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ATTACHMENT B

DESIRED CONDITIONS IN PONDEROSA PINE FORESTS: THE SUPPORTING SCIENCE

This document summarizes the scientific literature supporting the key compositional and structural aspects of the Desired Conditions in southwestern ponderosa pine forests. It outlines the work completed to date on a manuscript describing the development and science basis for the Desired Conditions. This summary focuses on the ponderosa pine forest type because (1) it is the most common non-woodland forest type in the Southwest, (2) it has been and is the focus of most vegetation management activities in the Southwest, and (3) it is the primary focus of the October 2011 Desired Conditions Workshop. There is a large body of literature on the ecology and natural range of variability of ponderosa pine forests. The key elements and functions of the Desired Conditions of a forest type are:

- species composition, overstory and understory,
- its characteristic tree density, spatial distribution, age composition,
- forest openings and the grass/forb/shrub vegetation matrix,
- habitats, biodiversity, and food webs,
- sustainability and resilience,
- fire frequency, behavior, and effects,
- hydrologic processes,
- visual attributes.

The Desired Conditions for ponderosa pine forests incorporated information on the ecology of the overstory and understory vegetation comprising this type as well as information on its historic or natural range of variability in the composition and structure of vegetation. The natural range of variation comes from 19th century descriptions of forest conditions by early explorers (Beale 1858, Wheeler 1875, Dutton 1882, Leopold 1924) and early scientists (Lieberg et al. 1904, Plummer 1904, Woolsey 1911, Pearson 1950), from tree ring, dendrochronological, and restoration studies (Fritts and Swetnam 1989, Covington and Moore 1994, Swetnam and Baisan 1996, Covington et al. 1997), vegetation classifications (Daubenmire 1968), forest vegetation simulations (cites), natural area and old growth studies (White 1985), fire histories (Morgan et al. 2001), and wildland fuel management strategies (e.g., Haig et al. 1941, Pearson 1950, Fulé et al. 1997, Reinhardt and Crookston 2003, Graham et al. 2004).

All southwestern forests and woodlands are periodically affected by natural disturbances such as fire, insects, disease, wind, and herbivory. These disturbances have variable effects on forest vegetation depending on the type, frequency, intensity, and spatial scale of disturbances. The type, frequency, and intensity of disturbances varied historically among forest and woodland types. A forest or woodland's characteristic composition, structure, and landscape pattern, the result of vegetation establishment, growth, and succession, combined with the periodic resetting of these by characteristic natural disturbances, constitutes a forest or woodland's natural range of variability. The temporal and spatial variability in vegetation establishment, growth, and mortality, and the consequences of natural disturbances in a forest or woodland define the natural range of variability. Much of the range of variability stems from fine- to landscape scale heterogeneity in aspect, slope, elevation, and soils that can lead to topographically different growing conditions and disturbance regimes (Beaty and Taylor 2001, Fulé et al. 2003). The ability of a forest ecosystem to absorb and recover from disturbances without drastic alteration of its inherent function is central to the concept of natural range of variability.

In the southwestern United States, fire is a primary disturbance agent and fire regimes are central to understanding natural range of variability as it relates to the composition, structure, and pattern in various forest types (Fulé et al. 2003). A description of fire regimes and ecological characteristics by forest type is displayed in Table 1.

Ponderosa Pine Forest

Key Characteristic: Species Composition

The Desired Condition is a forest overstory dominated by ponderosa pine, mixed where possible with pinyon and juniper species, oaks, aspen, or Douglas-fir, and a species-diverse and productive grass/forb/shrub understory. The ponderosa pine forests considered here are exclusive of the ponderosa pine-oak forests types, whose desired conditions are treated separately.

In this type, ponderosa pine is the dominant seral and climax tree species, but depending on locale may mix with gamble oak, several juniper and pinyon species (DeVelice 1986), quaking aspen, Douglas-fir, or southwestern white pine. Composition of the grass/forb/shrub understory is typically diverse in ponderosa pine forests, especially when canopy openings are present (Moir 1966, Naumburg and Dewald 1999, Laughlin et al. 2006, Abella 2011). Presence of shrubs is variable depending on habitat type and locale (USDA 1997), but when present may consist of sagebrush (*Artemisia* spp.), currant (*Ribes* spp.), snowberry (*Symphoricarpus* sp.), mahogany (*Cercocarpus* sp.), rabbitbrush (*Chrysothamnus* spp.), saltbrush (*Atriplex* sp.), morman tea (*Ephedra* sp.), manzanita (*Arctostaphylos* spp.), ceonothus (*Ceonothus* spp.), bitterbrush (*Purshia* spp.), *Oregongrape* (Mahonia spp.), oak shrub (*Quercus* sp.), rose (*Rosa* spp.), and locust (Robina sp.). While grasses and herbs occur in most ponderosa pine types, the composition, abundance (cover), and productivity is variable depending on soil, aspect, elevation, latitude, moisture, and the presence or absence of tree cover (Moir 1966, Naumburg and Dewald 1999, Laughlin et al. 2006, Abella 2011). The more common grasses are sedge (*Carex* spp.), muhly (*Muhlenbergia* spp.), muttongrass (*Poa* sp.), junegrass (*Koeleria* sp.), bluestem (*Schizachyrium* sp.), ricegrass (*Piptochaetium* sp.), squirreltail (*Elymus* sp.), fescue (*Festuca* spp.), grama (*Boutuloua* spp.), needlegrass (*Stipa* spp.), pine dropseed (*Blepharoneuron* sp.), threeawn (*Aristida* sp.), bluestem (*Andropogon* spp.), brome (*Bromus* spp.), and wheatgrass (*Pascopyrum* spp.) (UDSA 1997). More common forbs are sagewort (*Artemisia* sp.), geramium (*Geranium* spp.), goldenrod (*Solidago* spp.), cinquefoil (*Potentilla* spp.), pussytoes (*Antennaria* sp.), fleabane (*Erigeron* sp.), groundsel (*Senecio* spp.), brackenfern (Pteridium sp.), vetch (Astragalus spp., Vicia sp.), peavine (Lathyrus sp.), goldenaster (*Heterothecs* spp.), meadowrue (*Thalictrum* sp.), buckwheat (*Eriogonum* spp.), and gromwell (*Lithospermum* sp.) (USDA 1997).

