Preliminary Thinning Guidelines Using Stand Density Index for the Maintenance of Uneven-aged Pinyon-Juniper Ecosystems

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Abstract*—This paper demonstrates how Stand Density Index may be used to guide post-thinning stand structure for the sustainable management of pinyon-juniper ecosystems. The post-thinning residual stand density can be varied to achieve various management objectives. Uneven-aged management is recommended, where possible, as a better approximation of the natural development process of pinyon-juniper stands.*

Introduction

Pinyon-juniper ecosystems cover expansive landscapes in the Western United States. As landscapes are developed, management of these systems is becoming increasingly important for various reasons, including wildland interface fire/fuels, visuals, wildlife habitat, wood products, and pine nuts. Where once most management of these ecosystems focused on removal of trees to favor herbaceous species, land managers today are giving greater consideration to the management of sustainable ecosystems.

Various valid guidelines have been used for thinning pinyon-juniper stands including single-tree selection, thin-from-below, and diameter limit prescriptions. Perhaps the most common has been the specification of a diameter limit, above which trees are to be left uncut. While diameter limit prescriptions can yield acceptable results, done without sufficient pre-treatment stand exam data, diameter limit prescriptions can yield undesirable results. Among these are conversion of a mixed stand into one dominated by a single species or retention of only the older portion of a population that, to be considered healthy and sustainable, should contain young, mid-aged, and old.

The following are preliminary thinning guidelines for forest health based upon research, standard principles of forest ecology, and the ecology of pinyon-juniper ecosystems.

Stand Density Index—Theory and Basics

Stand Density Index (SDI) (Reineke 1933) is an index of competitive interaction. The maximum SDI varies for each tree species and is measured at a given reference diameter. At 25% of maximum SDI, trees begin competing with each other and begin to out-compete understory species (Long 1985). At 35% of maximum SDI, trees fully occupy the site. At higher densities, competition between trees either results in reduced growth and vigor on individual trees or may result in competitive stress and tree mortality, perhaps due in part to secondary agents such as insects that are attracted to stressed trees.

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The maximum SDIs for pinyon and juniper are still being studied,[2] and current literature should be consulted to determine if the numbers presented here should be modified prior to implementing a thinning strategy. SDIs have been developed for Rocky Mountain juniper (*Juniperus scopulorum*) and common pinyon (*Pinus edulis*), but not to date for Utah juniper (*Juniperus osteosperma*) or singleleaf pinyon (*Pinus monophylla*). Research by Schuler and Smith (1988) suggests that the maximum SDI for mixed pinyon-juniper stands is higher than for single-species stands of either species. Speculation is that this may be, in part, a factor of differing rooting depths of the two species. The Central Rockies and Utah variants of the Forest Vegetation Simulator currently use 415 as the maximum SDI values for pinyon and juniper species (Van Dyck 2006). For the purposes of this paper, maximum SDI of 415 for mixed stands was selected. It is recommended that when faced with a choice of differing maximum SDIs, the lower SDI should be selected as the more conservative approach.[3]

SDI can be used as a guideline to develop desired residual stand structure goals. Residual SDI targets may be varied to help achieve various resources objectives. Higher residual SDIs will retain more dense trees, and lower SDIs may be appropriate for projects where more open conditions are desired, such as hazardous fuels reduction projects.

It is my recommendation that thinning leave no more than 25% of maximum SDI after treatment. This will maintain the site in tree cover (providing aerial cover and root mass to protect soils), but still open the canopy sufficiently to allow understory species to increase or become established in the canopy gaps between trees. It will also allow for a reasonable interval of time before retreatment will become necessary to maintain desired densities. The length of time between treatments will vary by site, and might best be estimated using a stand growth simulator program such as the Forest Vegetation Simulator. A residual stand density index of 5% of maximum SDI will leave very open, savanna like conditions. For management goals that are to retain a "woodland" component, it is suggested that residual stand density targets be between 5% and 25% of maximum SDI. When initiating a thinning program, it may be desirable to try several different residual densities, and to monitor the initial treatments over a several year period to determine which residual density seems the best fit for a given site and set of management objectives.

