Forests and Woodlands of the Sky Islands: Stand Characteristics and Silvicultural Prescriptions

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Abstract.—The mountains of the Sky Islands or Madrean Archipelago are noted for their biological diversity. The higher elevations support pine, mixed conifer, and spruce-fir forests, while encinal and pinyon-juniper woodlands are found at more intermediate elevations. The highest forest zones are representative of the Rocky Mountain flora and the woodlands are representative of the Madrean flora of Mexico. Local and regional climatic patterns over the past 24,000 years have influenced the establishment and survival of these ecosystems. Past natural and human disturbances have affected stand conditions. The diversity of forest and woodlands can be observed on the five highest and largest mountain ranges in southeastern Arizona, namely, the Santa Catalina, Santa Rita, Huachuca, Chiricahua, and Pinaleno Mountains.

Human activities in the forests and woodlands have changed over time. Some traditional industries have declined while demands for other activities, such as recreation, have increased. There are concerns about the condition of these mountain ecosystems. Silviculture can be used as a ecosystem management tool to enhance long-term productivity of a variety of resources and amenities, to enhance biological diversity, and to help ensure forest and woodland health.

INTRODUCTION

The mountains of the Madrean Archipelago, or Sky Islands of southern Arizona, New Mexico, and northern Mexico are recognized for their diverse mixtures of plants and animals. Variety characterizes the region, which includes an area approximately 160 to 175 km on each side of the international border (Gehlbach 1981). The highest mountains support pine, mixed conifer, and spruce-fir forests, while encinal and pinyon-juniper woodlands are common at more intermediate elevations. The varied plant communities and their animal populations reflect the meeting, mergence, and coexistence of species representative of the northern Rocky Mountain flora or the Madrean flora of Mexico. Some species find their northern or southern limits in these mountains. The mountains have allowed for the migration of some species to the north or south (Gehlbach 1981). The northern mountain ranges in the Madrean Archipelago of Arizona have more components of the Rocky Mountain flora and fauna than those further south, where Mexican affinities are greater. Local and regional climatic patterns and the natural impacts of fire, wind, and insects have influenced the establishment and survival of the forests and woodlands.

Human activities since pre-historic times have affected the distribution, characteristics, and health of the region's forests and woodlands. Although these lands have been heavily utilized, especially since European settlement, 96 percent of the original postglacial forests and woodlands still exist (Gehlbach 1981). Utilization of these lands continues to change; traditional land uses to supply wood for forest products or mining industries or forage for livestock grazing are often perceived to be in conflict with increasing de-

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mands for recreation, landscape preservation, watershed protection, and habitats and site requirements of rare species. Demands for fuelwood have increased. Privately owned woodlands are increasingly being converted to home sites, causing land management conflicts, fragmentation of wildlife habitats, and potential fire control problems. There are concerns about the sustainability and health of the mountain ecosystems under pressure from human activities and natural effects of fires and insect infestations, and the impacts of past fire suppression activities.

Silvicultural prescriptions can be developed to help ensure long-term sustainability and to provide for forest and woodland health. Silviculture can be used as an ecosystem management tool to enhance wildlife habitat, the production of herbaceous species for both livestock and wildlife, and watershed protection. It can also be used to enhance and maintain biological diversity within the region.

The objectives of the paper are to review the characteristics of the forests and woodlands of the Madrean Archipelago, some of their historical land uses, and some appropriate silvicultural prescriptions. Riparian woodlands, an extremely important ecosystem within the Sky Islands, will not be covered here; they are covered elsewhere in these proceedings. Although the region contains numerous isolated mountain ranges that vary in physical size and vegetational associations, the current effort will concentrate on the five largest and highest mountain ranges: Santa Catalina, Huachuca, Santa Rita, Chiricahua, and the Pinaleno or Graham Mountains.

GENERAL DESCRIPTION

Physiography

The five mountain ranges are within the mountain subdivision of the Basin and Range Geological Province that crosses Arizona in a northwest to southeast belt (Wilson 1962). The Province is characterized by elongated mountain ranges trending northwest to southeast, separated by broad, generally alluvial valleys (Nations and Stump 1981). Peaks range from Mt. Lemmon in the Santa Catalina Mountains with an elevation of 2,791 m to Mt. Graham, the highest peak in the zone, with an elevation of 3,265 m. Mt. Graham is over 2,377 m above the Gila Valley at Safford. Most other peaks in the region do not extend above 2,438 m. The ranges tend to be elongated, for example, the Chiricahua Mountains are approximately 64 km long and between 6 and 32 km wide (Jackson 1970).