Key Characteristic: Tree density and distribution

The vegetation structure in ponderosa pine forests throughout the Southwest has changed considerably from the natural or historical condition. Tree harvests and livestock grazing, coupled with a reduction in fire frequency and intensive fire suppression since Euro-American settlement have resulted in significant increases in tree densities, mostly in the smaller diameter classes, increased densities of shade-tolerant, less fire resistant tree species (e.g.,Douglas-fir, white fir, juniper), and increased fuel loads (Parsons and Debenedetti 1979, Moore et al. 2004, Naficy et al. 2010, Scholl and Taylor 2010). For example, a 1990s re-measurement of tree densities on 15 partially-harvested 2.5-acre plots in ponderosa pine in Arizona and New Mexico, originally measured by T. S. Woolsey and G. A. Pearson in 1909-1913, showed that mean trees per acre increased over nine decades by a factor of almost 7; from

77 to 519 trees per plot (Moore et al. 2004). In many areas, tree species compositions have shifted towards more shade tolerant and less fire resistant species. Increased tree densities and tree encroachment into openings and meadows has resulted in increased shading and a decline in percent cover, abundance, and diversity of understory grasses, forbs, and shubs (Covington and Moore 1994, Bogan et al. 1998, Swetnam et al. 1999, Abella 2009). Increased tree densities also altered hydrologic cycles by lowering total stream flows, peak flows, and base flows (Ffolliott et al. 1989, see Troendle and King 1985 for effects of tree removal on hydrologic cycles). Increased tree densities and invasion of ponderosa pine and dry mixed conifer forests by less fire-tolerant tree species has resulted in increased number, size, and severity of wildfires (Allen 2007).

Historical tree densities on reconstructed plots throughout the Southwest varied depending on factors such as elevation, aspect, slope, soils, moisture, and a site's unique history. An example of this was a reconstruction study involving 53 2.5-acre plots representing nine different ponderosa pine ecosystem types near Flagstaff, Arizona. Historical tree densities on these sites varied 19-fold, and averaged between 2 -40 trees per acre (Abella and Denton 2009). Moore's et al. (2004) reconstruction study on their 15 2.5 acre Woolsey plots (discussed above) estimated (based on live tree and cut-stump BA) a mean density of 40 trees per acre (Moore et al. 2004). On the same Woolsey plots, Sánchez-Meador et al. (2010) found that the number of tree groups ranged from 4-11 per acre and ranged in size from 0.004 ac to 0.06 acre. Other reports of historical tree densities include 22 trees per acre near Walnut Canyon (Menzel and Covington 1970), 23 trees per acre at Bar-M-Canyon (Covington and Moore 1994), 24 trees per acre on the Gus Pearson Natural Area (GPNA) on the Fort Valley Experimental Forest (Mast et al. 1999), and 24 trees per acre at Camp Navajo (Fulé et al. 1997). A 1938 forest inventory on the Long Valley Experimental Forest (central Arizona) showed that 75 trees per acre were present prior to the cessation of frequent fire (between 1880 and 1900). Woolsey (1911) reported an average of 18 trees per acre (> 4 inches dbh) in northern Arizona in the early 20th century.

Structural characteristics widely reported for historical Southwest ponderosa pine are relatively open forests with trees typically aggregated in small groups within a grass/forb/shrub matrix (Cooper 1960, White 1985, Pearson 1950, Covington et al. 1997, Abella and Denton 2009). Recent work in northern Arizona has shown that tree densities across nine different ponderosa pine ecosystems depended to a large extent on soil type and climatic variables (minimum spring and fall temperatures, May precipitation) (Abella and Denton 2009). This work also showed that the degree to which trees were aggregated into groups was largely explained by ecosystem soil type. Twenty-eight to 74 percent of all trees were in groups; the remaining trees were scattered individual trees (Abella and Denton 2009). These structural conditions were maintained by frequent low-intensity surface fires that more often killed small rather than large trees (Dieterich 1980, Weaver 1951, Fiedler et al. 1996; but see Leirfallon and Keane 2011). Other small-scale disturbances such as insects, disease and others also shaped this characteristic forest structure. Low intensity fires occurred every 2 to 12 years and maintained an open canopy structure (Covington et al. 1997, Moir et al. 1997). Typical historical tree groups ranged from 0.1 to 0.75 acres in size and comprised 2 to 40+ trees per group (White 1985, Fulé et al. 1993, Covington et al. 1997). The grass/forb/shrub understory and fine fuels (needles, cones, limbs) from large trees fueled these frequent fires started by lightning and, to an uncertain extent by Native Americans (Kaye and Swetnam 1999, Allen 2002). Regular fire thinned or eliminated thickets of small trees, resulting in open, park-like forests (Cooper 1960, Covington et al. 1997, Allen et al. 2002). Restoration studies on the Fort Valley Experimental Forest near Flagstaff, Arizona, showed an average of 23 trees per acre that were grouped into distinct 0.05- to 0.7-acre groups consisting of 2-40 trees (Covington et al. 1997). In the White Mountains of Arizona, the average size of tree groups in ponderosa pine was 1/5th of an acre (Cooper 1961).

