Dq, this defining point is where the maximum line is intercepted by a projection from 10" average stand diameter (Point B).

A projection to the tpa axis from the point where the previous two lines meet is the maximum number of tpa any single-species, even-aged, fully stocked site is biologically capable of growing for the species in question when Dq is 10" dbh. A line plotted through this maximum number of tpa where Dq is 10" dbh (Line segment A-C) is the reference curve for the species. Lines parallel to this line can be plotted which represent the same level of site occupancy all along the line (Line segments D-E, F-G and H-I) and thus can be converted into an equivalent density where Dq is 10". "Thus Reineke's stand-density index (SDI) is the number of trees [per acre] at a [Dq] of 10 in." (Daniel, et al.)

Several formulas are useful in understanding how SDI relates to frequently used measures of absolute density:

for a group or site:

$$SDI = (Dq/10)^{1.605} * tpa$$

$$Dq = \sqrt{BA / (tpa * 0.005454)}$$

or

$$tpa = BA / (Dq^2 * 0.005454)$$

for an individual tree:

$$tpa = BAF / (dbh^2 * 0.005454)$$

Where:
Dq = quadratic mean diameter
dbh = tree diameter at breast height
BAF = basal area factor for the sample
tpa = trees per acre

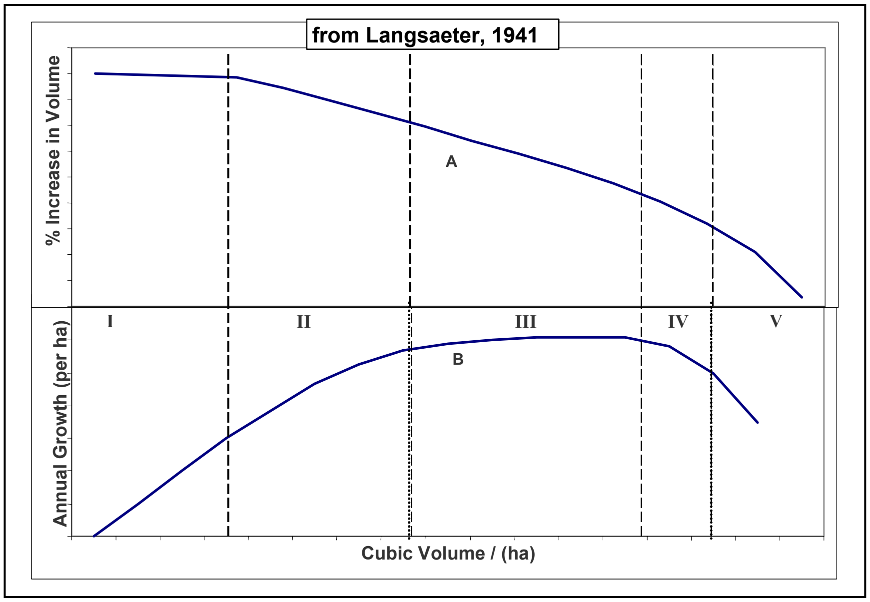
While SDI was developed from even-aged conditions, there is some empirical evidence it applies to other stand structures as well. Deiter (1990) found SDI to have virtually the highest correlation of any measure of density to forage production on the North Kaibab RD. We believe it is quite useful in describing stocking conditions for even-aged groups in uneven-aged sites also, which is the preferred method of management under the MRNG. Also, other papers have been published suggesting the use of SDI for density control in uneven-aged management. (Long & Daniel, 1990; Cochran, 1992)

Growth-growing stock relationships

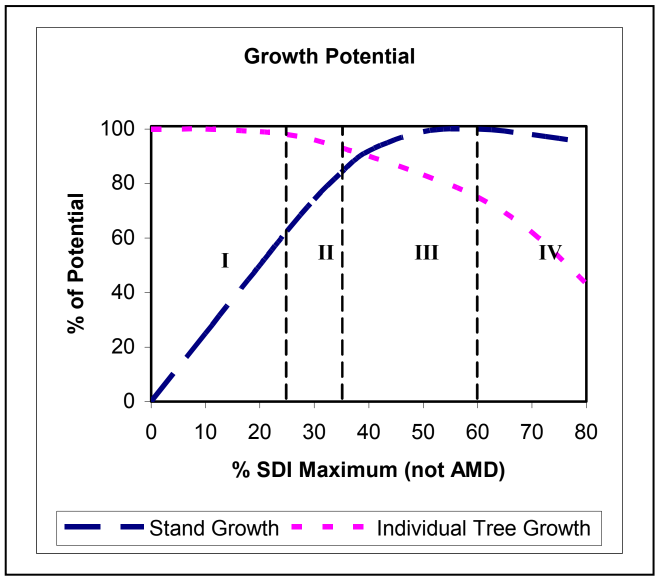
Langsaeter's hypothesis (1941) states, "The total production of cubic volume by a stand of given age and composition on a given site is, for all practical purposes, constant and optimum for a wide range of density and stocking. It can be decreased, but not increased, by altering the amount of growing stock to levels outside this range."