Climate

The regional climate in southeastern Arizona is semiarid, and precipitation is bimodal. Winter precipitation is associated with frontal storms originating in the Pacific Ocean that move westerly over the State. Winter conditions generally prevail from October through May, but most intense storms occur between mid-November and mid-April. Late spring and early summer are typically dry. Summer monsoon moisture begins to enter the region in late June or July; storms are convective resulting from the flow of tropical air over heated mountain terrain. Intense summer thunderstorms, which are common over mountains, result from a combination of thermal heating, orographic uplifting, and conveyance of air on the windward side of the mountains (Gottfried 1989). Late summer and early autumn tend to be dry, although tropical cyclones during this season may push moisture into the State producing record rainfalls. Summer precipitation may account for up to 70 percent of the annual total in southeastern parts of Arizona (Bahre 1991). Records at the Chiricahua National Monument indicate that 50 percent of the precipitation occurs in July and August, and that May is the driest month. Annual precipitation ranges from 230 to 635 mm, although higher elevations can receive over 890 mm, often as snows in December and January. Bahre (1991) indicated that average temperatures at higher elevations can average 1.6° C in January and 18.3° C in July.

The amounts of precipitation, available moisture, and the resulting distribution of vegetation zones within the Madrean Archipelago are influenced by mountain physiography. Elevation affects precipitation and temperature; however, Lowe (1961) indicated that mountain geomass is more important than elevation in determining vegetation. He reported a different vertical displacement of vegetation types and species on adjacent peaks of different mass. He referred to this phenomenon as the Merriam effect. This may be one reason for the absence of Engelmann spruce (*Picea engelmannii*) at 2,740 m in the Santa Catalina Mountains, while it is common at that elevation in the more massive Pinaleno Mountains (Lowe 1961). Gehlbach (1981) stated that less massive mountains tend to be more arid. He indicated that because the Huachuca Mountains are lower and a third smaller in area than the Chiricahua Mountains, coniferous forests are displaced 305 m upward there. The Merriam effect may be related to drying winds (Hanks and Dick-Peddie 1974), or to the influence of geomass on orographic precipitation. Gehlbach (1981) indicated that mass may be linked to the speed that mountains heat and cool during the summer, since slower changes reduce evaporation rates and allow for more efficient utilization of summer moisture.

Geology and Soils

The mountains of the Madrean Archipelago consist of tilted, and sometimes structurally deformed blocks of rocks that are bounded by faults and have been severely eroded (Nations and Stump 1981). Precambrian and Tertiary granites are common in the Basin and Range Province, as are volcanic rocks from the Mesozoic to Quaternary (Hendricks 1985). The Chiricahua Mountains were an important volcanic center about 26 million years ago, characterized by explosive production of large quantities of ash and the formation of caldera complexes (Nations and Stump 1981). The orogeny which had the greatest impact on the Province began about 13 million years ago, and may have ended in southeastern Arizona about 6 to 3 million years ago (Hendricks 1985).

Mountain soils within the Province are generally shallow, rocky and gravelly (Hendricks 1985). Soil development depends on parent material and erosional surface stability. Weathering of granitic material tends to produce soils with coarse surface material and little profile development, and subsurface soils that are gravelly sandy loams or gravelly loams. Volcanic rocks weather into fine-grained material; soil development depends largely upon erosional dynamics on the site, although relatively deep soils are possible where particle removal is low. Higher elevation mountain soils tend to be more acidic and contain more organic matter than soils at lower elevations.

Hendricks (1985) classified most of the soils within the five mountain ranges as Mesic Subhumid soils. These soils are found at about 2,135 m in southeastern Arizona, where mean annual soil temperatures of 8.3 to 15.0° C and more than 405 mm of mean annual precipitation occur. Most of these soils, except for some areas in the Huachuca Range, are within the Lithic Haplustolls-Lithic Argiustolls-Rock Outcrop Association. The soils are shallow, gravelly and cobbly, moderately coarse to moderately fine-textured. Slopes are variable; rock outcrops are found in the hills and mountains. They usually support woodlands of oak, pinyon, and juniper. The Huachuca Mountains contain some areas of the Casto-Martinez-Canelo Association. These soils are found on mesas and valley slopes between 1,675 and 1,890 m in elevation, and are deep, gravelly, moderately fine or fine-textured. The Casto and Canelo soils support woodlands while the Martinez soils support grasslands. The Casto and Martinez soils are Udic Haplustalfs and the Canelo is an Aeric Ochraqualf.