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Key characteristic: Forest openings and grass/forb/shrub matrix

A key characteristic of the Desired Conditions for ponderosa pine are canopy openings that comprise between 30 and 70 percent (extremes =10 to 80%) of a landscape. These openings lack tree crown cover and support a desired grass/forb/shrub community. Woolsey (1911) described late 19th century southwestern ponderosa pine forests as having "*...pure park-like stand(s) made up of scattered groups of from 2 to 20 trees, usually connected by scattering individual. Openings are frequent and vary in size. Because of the open character of the stand and the fire-resisting bark, often 3 inches thick, the actual loss in yellow (ponderosa) pine by fire is less than with other more gregarious species.*" Others also described historical ponderosa pine forests as having low tree density, open, savanna-like stands consisting of groups of pine trees interspersed with grassy or shrubby openings (White 1985). Grass openings in southwestern ponderosa pine account for the highest level of plant diversity (Laughlin et al. 2006) and spatial patterns influence genetic diversity (DeWald 2003), growth of trees (Biondi 1996, Ffolliott et al. 2000), forest dynamics (Youngblood et al 2004, Boyden et al. 2005, Sánchez-Meador et al. 2009), wildlife habitat (Reynolds et al. 1992, Waltz and Covington 2003, Dodd et al. 2006, Wightman and Germaine 2006), and risk of stand-replacing crown fires (Fulé et al. 2007). Unfortunately, the actual degree of "openness" has received little measurement; instead, most reconstruction/restoration studies focused on tree densities and tree aggregation. Although White (1985) did not define how close trees had to be to constitute a "group" (he appeared to use the absence of 1919 regeneration beneath large tree crowns to define groups, which consisted of ≥3 trees), he reported 22 percent of his plot on the GPNA was under tree groups. Thus, 78 percent of the 18 acre area would likely have been open before the 1919 regeneration pulse (White 1985). White (1985) reported that 12 percent of the historical trees on his plot were not in groups of three trees; if he had included single trees and groups of 2 trees, the percent open would have been less than 78 percent. Covington et al. (1997), also working on the GPNA, reported that while canopy cover was high within groups of trees, only 19 percent of the surface area of their Fort Valley study plot was under pine canopy; the balance (81%) represented grassy openings (Covington et al. 1997). Gill's et al. (2000) estimate of mean crown radius of mature ponderosa pine of 19.7 feet to estimate the range of total per-acre area under projected crowns, on the 53 study plots of Abella and Denton (2009), plots with two trees had less than 2 percent under crowns (98% open) and the 40-tree plot had 28 percent under crowns (72% open). The same approach for the 75 trees present before the cession of fire (about 1900) on the Long Valley Experiment Forest resulted in about 52 percent of the per acre area under tree crowns (48% open).

Trees in ponderosa pine forests affect soil properties, and species richness, cover, and the distribution of grass/forb/shrub species. For example, trees affect soil moisture, nutrients, and other ecosystem components such as microclimates above and below the soil surface (Arnold 1950, Barth 1980, Moir 1966, Parker and Muller 1982, Covington et al. 1997, Scholes and Archer 1997, Abella 2009). These components and microclimates can affects many plant and animal species and ecological processes, including biodiversity, trophic interactions, food webs, wildlife, and hydrology. Environmental parameters such as light intensity, pH, litter depth, soil depth, percentage of exposed rock, and percentage of litter cover are directly influenced by the presence or absence of canopy cover (Evensen et al. 1960). In northern Arizona ponderosa pine-Gamble oak forests, openings had greater species richness, three to eight times greater plant cover than under tree canopies, and there were no species more abundant under ponderosa pine trees (Abella 2009). In addition to the importance of openings, Abella's (2009) work pointed to the importance of Gamble oak in pine forests. Single oaks had the high species richness beneath them while oak clumps and thickets provided unique habitat for several forb species. Clearly, canopy openings need to be re-established and maintained in ponderosa pine forests if grass/forb/shrub communities are to be diverse, productive, and support plant, invertebrate, and vertebrate species that depend on these communities (Kruse et al. 1992, Rosenstock 1998, Ganey et al. 1992, Reynolds et al. 1992, 2006, Abella 2009).

Key Characteristic: Snags, logs, woody debris

To be completed

Key Characteristic: Habitats, biodiversity, food webs

Many ecosystem processes influence plant productivity, soil fertility, water availability and quality, atmospheric chemistry, and other local and global environmental conditions. These ecosystem processes are controlled by both the diversity and identity of plant, animal, and microbial species native to an ecosystem. Recent studies suggest that reductions in biodiversity can alter both the magnitude and stability of ecosystem processes (Naem et al. 1999). As the dominant tree species, ponderosa pine influences the entire forest ecosystem, affecting understory vegetation, soils, and plant and animal habitats and communities (Moore et al. 1999). Southwestern ponderosa pine forests are habitat for over 250 species of vertebrates, many species of plants, invertebrates, and soil organisms (Patton and Severson 1989, Allen 2002). Native plants and animals are adapted to naturally high levels of heterogeneity in ponderosa pine ecosystems, and some species are dependent on diverse habitats for their survival (Reynolds et al. 1992, 2006; Dodd et al. 1998). Current conditions are atypically homogeneous in composition and structure with reduced plant and animal habitats and lowered biodiversity. Moving the current forest conditions to the Desired Conditions can affect many of these plants and animals in various ways (Reynolds et al. 1992, Rieman and Clayton 1997, Oliver et al. 1998, Reynolds et al. 2006, Abella 2009). Achieving the Desired Conditions restores habitats at the fine-, mid-, and landscape scales, particularly by increasing diversity and productivity in grass/forb/shrub layers. Nonetheless, there may be a potential for the Desired Conditions to lower the viability of sensitive and threatened species through habitat alteration and fragmentation (U.S. Fish and Wildlife Service 1998, 2011, Holthausen et al. 1999). For some of these species, concerns might be ameliorated by developing site-specific desired conditions for breeding sites, feeding sites, or entire refugia (for changed desired forest conditions with increasing distance from nest sites see Reynolds et al. 1992). Also, it is worth noting that breeding sites or entire refugia for species of special concern could be protected from catastrophic loss by surrounding them with the Desired Conditions, thereby lowering the risk of complete loss due to forest-killing crown fires. The ponderosa pine Desired Conditions are comprised of diverse landscapes with groups and patches of variable tree densities, including groups with dense, closed canopies (interlocking crowns); densely shaded soils beneath tree groups; tree ages young to old; species-rich and productive grass/forb/shrub communities; dead, deformed, and diseased trees; large logs, and woody debris; and old large oaks, aspen, and other important trees. Each of these is a critical component of the habitat of many native species (Reynolds et al. 1992, Rosenstock 1998, Bennetts et al. 1996, Bull et al. 1997, Dodd et al. 1998).