This range is referred to as zone III. "Below" this are zone I, where there is a one-for-one increase in site growth for every increase in stand volume and zone II where this effect attenuates as zone III is approached. "Above" zone III is zone IV where density-related mortality (self-thinning) occurs. Since there is a time lag between the time a tree dies and the time its neighbors occupy the available growing space, the site is growing at a rate below its potential. Zone V is the condition where the site is so over-stocked that individual trees are unable to fully reoccupy the site after neighbors die and the site remains below potential until regeneration takes up the available space.

In zone I, individual trees are growing at their biological potential, with no competition from their neighbors. Trees have full crowns, although some lifting will occur as they age except in very open sites. In zone II, competition is occurring but the addition of a tree to the site is not fully offset by the decrease in growth of its neighbors. Crowns have begun to lift but total foliar biomass is still increasing with additions of trees to the site. In zone III, the diminishing return has been reached; for each tree added to the site, there is a corresponding decrease in the growth of its neighbors. Foliar biomass is also constant; there is a proportional loss in individual tree crown lengths to balance the increase in number of live crowns with each tree added to the site. In zones IV and V, trees are in a weakened state and are much more susceptible to many insect and disease problems than they would be in other zones.



Putting these two density management tools together and evaluating data from some real plots for various species, the approximate breaks between the Langsaeter zones can be expressed in terms of SDI percents of the maximum SDI. The boundary between Zones I and II is about 25% of the SDI maximum for a species. The boundary between zones II and III is about 35% of maximum SDI. For the zone III/IV break, it is about 60% of maximum SDI.



Thus, if producing the largest individual trees possible is desired, management should retain sites in zone I. If producing the largest trees possible without giving up any foliar biomass is the goal, management should range near the break between zones II and III. If there is a dire need of immediate hiding cover in a grassy understory habitat type, consider leaving the target areas in the upper part of zone III.

Several publications using SDI to evaluate and manage wildlife habitat have come out in the past few years. See "Evaluating Elk Hiding and Thermal Cover Guidelines in the Context of Lodgepole Pine Stand Density" (Smith & Long, 1987) and "Stand Density Index and Its Application in Describing Wildlife Habitat" (McTague & Patton, 1989).

There is a good discussion of Reineke's SDI and work by Langsaeter in "Principles of Silviculture", by Daniel, Helms and Baker. Most silviculturists have a copy of this text.

RESIDUAL (Minimum) DESIRED FUTURE CONDITION

Note: These tables have been modified a number of times since the original version in 1992, allowing for movement of % in each VSS over time, increasing residual BA of large trees as a result of leaving 3-5 reserve trees over groups converted to VSS 2-4 in addition to those already left over VSS 1, and, expanding to include other cover types. These are for sites with a site index >= 55.

Ponderosa Pine - Post-fledging Family Area

			Group basis			Site basis	
DBH Class	**Mean DBH**	**% of Area**	**SDI**	**Mean tpa**	**BA/Ac**	**Mean tpa**	**BA/Ac**
	< 1”	12	0	512	0	61	0
1 - 4.9"	3.0"	10	60	414	20	41	2
5 - 11.9"	8.5"	20	120	156	61	31	12
12 - 17.9"	15.0"	20	150	78	96	15.6	19
18 - 23.9"	21.0"	20	165	50	121	11.2[1]	27
24" +	27.0"	18	172	35	140	7.5[2]	30
Leave 4 tpa >18" when regenerating and removing overstory. This will occur where groups are to be managed currently as VSS 1 through VSS 4. .						167	90
						Dq[3]: 12.4"	
						SDI[3]: 152	
						Site VSS: 5-6/B-C/MS	

Ponderosa Pine - Foraging Area

			Group basis			Site basis	
DBH Class	**Mean DBH**	**% of Area**	**SDI**	**Mean tpa**	**BA/Ac**	**Mean tpa**	**BA/Ac**
< 1.1	0.1"	12	0	512	0	61	0
1 - 4.9"	3.0"	10	44	304	15	30	1
5 - 11.9"	8.5"	20	77	100	40	20	8
12 - 17.9"	15.0"	20	96	50	61	10.0	12
18 - 23.9"	21-0"	20	115	35	84	8.2[1]	20
24" +	27-0"	18	123	25	99	5.7[2]	23
Leave 4 tpa >18" when regenerating and removing overstory. This will occur where groups are to be managed currently as VSS 1 through VSS 4.						136	64
						Dq[3]: 12.6"	
						SDI[3]: 107	
						Site VSS: 5-6/A-B/MS	

[1] Includes residual trees in groups of VSS 1-4 averaging 1.2 tpa on a site basis (stand average).
[2] Includes residual trees in groups of VSS 1-4 averaging 1.2 tpa on a site basis (stand average).
[3] Calculation of Dq and SDI does not include trees < 1" dbh.

