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INFLUENCE OF SITE QUALITY AND STAND DENSITY ON GOSHAWK HABITAT IN SOUTHWESTERN FORESTS

RICHARD L. BASSETT, DOUGLAS A. BOYCE, JR., M. HILDEGARD REISER
RUSSELL T. GRAHAM, AND RICHARD T. REYNOLDS

Abstract. Current management guidelines for the Northern Goshawk (Accipiter gentilis) in the Southwest call for a mosaic habitat consisting of approximately 10 percent of the forest area in grass-forb/shrubs, 10 percent in 2.5–12.7 cm trees, 20 percent in 12.7–30.5 cm trees, 20 percent in 30.5–45.7 cm trees, 20 percent in 45.7–61.0 cm trees, and 20 percent in 61.0 cm and greater trees. This habitat mosaic was conceived as convenient categories to describe a generally balanced, ecologically sustainable, forest ecosystem. In reality, however, the vegetative structural percentages vary. We describe how differences in site quality and stand density affect vegetative structural stage percentage and forest age.

Key Words: Accipiter gentilis; forest regulation; Northern goshawk; site quality; stand density, SDI; vegetative structural stages.

A goshawk scientific committee developed recommendations for managing the Northern Goshawk (Accipiter gentilis) in the southwestern United States (Reynolds et al. 1992). These recommendations focused on developing and maintaining forest conditions to provide habitat for sustaining goshawks and their key prey species. The recommendations defined size, location, stand structure, woody debris, and soil condition requirements for nest, post-fledging family, and foraging areas. Stand structure included such properties as the proportion and distribution of six different diameter classes or vegetative structural stages (VSS), and number of large (>46 cm) trees, snags, and down logs per ha.

Reynolds et al. (1992) recommended a mosaic of vegetative structural stages interspersed throughout the post-fledging family and foraging areas in small, less than 1.7 ha patches to form a balanced, ecologically sustainable, uneven-aged forest. Vegetative structural stage is a generalized description of forest structure and age based on the majority of trees in a specific diameter class within the forest (Table 1). The mosaic included patches ranging from grass-forb/shrub to old forests, with a high priority on sustaining as much as 40 percent of the area in mature and old forests. The recommended average proportion was about 10 percent of the goshawk management area (14,820 ha) in grass-forb/shrubs, 10 percent in 2.5–12.7 cm (1–5 in.) trees, 20 percent in 12.7–30.5 cm (5–12 in) trees, 20 percent in 30.5–45.7 cm (12–18 in) trees, 20 percent in 45.7–61.0 cm (18–24 in) trees, and 20 percent in 61.0 cm (24 in) and greater trees.

In this paper, we examine how differences in site quality and stand density influence VSS percentage and forest age. This paper also describes the impacts of varying VSS proportions within goshawk management areas to goshawk habitat and their key prey species.

FOREST DEVELOPMENT

Reynolds et al.'s (1992) recommended VSS and forest mosaic can be approached by traditional, even-aged area regulation. Area regulation consists of dividing the forested post-fledging family and foraging areas into as many ≤ 1.7 ha patches as there are years in the expected life of a forest (forest age) and regenerating an equal percentage of the forest each entry period (Smith 1986). The entry period could vary from 10 to 20 years depending upon existing forest conditions.

Three basic principles apply to area regulation. First, structural stages become important to sustain a forest over time, even where the desired condition is to have large, old trees. Second, new trees must be established at regular intervals to sustain the desired structural stages in a forest through time. Third, forests are dynamic. Trees regenerate and grow at different rates and die at different ages, resulting in a forest that is constantly changing over time (Oliver and Larson 1990).

Four variables that affect VSS distribution and forest age are: (1) length of stand establishment period, (2) site quality, (3) stand density, and (4) tree longevity.

STAND ESTABLISHMENT

Length of stand establishment varies by species, regeneration method (natural or planting), amount and kind of forest floor disturbance, and climatic variation. The observed stand establishment period (or years in VSS 1) for ponderosa pine (*Pinus ponderosa*) forests can range from 15 years on a highly productive site to 30 years on

TABLE 1. VEGETATIVE STRUCTURAL STAGES AND THEIR DIAMETERS

Vegetative structural stage	Forest description	Diameters[1] (cm)
1	Grass-forb/Shrub Opening	0–2.5
2	Seedling/Sapling	2.5–12.7
3	Young	12.7–30.5
4	Mid-aged	30.545.7
5	Mature	45.7–61.0
6	Old	>61.0+

[1] Tree diameter measured at 1.4 m above ground level.

a poor site. Generally, south- to west-facing, dryer slopes with shallow soils require the longest seedling establishment period; north-facing, more mesic sites with deeper soils require the least time. Under similar topographic and soil conditions, sites where annual precipitation is usually less require more time than when moisture is more plentiful.