The habitat diversity components of the ponderosa pine Desired Conditions as described above can lead to more robust food webs. The importance of forest habitat diversity and robust food webs is illustrated in efforts to conserve northern goshawk populations in the Southwest (Reynolds et al. 1992, 2006). In the American Southwest, goshawk reproduction output varies extensively year to year and is strongly associated with the abundance and availability of food; in years when prey numbers are low, goshawk population reproduction can be a small fraction of reproduction in years when prey is abundant (Reynolds et al. 2005, Reynolds et al. 2006, Salafsky et al. 2005a, 2007b). Goshawks are prey generalists that feed on a broad suite of prey; from robins, jays, woodpeckers, doves, and grouse to tree squirrels, ground squirrels, rabbits, and hares (Reynolds and Meslow 1982, Squires and Reynolds 1997). Each goshawk prey species occupies a different habitat; tree squirrels, woodpeckers, and jays primarily occupy tree habitats while ground squirrels, rabbits, and hares occupy open grass/forb/shrub habitats, and still others (robins, grouse, doves) use both habitats (reviewed in Reynolds et al. 1992). Annual population highs and lows of each prey species are not always in phase, a years' population low in one or more prey is often compensated by higher numbers in other species (Salafsky et al. 2006). Over a period of years it becomes clear that because of this compensation, the entire suite of prey -- not any single prey species -- is important to goshawk reproduction. A forest management strategy that maximizes the habitats for one or a few prey species is not likely to sustain a goshawk population. Rather, a strategy that provides habitats of the wide variety of plants and animals in the hawk's food web is more likely to succeed (Reynolds et al. 1992). The Desired Conditions in ponderosa pine provide a wide variety of habitats; densely canopied tree groups with interlocking crowns and limby boles on the outside, a matrix of grass/forb/shrub vegetation, and old forest structural elements (large snags, logs, and woody debris). Each of these habitats is critically important for one or more of the goshawk prey species.

Key Characteristic: Sustainability and Resilience

The compositional and structural changes have resulted in increased vulnerability of current southwestern ponderosa pine forests to uncharacteristically high disturbance intensities and extents, particularly from fire and insects (Covington 1993, Moore et al. 1999, Allen 2007, North et al. 2009, Collins et al. 2011). Greatly increased tree densities due to fire exclusion have negatively affected forest health by accelerating old tree mortality, facilitating insect outbreaks, diminishing productivity of understory plants, altering food webs, and increasing fire severity (Covington and Moore 1994, Abella and Denton 2009). Current conditions are therefore not natural or sustainable (Swetnam et al. 1999). Current conditions in ponderosa pine are conducive to insect epidemics and stand-replacing wildfires, which can convert forests to shrublands (Savage and Mast 2005). This highlights the importance of understanding natural (or reference) conditions when developing Desired Conditions for forest restoration. Woolsey (1911) described how fire functions to maintain natural range of forest structure, ..."*A crown fire in mature timber is almost unheard of, and in a ground fire in the virgin forest young saplings often escape complete destruction, though with a fair wind and on a steep slope destruction of seedlings and saplings is often complete...In June 1910, a fire occurred on the Gila, Datil and Apache National Forests which burned over about 60 square miles. The area burned was steep and rocky, with an unusual quantity of dry forage. An investigation showed that injury to the yellow (ponderosa) pine was confined very largely to the reproduction. On the area as a whole, from 40 to 50 percent of the seedlings were killed.*"

Sustaining the Desired Condition mix of plant and animal habitats over space and time requires the incorporation of the spatial and temporal dynamics of forest vegetation. Vegetation dynamics, including the establishment, development, senescence, and its composition, structure, and pattern, can be estimated and modeled (see Oliver and Larson 1990, Reynolds et al. 1992, Franklin et al. 2002, Reinhardt and Crookston 2003). An example of the incorporation of dynamics in sustaining the maximum amount of mature and old trees in southwestern forests was best achieved with about 20% in seedlings/saplings), 20 % in young forest, 20 % in mid-aged forest, 20 % in mature forest, and 20 % in old forest (Reynolds et al. 1992). These proportions reflect forest development from cohort establishment (seedling/saplings) to old forest structure (Figure 1). Based on forest type, these structural stages are distributed at the fine scale for ponderosa pine, dry mixed conifer, and some pinyon-juniper types, at the mid-scale for wet mixed conifer, some spruce-fir, and pinyon-juniper types, and at the landscape-scale for most spruce-fir types.

The Desired Conditions have a range of metrics (trees/ac, BA, degree of tree aggregation and openness) that match a site's capability so that the conditions can be attained and sustained. Knowledge of the historical forest composition and structure on a site can provide estimates of tree species and densities that were sustainable through at least several generations of trees (Allen et al. 2002, Abella et al. 2011). It may not be necessary, or even desirable in some cases, to have desired conditions that are within the natural range of variability at every site in southwestern forests and woodlands. However, historical conditions are more synchronous with the natural disturbance regime to which the forest and woodland ecosystems are adapted. Social, political and economic factors are much different today than a century ago and there are valid considerations for leaving areas of higher or lower tree-density or differing composition to meet resource management needs. But restoration on some portion of the landscape to conditions reminiscent of pre-European settlement times would most likely provide for greater biodiversity, and greater ecosystem productivity, stability, sustainability, and services.