Developing Thinning Guides—Planning

The desired after treatment species mix will be determined by what is available on the pre-treatment site and by management objectives. Managers will want to keep in mind that juniper species tend to regenerate faster than pinyons, and where high proportions of juniper-to-pinyon are retained, this may lead to the need to retreat units earlier to maintain the proper size class mix.

The example below (table 1) illustrates an uneven-aged system. To manintain multiple size classes, the target stand SDI (in this example, 25% of 415, or 105) should be apportioned among size classes. Here, SDI = 26 is allocated to each of 4 diameter classes.

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[2]Sources for information on SDI for pinyon and juniper include: Schuler and Smith, 1988; Shaw, 2004; and the USDA-Forest Service Forest Vegetation Simulator (FVS). The current version of FVS lists the maximum SDI's for pure pinyon or pure juniper as 360 and the maximum for mixed stands as 415.

[3]Personal communication, Dr. James N. Long, Utah State University.

Table 1—Target After-Treatment Stand (at 25% of max SDI)[a].

Size Class (in)[b]	SDI	TPA	BA[c]	Spacing[d]
Regen (<3”)	26	178	8.8	8
Small (3-6”)	26	59	11.6	14
Mid (6-9”)	26	31	13.6	19
Large (>9”)	26	15	16.2	27
Total	*104*		*50.2*	—

[a] Numbers calculated on larger trees in each size class: 3”, 6”, 9”, and 14” DRC, respectively.
[b] Diameter class breaks will be specific to a given site, and it is desirable to use stand examination data to help set these breaks.
[c] Basal area is depicted here for comparative purposes.
[d] It should be noted that the “spacing” column represents space between trees of the same size class. To obtain approximate spacing between trees of different size classes, divide the figure for each size class by two then add these figures together.

Relatively simple mathematical equations may be used to compute the number of residual trees and spacing for any given SDI and size class by manipulating the basic SDI formula: $SDI = N (D/10)^{1.6}$, where N = number of trees and D = diameter root collar. The desired number of residual trees then becomes: $N = SDI/(D/10)^{1.6}$. Spacing is a function of the number of size classes and the number of trees per acre by size class: $S = \sqrt{(43560/C/N)}$, where S is the spacing of trees in diameter class in feet, C is the number of diameter classes, and N is the desired number of trees in diameter class, based on SDI allocation.

It might be noted, that to be scientifically accurate, calculations should be done on mid-point diameters, and where woody biomass growth is to be maximized for high value crops, this would be the more appropriate than that presented above. I, however, have chosen to use the largest tree in each size class for the following reasons:

- The smallest size class really does not need to retain more than its upper-end diameter number as there will be advance regeneration and seedling recruitment to more than compensate. Thinning down to the lower number is consistent with pre-commercial thinning philosophy.
- The middle size class(es) may come up somewhat deficit in numbers of trees per acre, depending upon the diameter distribution of acceptable leave trees. However, thinning crews tend to focus on size, and crews have a tendency to cut too few rather than too many trees.
- The largest size class may have more large trees (or at least more SDI) than targeted as there will likely be trees larger than that used to calculate the desired residual number, and larger trees ideally would have even wider spacing than that listed in the table.

Developing Thinning Guides—Implementation

For practical contract application, size classes may be rather broad, with perhaps no more than three to four classes (or implementation may get too complex to be practical). The example in table 2 uses 15% of maximum SDI and three broad size classes. Spacing guides are more important to follow than are the target trees per acre, as not every acre will contain the correct mix of trees to obtain the ideal number of trees. Target SDIs do not need to be in the contract table: SDIs are calculated for planning purposes and are not a field implementable guideline.

Table 2—Contract: Target After-Treatment Stand (at 15% of max SDI).

Diameter Root Collar [a]	TPA	Spacing (clearing radius)
<8”	30	22’ (11’ radius)
8-16”	10	38’ (19’ radius)
>16”	7	46’ (23’ radius)

[a] Numbers calculated on larger trees in each size class: 8”, 16”, and 20” DRC, respectively.

Some will find illustrations easier to understand than tables, thus graphics similar to figure 1 may be an appropriate addition to a contract. Photographs of previous treatments that successfully achieved management goals may also be an aid to contractors.