SITE QUALITY

Site quality influences tree growth and varies greatly in the Southwest. Site quality denotes the relative productivity of a site for a particular tree species (Ford-Robertson 1971). Factors that influence site quality include soil characteristics, mineral composition, slope, aspect, microclimate, and tree species (Daniel et al. 1979). Site index is useful to help quantify site quality, and refers to the average height of dominant and codominant trees in a stand at an arbitrarily chosen age. Minor (1964) developed site index curves for ponderosa pine in northern Arizona, measuring age at 1.4 meters above ground level using a chosen base age of 100 years. For example, a site index of 70 (a tree 21.3 m [70 ft] tall at 100 years of age at 1.4 m above ground level) is considered about average for ponderosa pine in the Southwest. Thus, the length of time required for trees in each VSS is a function of site quality and stand density (Table 2).

A forest growth simulator model (Edminster et al. 1991) was used to project diameter growth per decade (Table 2) for two key stand densities: (1) Stand density index (SDI) 113 (25% of maximum SDI 450 for ponderosa pine); and (2) 157 SDI (35% of maximum SDI). The first level is considered to be the onset of competition between trees, whereas the second is the lower limit of full site occupancy (Long and Daniel 1990). Stand density index is the number of trees at an average stand density of 25.4 cm (10 in) (Daniel et al. 1979, Lilliholm et al., this volume).

During modeling, the growth of 500 ponderosa pine seedlings and 4 large reserve trees (trees > 46 cm dbh) were simulated over a 320-year period at SDIs of 113 and 157. Four reserve trees were allowed to die (snag creation) at stand age 30, and thereafter thinning from below, to the specified SDI, was allowed at 20-year intervals, starting at stand age 40 years.

Generally, seeding/sapling and young trees have a faster diameter growth rate than mature and old trees (Table 2). The time it took for a tree to move through one VSS ranged from 11 to 59 years for 25% maximum SDI, and from 11 to 95 years for 35% maximum SDI depending on the site quality and VSS. Also, it takes longer to grow through a stage on the low productivity sites than on high productivity sites; the exception was VSS 3 on average and high sites.

STAND DENSITY

Stand density influences tree diameter growth. On sites with the same site quality, tree diameter growth will vary with different management intensities. For example, the number of years in VSS 4, 5, and 6 are longer for the higher stand density (35% SDI) than for the lower stand density (25% SDI). The growth simulator model showed no differences in number of years for VSS 2. The seedling establishment period for low (30 years), average (20 years), and high (15 years) site quality was assumed to be equal for the two densities.

Stand density and site quality also influence VSS percentage and the time required to achieve the desired forest structure for goshawks and their prey species (Tables 3 and 4). One desired forest structure condition is to maintain 40% of the goshawk post-fledging family and foraging areas in VSS 5 and 6 to sustain moderate to high populations of key prey species. These older age classes maintain the most species at an abundant population level (10 of 12 species found in ponderosa pine forests: i.e., woodpeckers, chipmunks, tassel-eared squirrels) (Reynolds et al. 1992). Since forest stands reach VSS 5 and 6 from 30 to 70 years earlier in stands with lower density (25% SDI), the desired forest structure could be maintained for a longer period of time. Older-aged stands (>200 years) are also more frequently used as goshawk nest sites. Because nest sites have a higher density of large trees, these areas should be managed for even higher density stands (43% SDI).

Actual VSS percentage varies from the recommended 10-10-20-20-20-20 (Reynolds et al. 1992). For example, the VSS percentage for a low quality site with 25% SDI is 12-9-18-17-23-21 and for a high quality site with 25% SDI, VSS is 9-6-22-19-22-22 (Table 3).

TABLE 2. ESTIMATED DIAMETER GROWTH AND NUMBER OF YEARS IN EACH VEGETATIVE STRUCTURAL STAGE (VSS) FOR DIFFERENT QUALITY PONDEROSA PINE SITES AND STAND DENSITIES IN THE SOUTHWEST