Mixed Conifer - Post-fledging Family Area

			Group basis			Site basis	
DBH Class	**Mean DBH**	**% of Area**	**SDI**	**Mean tpa**	**BA/Ac**	**Mean tpa**	**BA/Ac**
	< 1"	12	0	594	0	71	0
1 - 4.9"	3.0"	10	70	481	24	48	2
5 - 11.9"	8.5"	20	139	181	71	36	14
12 - 17.9"	15.0"	20	174	91	111	18.2	22
18 - 23.9"	21.0"	20	191	58	140	13.5[1]	33
24" +	27.0"	18	200	41	161	9.2[2]	37
Leave 6 tpa >18" when regenerating and removing overstory. This will occur where groups are to be managed currently as VSS 1 through VSS 4. .						196	108
						Dq[3]: 12.6"	
						SDI[3]: 181	
						Site VSS: 5-6/B-C/MS	

Mixed Conifer - Foraging Area

			Group basis			Site basis	
DBH Class	**Mean DBH**	**% of Area**	**SDI**	**Mean tpa**	**BA/Ac**	**Mean tpa**	**BA/Ac**
	< 1"	12	0	594	0	71	0
1 - 4.9"	3.0"	10	51	352	17	35	2
5 - 11.9"	8.5"	20	90	116	46	23	9
12 - 17.9"	15.0"	20	111	58	71	11.6	14
18 - 23.9"	21.0"	20	133	41	98	10.0	24
24" +	27.0"	18	143	29	115	7.1[2]	28
Leave 6 tpa >18" when regenerating and removing overstory. This will occur where groups are to be managed currently as VSS 1 through VSS 4. .						158	78
						Dq[3]: 12.6"	
						SDI[3]: 181	
						Site VSS: 5-6/A-B/MS	

[1] Includes residual trees in groups of VSS 1-4 averaging 1.2 tpa on a site basis (stand average).
[2] Includes residual trees in groups of VSS 1-4 averaging 1.2 tpa on a site basis (stand average).
[3] Calculation of Dq and SDI does not include trees < 1" dbh.

Spruce-fir - Post-fledging Family Area

			Group basis			Site basis	
DBH Class	**Mean DBH**	**% of Area**	**SDI**	**Mean tpa**	**BA/Ac**	**Mean tpa**	**BA/Ac**
	< 1”	12	0	762	0	91	0
1 - 4.9"	3.0"	10	89	617	30	62	3
5 - 11.9"	8.5"	20	179	232	91	43	18
12 - 17.9"	15.0"	20	223	117	143	23.3	29
18 - 23.9"	21.0"	20	246	75	180	16.8[1]	40
24" +	27.0"	18	256	52	207	11.3[2]	45
Leave 6 tpa >18" when regenerating and removing overstory. This will occur where groups are to be managed currently as VSS 1 through VSS 4. .						251	135
						Dq[3]: 12.5"	
						SDI[3]: 227	
						Site VSS: 5-6/B-C/MS	

Spruce-fir - Foraging Area

			Group basis			Site basis	
DBH Class	**Mean DBH**	**% of Area**	**SDI**	**Mean tpa**	**BA/Ac**	**Mean Tpa**	**BA/Ac**
	< 1”	12	0	762	0	91	0
1 - 4.9"	3.0"	10	66	452	22	45	2
5 - 11.9"	8.5"	20	115	149	59	30	12
12 - 17.9"	15.0"	20	143	75	91	14.9	18
18 - 23.9"	21.0"	20	171	52	125	12.3	30
24" +	27.0"	18	183	37	148	8.6[2]	34
Leave 6 tpa >18" when regenerating and removing overstory. This will occur where groups are to be managed currently as VSS 1 through VSS 4. .						202	96
						Dq[3]: 12.6"	
						SDI[3]: 161	
						Site VSS: 5-6/A-B/MS	

[1] Includes residual trees in groups of VSS 1-4 averaging 1.2 tpa on a site basis (stand average).
[2] Includes residual trees in groups of VSS 1-4 averaging 1.2 tpa on a site basis (stand average).
[3] Calculation of Dq and SDI does not include trees < 1" dbh.

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