Hendricks (1985) identified Frigid Subhumid soils at the highest elevations in the Pinaleno and Santa Catalina Mountains. These soils occur at elevations of from 2,075 to 3,290 m, where the mean annual soil temperature is less than 8.3° C and mean annual precipitation is over 405 mm. They are associated with pine, mixed conifer, and spruce-fir forests, and are representative of the Mirabal-Baldy-Rock Outcrop Association. The soils are classified as Typic Ustorthents and Typic Cryorthents, and are shallow to deep, gravelly and cobbly, and moderately coarse-textured; rock outcrops are characteristic of some sites.

FOREST AND WOODLAND VEGETATION

General Distribution Patterns

The elevational zonation of woodlands and forests within the Madrean Archipelago has been described by a number of authors (Lowe 1964, Whittaker and Niering 1965, Brady and Bonham 1976, Gehlbach 1981, Niering and Lowe 1984, Hendricks 1985, Bahre 1991). Whittaker and Niering (1965) and Niering and Lowe (1984), in their studies on a south slope of the Santa Catalina Mountains and in the highest elevations of the Pinaleno Mountains, listed the plant communities and their elevational distributions. These can be regrouped, based on Niering and Lowe (1984), as: Sonoran Desert scrub (below 1,220 m), semi-desert grassland (1,220 to 1,700 m), open oak woodland (1,400 to 1,700 m), pygmy conifer-oak woodlands (1,520 to 2,130 m), pinyon-oak woodland (1,830-2,130 m), Chihuahua pine-oak woodlands (1,830 to 2,130 m), ponderosa pine-oak forest (2,130 to 2,440 m), ponderosa pine forest (2,440 to 2,740 m), montane fir forest (2,440 to 2,740), mixed conifer forest (2,740 to 2,920 m) and subalpine forest communities (above 2,920 m).

Whittaker and Niering (1965) indicated how community distribution also varied by aspect. The drier the site, the higher the elevational displacement. Species distribution patterns by aspect and elevation in the Huachuca Mountains and in the Santa Catalina Mountains are similar (Brady and Bonham 1976), although there appear to be differences between the Huachuca and Chiricahua Mountains (Gehlbach 1981). In the current review, we have grouped Niering and Lowe's open oak and Chihuahua pine-oak woodland as the encinal woodlands, the pygmy conifer-oak and pinyon-oak woodlands as the pinyon-juniper woodlands, and the five forest zones together as the high elevation coniferous forests.

VEGETATION CHANGES OVER TIME

Biogeography

The current distribution of woodlands and forests on the isolated mountains of the region is the result of shifts in the climate conditions over the past 24,000 years (Jackson 1970). Merrill and Pewe (1977) indicated that temperatures in the Southwest were 5 to 6° C cooler and precipitation was 20 to 25 percent greater during the late Quaternary when glaciers occurred on Mount Baldy in the White Mountains (8,000 to 35,000 B.P.). Palynological evidence from the Willcox Playa indicates a vertical displacement of vegetation zones of at least 915 to 1,220 m during pluvial times (Hevly and Martin 1961). This displacement allowed Rocky Mountain forest flora to spread from the Colorado Plateau into the sub-Mogollon mountain ranges and into the Sierra Madre Occidental. The changing distributions of vegetation types in the Southwest over the past 22,000 years and their relationships to climate have been document by analyses of packrat (*Neotoma* spp.) middens (Van Devender and Spaulding 1979).

The Hypsithermal Interval, also called the Medieval Warm Period, brought warmer and drier conditions and a rise in the elevational distribution of vegetation zones; the vegetational links between mountain ranges and the Colorado Plateau were broken and xerophytic species invaded the lower elevations within the Basin and Range Province. Climatic conditions over the past 4,000 years have been moderately cool and moist although extended periods of drought have occurred (Jackson 1970).