Literature Cited

Abella, S.R. 2008. Managing oak in southwestern ponderosa pine forests: the status of our knowledge. General Technical Report RMRS-GTR 218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 27 pp.

Abella, S. R. 2009. Tree canopy types constrain plant distributions in ponderosa pine-Gambel oak forests, northern Arizona. Research Note RMRS-RN-39. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 7p.

Abella, S . R., and C. W. Denton. 2009. Spatial variation in reference conditions: historical tree density and pattern on a *Pinus ponderosa* landscape. Canadian Journal of Forestry 39: 2391-2403.

Abella, S. R., C. W. Denton, D. G. Brewer, W. A. Robbie, R. W. Steinke, and W. W. Covington. 2011. Using a terrestrial ecosystem survey to estimate the historical density of ponderosa pine trees. Research Note. RMRS-RN-45. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 9 p.

Abella, S. R., W. W. Covington, P. Z. Fulé, L. B. Lentile, A. J. Sánchez Meador, and P. Morgan. 2007. Past, present, and future old growth in frequent-fire conifer forests of the Western United States. Ecology and Society 12(2): 16.

Allen, C. D. 2007. Interactions across spatial scales among forest dieback, fire, and erosion in Northern New Mexico landscapes. Ecosystems 10:797-808.

Allen, S. R., M. Savage, D. A. Falk, K. F. Suckling, T. W. Swetnam, T. Shulke, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications 12:1418-1433.

Arnold, J. F. 1950. Changes in ponderosa pine bunchgrass ranges in northern Arizona resulting from pine regeneration and grazing. Journal of Forestry 48: 118-126.

Barth, R. C. 1980. Influence of pinyon pine trees on soil chemical and physical properties. Soil Science Society of America Journal 44: 112-114.

Beale, E. F. 1858. Eagon road from Fort Defiance to the Colorado River. Sen. Exec. Doc. 124, 35 Congress, 1st Session.

Bennetts, R. E., G. C. White, F. G. Hawkworth, and S. Severs. 1996. The influence of dwarf mistletoe on bird communities in Colorado ponderosa pine forests. Ecological Applications 6: 899-909.

Bernardos, D. A., C. L. Chambers, M. J. Rabe. 2003. Selection of Gambel oak roosts by Southwestern myotis in ponderosa pine-dominated forests, Northern Arizona. Journal of Wildlife Management 68: 595-601.

Bogan, M. A., C. D, Allen, E. H. Muldavin, S. P. Platania, J. N. Stuart, G. H. Farley, P. Melhop, and J. Melhop. 1998. Pp. 543-592 in M. J. Mac, P. A. Opler, C. E. Puckett Haecker, and P. D. Doran, eds. Status and trends of the nation's biological resources. U.S. Department of Interior, U. S. Geological Survey, Reston Virginia, USA.

Braun, C. E., J. H. Enderson, Y. B. Linhart, C. D. Marti, and M. R. Fuller. 1996. Northern goshawk and forest management in the southwestern United States. The Wildlife Society, Technical Review 96-2.

Brown, J. K., E. D. Reinhardt, K. A. Kramer. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. Gen. Tech. Rep. RMRS-GTR- 105. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 pp.

Bull, E. L., C. G. Parks, and T. R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia River Basin. USDA Forest Service General Technical Report PNW-GTR-391.

Bush, R., A. Leach. 2009. Detailed estimates of old growth and large-snags on the Lewis and Clark National Forest. USDA-Forest Service technical report available online Northern Region, Missoula MT.

Choi Y, D., V. M. Temperton, E. B. Allen, A. P. Grootjans, M. Halassy, R. J. Hobbs, N. A. Naeth, and K. Torok. 2008. Ecological restoration for future sustainability in a changing environment. Écoscience. 15(1): 53-64.

Clewell, A., J. Rieger, and J. Munro. 2005. Guidelines for Developing and Managing Ecological Restoration Projects, 2nd ed. Tucson AZ: Society for Ecological Restoration International. Reprinted in Clewell and Aronson 2007. www.ser.org/content/guidelines_ecological_restoration.asp

Cooper, C F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs 30: 129-164.

Cooper, C. E. 1961. Patterns on ponderosa pine forests. Ecology 42: 493-499.

Covington, W. W. 1993. Implications for ponderosa pine/bunchgrass ecological systems. Sustainable Ecological Systems: implementing an Ecological Approach to Land Management. U.S. Forest Service General Technical Report RM-247. pp. 92-97.

Covington, W. W., and M. M. Moore. 1994. Postsettlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. Journal of Sustainable Forestry 2: 153-181.

Covington, W. W., P. Z. Fulé, M. M. Moore, S. C. Hart, T. E. Kolb, N. J. Mast, S. S. Sackett, and M. R. Wagner. 1997. Restoring ecological health in ponderosa pine forests of the Southwest. Journal of Forestry 95: 23-29.

Dodd, N. L., S. S. Rosenstock, C. R. Miller, and R. E. Schweinburg. 1998. Tassel-eared squirrel population dynamics in Arizona: index techniques and relationships to habitat conditions. Technical Report 27. Arizona Game and Fish Department, Phoenix, Arizona, USA>

Dutton, C. 1882. Tertiary history of the Grand Cañon District. U. S. Geological Survey, Monograph 2.

Er, K. B. H., and J. L. Innes. 2003. The presence of old-growth characteristics as a criterion for identifying temperate forests of high conservation value. International Forestry Review 5: 1-8.

Evenson, W. E., J. D. Brotherson, and R. B. Wilcox. 1980. Relationship between environmental and vegetational parameters for understory and open-area communities. Great Basin Naturalist 40: 167-174.

Ffolliott, P. F., G. J. Gottfried, C. L. Stropki. 2008. Vegetative characteristics and relationships in the oak savannas of the Southwestern Borderlands. Research Paper RMRS-RP-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 16 p.