Vegetative structural stages	Site quality[1]	Stand density[2]: Diameter growth per decade (cm), 25% Max SDI	Diameter growth per decade (cm), 35% Max SDI	Approximate years in each VSS, 25% Max SDI	Approximate years in each VSS, 35% Max SDI
1	Low	Seedling establishment period	Seedling establishment period	30	30
	Average			20	20
	High			15	15
2	Low	4.32	4.32	24	24
	Average	6.86	6.86	15	15
	High	9.40	9.40	11	11
3	Low	3.68	3.05	48	58
	Average	4.83	4.32	37	41
	High	4.75	4.24	37	42
4	Low	3.48	2.79	44	55
	Average	4.06	3.25	38	47
	High	4.83	3.63	32	42
5	Low	2.59	1.60	59	95
	Average	3.63	2.44	42	63
	High	3.99	2.97	38	51
6	Low	1.52	1.27	—[3]	—[3]
	Average	2.08	1.70		
	High	2.52	2.08		

[1] Site quality (Minor 1964). Low = 50 SI (SI = site index − dominant tree height at 100 years), Average = 70 SI, High = 90 SI.
[2] Stand density index (SDI) is the number of trees of average stand diameter of 25.4 cm. 25% max SDI = onset of competition; 35% max SDI = lower limit of full site occupancy.
[3] Years in VSS 6 depends on the selected forest age.

TREE LONGEVITY

Tree longevity influences forest life expectancy and forest age required to achieve desired forest structure. The lifespan of trees varies within and between species. For example, the oldest known living ponderosa pine tree in the Southwest was found to be 742 years old (Swetnam and Brown 1992), whereas the average life expectancy of most ponderosa pine is closer to 200 years or less (Pearson 1950, White 1985, Covington and Moore 1991). Life expectancy for Engelmann spruce (Picea *engelmannii*) ranges from 250–450 years (Alexander and Shepperd 1990). The life expectancy of the typical tree would be more appropriate to set targets for sustaining forests then the age of the oldest tree. Tree species and

TABLE 3. ESTIMATED DIAMETER GROWTH, YEARS IN VEGETATIVE STRUCTURAL STAGE, ACCUMULATED AGE, AND PERCENT OF LANDSCAPE IN EACH VSS FOR PONDEROSA PINE ON LOW, AVERAGE, AND HIGH QUALITY SITES WHERE STAND DENSITY IS 113 SDI (25% MAX SDI)[1]

Site quality		Vegetative structure stages: VSS 1	VSS 2	VSS 3	VSS 4	VSS 5	VSS 6[2]
Low (50 SI)	Diameter growth/decade	0	4.32	3.68	3.48	2.59	1.52
	Years (Acc-years)[3]	30 (30)	24 (54)	48 (102)	44 (146)	59 (205)	55 (260)
	% in VSS	12	9	18	17	23	21
Average (70 SI)	Diameter growth/decade	0	6.86	4.83	4.06	3.63	2.08
	Years (Acc-years)[3]	20 (20)	15 (35)	37 (72)	38 (110)	42 (152)	48 (200)
	% in VSS	10	8	18	19	21	24
High (90 SI)	Diameter growth/decade	0	9.40	4.75	4.83	3.99	2.52
	Years (Acc-years)[3]	15 (15)	11 (26)	37 (63)	32 (95)	38 (133)	37 (170)
	% in VSS	9	6	22	19	22	22

[1] Maximum stand density index for ponderosa pine is 450.
[2] Number of years in VSS 6 is determined by selecting a growth period that is approximately 20% of forest age.
[3] Number of years in VSS and accumulated years.

TABLE 4. ESTIMATED DIAMETER GROWTH, YEARS IN VEGETATIVE STRUCTURAL STAGE, ACCUMULATED AGE, AND PERCENT OF LANDSCAPE IN EACH VSS FOR PONDEROSA PINE ON LOW, AVERAGE, AND HIGH QUALITY SITES WHERE STAND DENSITY IS 157 SDI (35% MAX SDI)[1]

Site quality		Vegetative structural stages					
		VSS 1	VSS 2	VSS 3	VSS4	VSS 5	VSS 6[2]
Low (50 SI)	Diameter growth/decade	0	4.32	3.05	2.79	1.60	1.27
	Years (Acc-years)[3]	30 (30)	24 (54)	58 (112)	55 (167)	95 (262)	65 (327)
	% in VSS	9	7	18	17	29	20
Average (70 SI)	Diameter growth/decade	0	6.86	4.32	3.25	2.44	1.70
	Years (Am-years)"	20 (20)	15 (35)	41 (76)	47'(123)	63 (186)	44 (230)
	% in VSS	9	7	18	20	27	19
High (90 SI)	Diameter growth/decade	0	9.40	4.24	3.63	2.97	2.08
	Years (Acc-years)[3]	15 (15)	11 (26)	42 (68)	42 (110)	51 (161)	39 (200)
	% in VSS	7	6	21	21	25	20

[1] Maximum stand density index for ponderosa pine is 450.
[2] Number of years in VSS 6 is determined by selecting a growth period that is approximately 20% of forest age.
[3] Number of years in VSS and accumulated years.

longevity must be considered when considering an older forest age.