Historical

Fire, wind, and insects are the main natural disturbances in the region. Changes in the characteristics and timing of natural fires affect the current distribution of vegetation zones. Increased fires during the Hypsithermal may have eliminated some vegetation types on marginal sites (Jones and Rietveld 1974). American Indians probably set some fires, but lightning was the main factor. Most fires were localized or ground fires that tended to reduce understory vegetation. Forests and woodlands were less densely stocked with trees prior to European settlement (Moody et al. 1992, Covington and Moore 1994). Fire suppression has eliminated most fires and allowed for potentially dangerous fuel accumulations and fire ladders to develop. Stand replacing crown fires are becoming more common because of these changes (Covington and Moore 1994).

Prior to European settlement, under natural fire regimes, upper mixed conifer forests may have contained less spruce, and ponderosa pine (*Pinus ponderosa*) forests less Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Overgrazing in the woodlands, which eliminated the herbaceous layer, also prevented the spread of wildfires and reduced competition for tree establishment. The movement of oaks and junipers into grasslands and the increased tree densities in juniper savannahs have been attributed to these two factors.

Although there are a large number of forest insect species within the area, they were not considered to be a major problem (Shupe and Solether 1973), although the evaluation may be different now, especially on Mt. Graham. Wind may have had a significant impact within the coniferous forests.

HUMAN USE OF FORESTS AND WOODLANDS

The encinal woodlands of the Madrean Archipelago have been important to prehistoric and historic people (Propper 1992). The prehistoric people gathered acorns for food and ceremonial purposes, and pinyon nuts and juniper berries for winter food. American Indians also collected fuelwood and construction materials and hunted game in the woodlands and forests.

The Apache Indians and Spaniards entered the region in the late 1600 (Propper 1992). The Spanish used the wooded areas primarily for fuelwood and construction material for their homes, mines, and ranching activities. However, intensive development in the region did not begin until the 1870s and 1880s, when hostilities with the Apaches began to decline and the railroad entered the region. Large herds of cattle were moved into the area from Texas and Sonora during this period; Bahre (1991) indicated that there were over 200,000 head in southeastern Arizona in 1890. The major impact on the woodlands during the late 19 century was the cutting of wood to support mining activities. The Tombstone Mining Region contained over 50 silver mines and 7 stamp mills in 1878 (Bahre 1991). Fuelwood, mostly oak (*Quercus* spp.), pinyon, juniper (*Juniperus* spp.), and mesquite (*Prosopis juliflora*), was cut to run the steam engines and meet the cooking and heating needs of the inhabitants (Bahre 1991). Over-cutting adjacent to settlements caused fuelwood shortages that resulted in increased transportation costs to bring in supplies from more distant mountains and in increased prices.

Sawmills in the Santa Rita Mountains supplied ponderosa pine and Douglas-fir to Tucson and neighboring mines before 1870. Logging began in the other mountain ranges after the settlement of the Upper Gila Valley and the beginning of the mining booms. The Huachuca and Chiricahua Mountains supplied much of the construction timber for Tombstone. Historic records indicate that only the five largest mountain ranges had significant logging activities, mostly prior to 1900 (Bahre 1991). Only the Pinaleno and Santa Catalina Mountains have had limited harvesting since that time. Most of the logging in the Pinaleno Mountains occurred after 1893; however, early activities were confined to isolated pockets of timber on the lower third of the mountain (Shupe and Solether 1973).

ENCINAL WOODLANDS

Information on the distribution, characteristics, and uses of encinal woodlands of the southwestern United States and northern Mexico has been obtained largely from Brown (1982). The encinals, also referred to as the Madrean evergreen woodland formation (Brown and Lowe 1980), are concentrated in the Sierra Madre Occidental of Mexico, from where they extend northward into southeastern Arizona, southern New Mexico, and Texas. Encinal woodlands cover approximately 80,300 km^2 in aggregate, although a precise delineation of this biotic community is difficult, since inconsistent criteria for classification have been employed (Gottfried and Ffolliott 1993).

Annual precipitation in the woodlands exceeds 405 mm; generally, half falls during the growing season of May through August. Extremes in annual precipitation range from 305 to over 1,015 m. Freezing temperatures are rare in the southern portions of the woodlands but increase to an average of almost 125 days at the northern limits.