Fiedler, C.E., S. F. Arno, M. G. Harrington. 1996. Flexible silvicultural and prescribed burning approaches for improving health of ponderosa pine forests. Conference on Adaptive Ecosystem Restoration and Management. USDA, Rocky Mountain Forest and Range Experiment Station, RM-GTR-278. pp.69-74.

Fiedler, C. E., P. Friederici, M. Petruncio, C. Denton, and W. D. Hacker. 2007. Managing for old growth in frequent-fire landscapes. *Ecology and Society* **12**(2): 20.

Franklin, J. F., K. Cromack, Jr., W. Dension, C. Maser, J. Sedell, J. Swanson, and G. Juday. 1981. Ecological attributes of old-growth Douglas-fir forests. General Technical Report PNW-GTR 118. Portland, OR. USDA Forest Service, Pacific Northwest Research Station.

Franklin, J. F., T. A. Spies, R. Van Pelt, A. B. Cary, D. A. Thornburgh. D. A. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D. C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir, as an example. Forest Ecology and Management 155:399-423.

Friederici, P., editor. 2003. Ecological restoration of southwestern ponderosa pine forests. Island Press, Washington, D.C.

Fulé, P. Z., M. M. Moore, and W. W. Covington. 1997. Determining reference conditions for ecosystem management in southwestern ponderosa pine forests. Ecological Applications 7: 895-908.

Fulé, P. Z., C. McHugh, T.A. Heinlein, W.W. Covington. 2001. Potential fire behavior is reduced following forest restoration treatments. Forest Service Proceedings RMRS P-22. 28-35.

Fulé, P. Z., J. E. Crouse, T. A. Heinlein, M. M. Moore, W. W. Covington, and G. Vankamp. 2003. Mixed-severity fire regime in high-elevation forest of the Grand Canyon, Arizona, USA. Landscape Ecology 18: 465-486.

Fulé, P. Z., W. W. Covington, M. M. Morre, T. A. Heinlein, A. E. M. Waltz. 2002. Natural variability in forests of the Grand Canyon, USA. Journal of Biogeography 29: 31-47.

Gill, S., G. S. Biging, and E. C. Murphy. 2000. Modeling conifer tree crown radius and estimating canopy cover. Forest Ecology and Management 126: 405-416.

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

Ganey, J. L., R. B. Duncan, and W. M. Block. 1992Use of oak and associated woodlands by Mexican spotted owls in Arizona. Pp. 125-128 in Ffolliott, P. F., G. J. Gottfried, D. A. Bennett, C. V. M. Hernandez, A. Ortega-Rubio, and R. H. Hamre, technical coordinators. 1992. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico. General Technical Report RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Research Station. 224 p.

Gori, D., J. Bate. 2007. Historical range of variation and state and transition modeling of historical and current landscape conditions for pinyon-juniper of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 141 pp.

Grissimo-Mayer, H. D., C. H. Baisan, T. W. Swetnam. 1995. Fire history in the Pinaleño Mountains of southestern Arizona: effects of human-related disturbances. General Technical Report GTR-RM-264. U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA.

Harmon, M. E., J. F. Franklin, E. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cluine, N. G. Aumen, J. R. Sedell, G. W. Leinkaemper, K. J. Cromack, and K. W. Cummins. 1986. Ecology of coarse wood debris in temperate ecosystems. Advances in Ecological Research 15: 133-302.

Harrod, R. J., B. H. McRae, and W. E. Hartl. 1999. Historical stand reconstruction in ponderosa pine forests to guide silvicultural prescriptions. Forest Ecology and Management 114: 433-446.

Helms, J. A. 2004. Old-growth: what is it? Journal of Forestry :8-12.

Holthausen, R. S., M. G. Raphael, F. B. Sampson, D. Elbert, R. Hiebert, and K. Manasco. 1999. Poulation viability in ecosystem management. Pp 135-156 in R. C. Szaro, et al. editors. Ecological Stewardship-a common reference for ecosystem management. Volume II. Elsevier Science. Oxford, UK.

Kaufmann, M. R., D. Binkley, P. Z. Fulé, M. Johnson, S. L. Stephens, and T. W. Swetnam. 2007. Defining old growth for fire-adapted forests of the western United States. Ecology and Society 12(2): 15. [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art15/.

Kaye, M. W., and T. W. Swetnam. 1999. An assessment of fire, climate, and Apache history in the Sacramento Mountains, New Mexico, USA. Physical Geography 20: 305-330.

Laughlin, D. C., M. M. Moore, J. D. Bakker, C. A. Casey, J. D. Springer, P. AZ. Fulé, and W. W. Covington. 2006. Assessing targets for the restoration of herbaceous vegetation in ponderosa pine forests. Restoration Ecology 14: 548-560.

Leopold, A. 1924. Grass, brush, timber, and fire in southern Arizona. Journal of Forestry 22: 2-8.

Leifallon, S. B., and R. E. Keane. 2011. Six-year post-fire mortality and health of relict ponderosa pine s in the Bob Marshall Wilderness Area, Montana. Research Note RMRS-RN-42. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 5p.

Lieberg, J. B., T. F. Rixon, and A. Dodwell. 1904. Forest conditions in the San Francisco Mountain reserve, Arizona. USDI U.S. Geological Survey, Professional paper No. 22, Washington D.C. 96 pp.

Long, J. N., and F. W. Smith. 2000. Restructuring the forest: goshawks and the restoration of Southwestern ponderosa pine. Journal of Forestry 98:25-30.

Ludwig, J. A., B. P. Wilcox, D. D. Bresshears, D. J. Tongway and A. C. Imeson. 2005. Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. Ecology 86(2): 288-297.

Mast, J. N., P. Z. Fulé, M. M. Moore, W. W. Covington, and A. E. M. Waltz. 1999. Restoration of presettlement age structure of an Arizona ponderosa pine forest. Ecological Applications 9: 228-239.