By decreasing or increasing forest age, VSS percentage is changed. For example, if the forest age on the low productive site was lowered from 327 to 250 years, the VSS percentage would change from 9-7-18-17-29-20 to 12-10-23-22-33-0 (Table 4). VSS 6 may not be achievable if a 327-year forest age is not ecologically sustainable. This should not influence goshawks, given the average life expectancy of ponderosa pine and that sites with low productivity (SI $\leq$ 50) account for only 2.3% (N = 4 national forests) of ponderosa pine stands in the Southwest (USDA 1993). Planning for forest ages less than 200 years, however, could negatively impact goshawks and their prey populations. Regardless of site quality or stand density index (25% or 35%), forests less than 200 years will not provide for the older classes (VSS 5 and 6) (Tables 3 and 4). Suitable goshawk nesting habitat is commonly composed of older trees (>200 years) in the VSS 5 and 6. Prey species like the Red-naped Sapsucker (*Sphyrapicus nuchalis*) and Williamson's Sapsucker (*Sphyrapicus thyroideus*) would lose 66% of the forest structure conditions that maintain high populations (Reynolds et al. 1992). Forests without VSS 5 and 6 would also not provide the large snags that are used by other nesting-cavity prey species.

SUSTAINING GOSHAWK HABITAT

Not all structural stages are equally important for the goshawk and its prey species, but all structural stages are equally important for a forest to become established and to sustain itself from the grass-forb/shrub stage (VSS 1) with seedlings through the old forest stage (VSS 6). The traditional area even-aged method of regulating a forest can be applied successfully to sustain a forest with the mosaic of VSS that will meet the habitat needs of the goshawk and its key prey species.

Of 12 goshawk prey species found in ponderosa pine forests, openings (VSS 1) are of no importance to 5 prey species (i.e., sapsuckers, tassel-eared squirrel), and important to 1 prey species (cottontail) for maintaining high populations. For only 1 prey species (tassel-eared squirrel) found in the ponderosa pine forests younger-aged forests (VSS 3) are important, and only when larger,

TABLE 5. APPROXIMATE PERCENT IN EACH VEGETATIVE STRUCTURAL STAGE (VSS) AND FOREST AGE THAT CAN BE EXPECTED TO OCCUR IN GOSHAWK POST-FLEDGING FAMILY AND FORAGING AREAS OF AVERAGE SITE QUALITY FOR PONDEROSA PINE FOREST TYPE AND MANAGEMENT INTENSITIES (REYNOLDS ET AL. 1992)

Management intensity	Percent in each vegetative structural stage						Forest age (years)
	VSS 1	VSS 2	VSS 3	VSS 4	VSS 5	VSS 6	
No management[1]	10	10	80	0	0	0	200
Minimal	9	13	20	17	20	21	233
Moderate	10	10	19	17	20	24	204
Intensive	10	8	18	17	21	26	194

[1] Unthinned ponderosa pine stand at Fort Valley Experimental Forest (Reynolds et al. 1992). An unthinned stand, using GENGYM growth and yield model, never grew beyond VSS 3 with a 200-year forest age (Ronco et al. 1985, Edminster et al. 1991).

older trees are available for nesting and seed sources (Reynolds et al. 1992).

Under varying management options, VSS percentages never attain 10-10-20-20-20-20. The youngest forest age (shorter time span) occurs under intensive management; oldest forest age (longest time span) occurs under minimal management (Table 5). Minimal management level is characterized by trees that are significantly competing with one another. When management intensities are at moderate and intensive levels, trees develop without significant competition. Without management, however, unthinned ponderosa pine stands of average site quality are unlikely to grow beyond the young forest structural stage (VSS 3), even after 200 years (Ronco et al. 1985, Edminster et al. 1991).

To provide the desired forest conditions of large old trees over 40% of the goshawk management area and small forest openings for prey species and tree regeneration, entry periods for management activities (i.e., harvesting, fire, etc.) would need to be about every 20 years for the moderate level. An expected level of management intensity (stand density) must be determined prior to establishing the desired VSS proportions and forest age.

The recommended 10-10-20-20-20-20 VSS percentage is now being considered as a hard-and-fast rule by those implementing and reviewing timber sale projects. However, the 10-10-20-20-20-20 distribution was intended to describe approximate percentages of each VSS throughout the post-fledging family and foraging areas to sustain suitable goshawk habitat (Reynolds et al. 1992). The achievable VSS percentage should be determined by considering existing local factors that influence forest establishment and growth, expected management intensity, and tree longevity.

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