The woodlands occur between 1,200 and 2,200 m in elevation. Structural development of the encinals is apparently determined by soil type and depth. Stands commonly are located in a variety of sites including along drainages, on rocky slopes, and on alluvial basin fill and fans (USDA Forest Service 1987).

Characteristics

A large variety of oak species are found in the encinal woodlands. Mexican blue (*Q. oblongifolia*) is found at the lowest elevations to the north. Among the oaks in the mountainous regions of southeastern Arizona, southwestern New Mexico, and Texas are Emory (*Q. emoryi*), Arizona white (*Q. arizonica*), Mexican blue, and gray (*Q. grisea*). Silverleaf oak (*Q. hypoleucoides*) and netleaf oak (*Q. rugosa*) are found at the intermediate elevations. Border pinyon (*P. discolor*) and juniper species are found intermixed with the oaks on many sites throughout the encinals. Other important pines within the encinal woodlands are: Chihuahua pine (*Pinus leiophylla* var. *chihuahuana*) and Apache pine (*P. engelmannii*).

At its upper elevations in the southwestern United States and in Mexico, the encinals often grade into the interior ponderosa pine type. They can merge with the pinyon-juniper woodlands with complex transitional forms.

Encinal woodlands contain relatively small, often multiple-stemmed, irregularly formed trees. Species compositions and stand densities depend largely upon specific site characteristics (Gottfried and Ffolliott 1993). One-, two-, or occasionally three-aged stand structures are found. Intermingled with these trees are shrubs, grasses and grass-like plants, forbs, and succulents, often in parks and savanna-like mosaics. Stand density is related to soil properties, site characteristics, and fire and land use histories.

Tree densities in the encinals vary considerably. The numbers of trees range from a few scattered individuals to several hundred stems/ha. Volumes of stemwood vary from less than 2 to over 100 m^3/ha (Ffolliott and Gottfried 1992). Annual growth rate is relatively slow, ranging from 0.25 to 0.50 m^3/ha, an annual growth rate of less than 1 percent. Mortality generally is low, likely because the long history of utilization in some areas has reduced the number of old trees (Conner et al. 1990).

Twelve habitat types in the Southwest are dominated by encinal oak species (USDA Forest Service 1987). A predominant habitat type of the encinals in southeastern Arizona is *Quercus emoryi/Bouteloua curtipendula*. In addition, a general scarp woodland habitat type is recognized on sites with slopes in excess of 40 percent.

PINYON-JUNIPER WOODLANDS

Pinyon-juniper woodlands cover approximately 19 million hectares in the western United States. The climate in the woodlands is classified as arid or dry sub-humid (Gottfried and Ffolliott 1993). In the Southwest, stands generally are found at elevations from 1,370 to 2,290 m where annual precipitation ranges from 305 to 560 mm.

Although Whittaker and Niering (1965) and Niering and Lowe (1984) did not identify a separate a pinyon-juniper community, these stands are unique and easily differentiated. Pollisco et al. (this volume), in a study of woodlands in three Sky Island mountain ranges, found numerous sites where pinyon and juniper constituted at least 80 percent of the tree basal area. The seasonal distribution of precipitation, particularly the relative amounts of winter and summer moisture, influences stand composition. The woodlands grade into grasslands, brushlands, and encinal woodlands on drier sites, and into ponderosa pine forests on more moist sites. They are found on soils associated with different parent materials and characterized as being shallow, well-drained, and generally of low fertility, although exceptions occur.

Characteristics

Although the two-needled Colorado pinyon (*P. edulis*) is the most characteristic pinyon of the woodlands of the Southwest, the three-needled border pinyon is associated with most pinyon-juniper and encinal woodlands of southern Arizona and New Mexico. A single-needled pinyon, *P. californiarum* var. *fallax*, also is found in the pinyon-juniper stands located south of the Mogollon Rim, including parts of the Madrean Archipelago. The Mexican pinyon (*P. cembroides*) is widespread at lower elevations in the mountains of northern Mexico, (Critchfield and Little 1966), and in the rain shadows of the eastern and western Sierra Madre mountain ranges (Segura and Snook 1992). Border pinyon is often classified as Mexican pinyon in some of the older literature.