Menzel, J. P., and W. W. Covington. 1997. Changes from 1876 to 1994 in a forest ecosystem near Walnut Canyon, northern Arizona. Pp. 151-172 in C. Van Riper and E. T. Deshler, eds., Proceedings of the Third Biennial Conference of Research on the Colorado Plateau. Transactions and Proceedings Series NPS/NRNAU/NRTP-97/12, U.S. Department of the Interior, National Park Service. 256pp.

Moir, W. H. 1966. Influence of ponderosa pine on herbaceous vegetation. Ecology 47: 1045-1048.

Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. Evolutionary environment, reference conditions, and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9: 1266-1277.

Moore, M. M., D. W. Huffman, P. Z. Fule, W. W. Covington, and J.E. Crouse. 2004. Comparison of historical and contemporary forest structure and composition on permanent plots in southwestern ponderosa pine forests. Forest Science 50:62-176.

Moir, W. H., B. Geils, M. Ann.Benoit, and D. Scurlock. 1997. Ecology of Southwestern Ponderosa Pine Forests." Pp. 3-27 in USDA Forest Service General Technical Report RM-GTR-292.

Morgan, T. A., C. E. Fiedler, and C. W. Woodall. 2002. Characteristics of dry site old-growth ponderosa pine in the Bull Mountains of Montana, USA. Natural Areas Journal 22:11-19.

Naeem, S., F. S. Chapin III, R. Costanza, P. R. Erlich, F. B. Golley, D. U. Hooper, J. H. Lawton, R. B. O'Neill, H. A. Mooney, O. E. Sala, A. J. Symstad, and D. Tilman. 1999. Biodiversity and ecosystem functioning: maintaining natural life support processes. Issues in Ecology, Ecological Society of America Number 4.

Naficy, C., A. Sala, E. G. Keeling, J. Graham, and T. H. DeLuca. 2010. Interactive effects of historical logging and fire exclusion on ponderosa pine structure in the northern Rockies. Ecological Applications 20:1851-1864.

Naumburg, E., and L. E. DeWald. 1999. Relationships between *Pinus ponderosa* forest structure, light characteristics, and understory graminoid species presence and abundance. Forest Ecology and Management 124: 205-215.

Noss, R. F., P. Beier, W. W. Covington, R. E. Grumbine, D. B. Lindenmayer, J. W. Prather, F. Schmiegelow, T. D. Sisk, and D. J. Vosick. 2006. Recommendations for integrating restoration ecology and conservation biology in ponderosa pine forests of the Southwestern United States. Restoration Ecology 14: 4-10.

Oliver, C. D., and B. C. Larson. 1990. Forest stand dynamics. New York: McGraw-Hill.

Oliver, C. D., A. Osawa, and A. Camp. 1998. Forest dynamics and resulting animal and plant population changes at the stand and landscape levels. Journal of Sustainable Forestry 6:281-312.

Pearson, G. A. 1950. Management of ponderosa pine in the Southwest: as developed by research and experimental practice. USDA Forest Service, Agriculture Monograph No. 6.

Parker, V. T., and C. H. Muller. 1982. Vegetational and environmental changes beneath isolated live oak trees (*Quercus agrifolia*) in a California annual grassland. American Midland Naturalist 107: 69-81.

Parsons, D. J., and S. H. Debenedetti. 1979. Impact of fire suppression on a mixed conifer forest. Forest Ecology and Management 2:21-23.

Patton, D. R., and K. E. Severson. 1989. WILDSHARE: a wildlife habitat relationship data model for southwestern ponderosa pine. Pp 268-276 in A. Techle, W. W. Covington, and R. H. Hamre, technical coordinators. Multi-resource management of ponderosa pine forests. USDA Forest Service General Technical Report RM-185.

Plummer, F. G. 1904. Forest conditions in the Black Mesa Foprest Reserve, Arizona. Professional paper No. 23, Series H, Forestry 8. Department of Interia, U.S.G.S., Washington Printing Office.

Reynolds, R. T., and E. C. Meslow. 1 984. Partitioning of food and niche characteristics of coexisting *Accipiter* during nesting. Auk 101:761-779.

Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, Jr., G. Goodwin, R. Smith, and E. L. Fisher. 1992. Management recommendations for the northern goshawk in the Southwestern United States. General Technical Report RMRS-

GTR-217, 90 pp. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Reynolds, R. T., R. T. Graham, and D. A. Boyce, Jr. 2006. An ecosystem-based conservation strategy for the northern goshawk. Studies in Avian Biology 31: 299-311.

Reynolds, R. T., J. D. Wiens, and S. R. Salafsky. 2006. A review and evaluation of factors limiting northern goshawk populations. Studies in Avian Biology 31: 260-273.

Reynolds, R. T., R. T. Graham, and D. A. Boyce, Jr. 2008. Northern goshawk habitat: and intersection of science, management, and conservation. Journal of Wildlife Management 72:1047-1055.

Rieman, B., and J. Clayton. 1997. Wildlife and native fish: issues of forest health of sensitive species. Fisheries 22:6-15.

Rosenstock, S. S. 1998. Influence of Gambel oak on breeding birds in Northern Arizona. Condor: 485-4920.

Salafsky, S. R., R. T. Reynolds, and B. R. Noon. 2005. Patterns of temporal variation in goshawks reproduction and prey resources. Journal of Raptor Research 39: 237-246.

Salafsky, S. R., R. T. Reynolds, B. R. Noon, and J. A. Wiens. 2007. Reproductive responses of northern goshawks to variable prey populations. Journal of Wildlife Management 71:2274-2283.

Sánchez-Meador, A. J., P. F. Parysow, and M. M. Moore. 2010. Historical stem-mapped permanent plots increase precision of reconstructed reference data in ponderosa pine forests of northern Arizona. Restoration Ecology 18: 224-234.