In additional to spacing guidance, tree selection guidelines similar to those below should be provided.

Trees to be left after thinning should have the following characteristics:

- Pinyon pine are favored over juniper; however, healthy juniper may be retained where there are no suitable pinyon pine.
- Full-crowned trees are preferred over trees with sparse crowns.
- Trees with healthy crowns and free of disease and damage/deformity are preferred over sparse-crowned, diseased, damaged, or deformed trees.

To begin, select a good quality leave tree. Based upon its diameter class, clear other trees around this tree equal to the radial spacing value in the table 2. From the edge of the cleared area, find another quality leave tree that is approximately its radial diameter-spacing from the cleared area and repeat step one around this tree, again clearing the radial spacing guide around this tree based on its size. Vary the size of leave trees when possible based upon the target number of trees to be left and the quality of the on-site trees from which to select. When thinning is complete, the desired condition will be variably spaced trees (based upon the size of the remaining trees) and variably sized trees with only a few large trees, a few more medium sized trees, and most trees in the smallest diameter class.

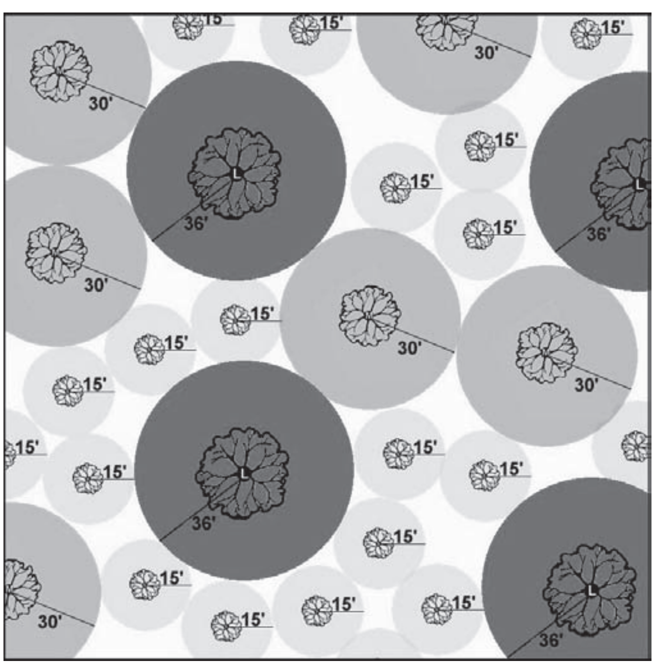

Figure 1—Shaded circles represent the clearing around three size classes of leave trees.

Additional Considerations

Should pinyon *Ips* beetles be a consideration, it may be appropriate to manage for more open canopied stands. Based on research by Negron and Wilson (2003), residual SDIs greater than 5.6% of maximum (where pinyon pine dominates) may leave stands that remain susceptible to attack by the beetle, particularly when high levels of beetle activity are present in the general area. Negron and Wilson studied unmanaged, post-epidemic residual stands and recorded post-epidemic densities at approximately 5.6% of maximum SDI. *Ips* beetles prefer trees with somewhat reduced crown ratios. Pinyon leave trees should be those with the higher percentage of crown-to-height ratio. *Ips* beetles prefer larger diameter pinyon trees, thus it may be desirable to remove most older/larger pinyon trees that show signs of declining vigor. Stand susceptibility to *Ips* may also be influenced by stand composition, and those stands with a higher percentage of pinyon-to-juniper tend to be more susceptible to *Ips*-caused mortality. Thus it is thought to be desirable to maintain a good mix of species.