Sánchez-Meador, A. J., P. F. Parysow, and M. M. Moore. 2010. A new method for delineating tree patche4s and assessing spatial reference conditions of ponderosa pine forest in northern Arizona. Restoration Ecology 19: 490-499.

Scholes, R. J., and S. R. Archer. 1997. Tree-grass interactions in savannas. Annual Review of Ecology and Systematics 28: 517-544.

Scholl, A. E., and A. H. Taylor. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. Ecological Applications 20:362-380.

Schussman, H., C. Enquist, and M. List. 2006. Historic fire return intervals for Arizona and New Mexico: a regional perspective for Southwestern land managers. The Nature Conservancy in Arizona.

Smith, E. 2006. Historical range of variation and state and transition modeling of historical and current landscape conditions for mixed conifer of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 31 pp.

Smith, E. 2006. Historical range of variation and state and transition modeling of historical and current landscape conditions for ponderosa pine of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 43 pp.

Smith, E. 2006. Historical range of variation and state and transition modeling of historical and current landscape conditions for spruce-fir of the Southwestern U.S. Prepared for the U.S.D.A. Forest Service, Southwestern Region by The Nature Conservancy, Tucson, AZ. 37 pp.

Spies, T. A. 2004. Ecological concepts and diversity of old-growth forests. Journal of Forestry ??:14-20.

Squires, J. R., and R. T. Reynolds. 1997. The northern goshawk (*Accipiter gentilis*). *In* The Birds of North America, No. 298, A. Poole and F. Gill, eds. The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C. 32 pp.

The Nature Conservancy. 2006. Historical range of variation and state and transition modeling of historic and current landscape conditions for potential natural vegetation types of the Southwest. The Nature Conservancy: Southwest Forest Assessment Project.

Troendle, C. A., and R. King. 1985. The effect of timber harvest of the Fools Creek Watershed, 30 years later. Water Resources Research 21: 1915-1922.

USDA-Forest Service. 1997. Coarse woody material guidelines -- habitat type groups of the Kootenai NF. Unpublished resource report on file. Libby MT.

USDA-Forest Service. 2000. Local snag levels using Northern Region snag management protocol -- VRU categories. FSVeg database summary of all stand data 1991-1999, unmanaged lands of the Fortine District, Kootenai NF. Fortine MT.

Vandendriesche, D. 2009. PNVT vegetation state attributes. USDA-Forest Service unpublished technical report on file. Southwestern Region, Albuquerque NM.

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society 9(2): 5.

Weaver, H. 1951. Fire as an ecological factor in southwestern ponderosa pine forests. Journal of Forestry 49: 93-98.

Wheeler, G. M. 1875. Annual report upon the geographical explorations and surveys west of the one hundredth meridian, in California, Nevada, Nebraska, Utah, Arizona, Colorado, New Mexico, Wyoming, and Montana. Appendix LL of the annual report of the Chief Engineers for 1875. Washington Government Printing Office.

White, A. S. 1985. Presettlement regeneration patterns in a Southwestern ponderosa pine stand. Ecology 66: 589-594.

Woolsey Jr., T. S. 1911. Western yellow pine in Arizona and New Mexico. Forest Service - Bulletin 101. U. S. Department of Agriculture, Forest Service. Government printing Office, Washington.

Youtz, J. A., R. T. Graham, R. T. Reynolds, and J. Simon. 2008. Implementing northern goshawk habitat management in southwestern forests: a template for restoring fire-adapted forest ecosystems. Pp. 173-191 *in* Deal, R. I., tech. ed. Integrated restoration of forested ecosystems to achieve multiresource benefits: proceeding of the 2007 national silviculture workshop. General Technical Report PNW-GTR-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 306 p.

Table 1. Southwestern forest types and dominant characteristic natural disturbance regimes.

Forest Type	Fire Regime [1, 2]	Fire Type [2]	Forest Structure	Seral Species	Climax Species
Ponderosa pine (and sub-types)	frequent/ low severity 2-17 yrs. (regime I)	surface	uneven-aged, grouped, open	ponderosa pine	ponderosa pine
Dry Mixed conifer/ frequent fire (warmer/drier)	relatively frequent/ low-mod severity 9-22 yrs. (regime I)	surface (common) mixed (rare)	uneven-aged, grouped, open uneven-aged, patched, open	dominant -ponderosa pine subdominant - aspen and/or oak (sub-stand scale patches)	fire dis-climax historic condition- shade intolerant species: dominant – ponderosa pine; subdominant - Douglas-fir, Southwestern white pine or limber pine
Wet Mixed Conifer/ infrequent fire (cooler/wetter)	relatively infrequent/ mod-high severity variable, 22-150 yrs. (regime III, IV)	mixed (common) stand-replacing (rare)	uneven-aged, patched, closed even-aged, closed	dominant – aspen or Douglas-fir, depending upon plant association habitat type	shade tolerant species, depending upon plant association habitat type: white fir, blue spruce
Spruce-fir (mixed, lower sub-alpine)	infrequent/ mod-high severity 150-400 yrs. (regime III, IV)	mixed/stand-replacing	even-aged, closed	dominant – aspen or Douglas-fir, depending upon plant association habitat type	shade tolerant species, depending upon plant association habitat type: Engelmann spruce, white fir
Spruce-fir (upper sub-alpine)	infrequent/ high severity 150-400 yrs. (regime IV, V)	stand-replacing	even-aged, closed	dominant – aspen, Douglas-fir or Engelmann spruce, depending upon plant association habitat type	shade tolerant species: Engelmann spruce and corkbark or sub-alpine fir co-dominate

[1] Schussman et al. 2006.
[2] Historical Range of Variation and State and Transition Modeling of Historic and Current Landscape Conditions for Potential Natural Vegetation Types of the Southwest. The Nature Conservancy: Southwest Forest Assessment Project. 2006.

Figure 1. Growth of tree groups.