Timing of implementation and treatment of pinyon slash can be critical factors when *Ips* beetles are present in the general area. Green pinyon slash can serve as an attractant to beetles. Beetles can colonize slash during the spring and summer months and maturing beetles can emerge from this slash seeking new hosts, which will tend to be the nearest available suitable pinyon trees. Even chipped pinyon debris can attract beetles during the beetles' flight periods (*Ips* cannot colonize chips but may attack nearby pinyon trees). If chips or slash are to be left on the site, then treatment is best done in late fall, allowing the winter months for material to dry and become less attractive to beetles. Even then efforts should be made to increase drying rates on any remaining larger green pinyon material. Scattering pieces in sunny locations and damaging the bark to expose the phloem will help dry the phloem layer so it is no longer provides good habitat for bark beetles. If green pinyon material greater than 3" in diameter can be removed from the site within four to six weeks of cutting, then operations may be done at any time without risking increasing the incidence of *Ips* beetles. If neither can be done, then maintaining a "green chain" of freshly cut material throughout the active beetle season will help insure that emerging beetles will attack the fresh cut material and not the standing leave trees.[4] If none of the above can be practically accomplished, then mitigation for increased beetle activity may be either to leave more juniper and fewer pinyon or to leave more trees than the target residual stand, realizing that many of these trees may be subsequently killed by *Ips* beetles. If retention of pinyon trees on the site is of prime concern and *Ips* populations are high in the drainage where the treatment is to take place, it may be best to delay thinning pinyon stands until *Ips* populations subside.

Debris from cut trees may be scattered in created openings to enhance soil protection and provide for microsite protection for establishing vegetation. However, use of green pinyon pine material >3" in diameter should be limited, as noted above.

It may be desirable to vary the spacing (density) within stands through a project area to achieve a mosaic of within-stand conditions, i.e. thin one area to 5% of maximum SDI and another to 25%. This technique is being used to reduce fuels along power line corridors in southern Utah: residual stand densities become progressively lower as one nears the power line.

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[4] Personal communication, Steve Munson, entomologist, USDA-Forest Service, Forest Health Protection, Ogden, Utah.

For wildlife habitat, groups of trees with interlocking crowns may be left interspersed with thinned trees. All trees in the group should have at least one side of the tree free from competition. Use either the largest tree in the group or the largest diameter class for the project as the spacing guide between the group and adjacent trees.

Effectiveness monitoring of the treatment areas will need to be done for a period of years following treatment to help refine future thinning prescriptions. A minimum of five years is suggested. Items to be monitored should be consistent with the project objectives and may include the response of understory species and the comparative incidence of post-treatment *Ips* beetle in treated and untreated areas. Pine nut production and tree vigor, as compared to nearby untreated areas, may also be monitored. These items should be monitored as they relate to residual stand densities and species composition.

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References

Long, J.N. 1985. A practical approach to density management. Forestry Chronicle 61:23-27.

Long, J.N. 2005. Personal communication. Utah State University.

Negron, Jose F., and Jill L. Wilson. 2003. Attributes associated with probability of infestation by the piñon *Ips*, *Ips confusus* (Coleoptera: Scolytidae), in piñon pine, *Pinus edulis*. Western North American Naturalist 63(4): 440-451.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Research 46:627-638.

Schuler, Thomas M., and Frederick W. Smith. 1988. Effect of species mix on size/density and leaf-area relations in southwest pinyon/juniper woodlands. Forest Ecology and Management 25(3,4): 211-220.

Shaw, John D. 2004. Personal communication. USDA-Forest Service, Forest Inventory and Analysis, Ogden, Utah.

Van Dyck, Michael G. 2006. Keyword Reference Guide for the Forest Vegetation Simulator. USDA Forest Service. Forest Management Service Center. 131 p. [Available online at: http://www.fs.fed.us/fmsc/fvs/documents/gtrs.php]

Appendix: Thinning Tables

The following tables may be used to determine the proper spacing between trees of various size classes for selected stand density indices. Guides are applicable to even-aged stands using average or quadratic mead diameter of the stand or they may be applied to uneven-aged stands, using the average or upper diameter limit in each size class. For a contract, numbers should be rounded to whole numbers.

Tables A1–A4 Spacing Guides for Pure Pinyon or Pure Juniper Stands.

(Maximum SDI for pure stands of either species is 360.)

Table A1. 35% of maximum SDI = Site fully occupied by trees leaving limited resources for understory species. Trees are competing with each other.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
126	6	285	56.0	12.4	6.2
126	8	180	62.9	15.6	7.8
126	10	126	68.7	18.6	9.3
126	12	94	73.9	21.5	10.8
126	14	74	78.6	24.3	12.2
126	16	59	82.9	27.1	13.5
126	18	49	86.9	29.8	14.9
126	20	42	90.7	32.4	16.2
126	22	36	94.2	34.9	17.5

Table A2. 25% of maximum SDI = Trees on site begin to compete with each other; space is available for understory species to maintain themselves.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
90	6	204	40.0	14.6	7.3
90	8	129	44.9	18.4	9.2
90	10	90	49.1	22.0	11.0
90	12	67	52.8	25.5	12.7
90	14	53	56.2	28.8	14.4
90	16	42	59.2	32.0	16.0
90	18	35	62.1	35.2	17.6
90	20	30	64.8	38.3	19.2
90	22	25	67.3	41.3	20.7

Table A3. 15% of maximum SDI = Trees do not generally compete with each other. A substantial amount of site resources is available for understory species.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
54	6	122	24.0	18.9	9.4
54	8	77	26.9	23.8	11.9
54	10	54	29.5	28.4	14.2
54	12	40	31.7	32.9	16.4
54	14	32	33.7	37.2	18.6
54	16	25	35.5	41.4	20.7
54	18	21	37.3	45.5	22.7
54	20	18	38.9	49.5	24.7
54	22	15	40.4	53.4	26.7

Table A4. 5% of maximum SDI = Savanna conditions where non-tree species dominate the site.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
18	6	41	8.0	32.7	16.3
18	8	26	9.0	41.2	20.6
18	10	18	9.8	49.2	24.6
18	12	13	10.6	56.9	28.5
18	14	11	11.2	64.4	32.2
18	16	8	11.8	71.6	35.8
18	18	7	12.4	78.7	39.4
18	20	6	13.0	85.7	42.8
18	22	5	13.5	92.4	46.2

Tables B1–B4 Spacing Guides For Mixed Pinyon-Juniper Stands.

(Maximum SDI for mixed stands is 415.)

Table B1. 35% of maximum SDI = Site fully occupied by trees leaving limited resources for understory species. Trees are competing with each other.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
145	6	328	64.5	11.5	5.8
145	8	207	72.3	14.5	7.2
145	10	145	79.1	17.3	8.7
145	12	108	85.1	20.1	10.0
145	14	85	90.5	22.7	11.3
145	16	68	95.4	25.2	12.6
145	18	57	100.0	27.7	13.9
145	20	48	104.4	30.2	15.1
145	22	41	108.4	32.6	16.3

Table B2. 25% of maximum SDI = Trees on site begin to compete with each other; space is available for understory species to maintain themselves.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
104	6	236	46.2	13.6	6.8
104	8	149	51.9	17.1	8.6
104	10	104	56.7	20.5	10.2
104	12	78	61.0	23.7	11.8
104	14	61	64.9	26.8	13.4
104	16	49	68.5	29.8	14.9
104	18	41	71.8	32.8	16.4
104	20	34	74.8	35.6	17.8
104	22	29	77.8	38.5	19.2

Table B3. 15% of maximum SDI = Trees do not generally compete with each other. A substantial amount of site resources is available for understory species.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
62	6	140	27.6	17.6	8.8
62	8	89	30.9	22.2	11.1
62	10	62	33.8	26.5	13.3
62	12	46	36.4	30.7	15.3
62	14	36	38.7	34.7	17.3
62	16	29	40.8	38.6	19.3
62	18	24	42.8	42.4	21.2
62	20	20	44.6	46.2	23.1
62	22	18	46.4	49.8	24.9

Table B4. 5% of maximum SDI = Savanna conditions where non-tree species dominate the site.

SDI	D	TPA	BA	Spacing Between Trees of Same Size	Clearing Radius
21	6	48	9.3	30.3	15.1
21	8	30	10.5	38.1	19.0
21	10	21	11.5	45.5	22.8
21	12	16	12.3	52.7	26.3
21	14	12	13.1	59.6	29.8
21	16	10	13.8	66.3	33.2
21	18	8	14.5	72.9	36.4
21	20	7	15.1	79.3	39.6
21	22	6	15.7	85.6	42.8