Junipers are the other major tree group in the southwestern woodlands. The major species in the Madrean Archipelago are: alligator (*J. deppeana*), one-seed (*J. monosperma*), and red berry juniper (*J. erythrocarpa*). Utah (*J. osteosperma*) and Rocky Mountain (*J. scopulorum*) are important in other parts of the Southwest. Alligator juniper is an important component of many encinal stands in the southwestern United States and in the Mexican pinyon forests. Red berry juniper (*J. erythrocarpa*) is found on drier sites in southern Arizona and New Mexico.

A typical pinyon-juniper stand in the Southwest is uneven-aged and contains about 1,150 trees and 21 m^2 of basal area per hectare (Barger and Ffolliott 1972). Niering and Lowe (1984) reported that an average Mexican pine-oak woodland on the south slope of the Santa Catalina Mountains contained 1,124 trees/ha. Although oak species dominated the smaller size classes, 46 percent of the total number of trees and 95 percent of the trees 15 cm and larger at breast height (bh) were pinyon and alligator juniper. Pinyons are more common in a typical stand in the Southwest and tend to dominate in the smaller size classes, while junipers are an important component of the larger size classes and contribute almost half of the wood volume. However, some pinyons in the Santa Catalina Mountains were over 60 cm in diameter (Niering and Lowe 1984). Even-aged stands develop after disturbances such as fire and tree control operations for range improvement or agricultural activities.

Pinyon-juniper woodlands are not homogeneous and consist of a large number of habitat types or plant associations (Moir and Carleton 1987). The USDA Forest Service (1987), for example, recognizes six habitat types in southern Arizona and New Mexico where border pinyon dominates and four where either alligator or red berry junipers dominate. Available soil moisture is the most critical factor controlling the distribution of woodlands, and the composition and density on undisturbed sites. Junipers, which are more drought-tolerant than pinyon, dominate on drier sites, but pinyons increase in importance as available moisture increases. The distribution of juniper species is influenced by the proportion of winter precipitation. Alligator, one-seed, red berry, and Rocky Mountain junipers dominate in summer moisture areas, while Utah juniper occurs in winter moisture areas. Temperature extremes also affect the upper and lower elevational distribution of woodland species.

THE HIGH ELEVATION CONIFEROUS FORESTS

Community Distribution

High elevation coniferous forests generally occur above 2,130 m. Niering and Lowe (1984) recognized six community types in the Santa Catalina Mountains and an additional two types in the higher Pinaleno Mountains. Spruce-fir forests, which are confined to the highest elevations within the Pinaleno Mountains, contain Engelmann spruce and corkbark fir (*Abies lasiocarpa* var. *arizonica*). These are usually found above 2,920 m. Mixed conifer forests, which includes montane forest communities described by Niering and Lowe (1984), are found from 2,440 to 2,920 m. These are diverse forests that can contain up to seven major tree species: Douglas-fir, Engelmann spruce, corkbark fir, white fir (*A. concolor*), ponderosa pine, southwestern white pine (*P. strobiformis*), and quaking aspen (*Populus tremuloides*). The mix of species and habitat types will vary throughout the Madrean Archipelago. Corkbark fir, for example, is found at one location in the Santa Catalina Mountains, where it occurs with aspen, Douglas-fir, and white fir, and is absent in the Santa Rita, Chiricahua, and Huachuca Mountains. Some mixed conifer stands can be dominated by Douglas-fir and white fir with minor components of other tree species.

The third major category of forests is dominated by ponderosa pine and is found from 2,130 to 2,740 m. Silverleaf and Arizona oaks are common in pine stands between 2,130 and 2,440 m, while Gambel oak (*Quercus gambelii*) is common at elevations between 2,440 and 2,740 m. Southwestern white pine with some Douglas-fir are found in stands between 2,590 and 2,740 m (Niering and Lowe 1984). The five-needled Arizona ponderosa pine (*P. ponderosa* var. *arizonica,* also classified as *P. arizonica*) replaces the Rocky Mountain variety (*P. ponderosa* var. *scopulorum*) on many southern Arizona sites (Lowe 1964). The spruce-fir, mixed conifer, and ponderosa pine forests respectively correspond to Merriam's Hudsonian, Canadian, and Transition Life-zones (Lowe 1964).

Habitat Types

The USDA Forest Service (1987) recognizes a large number of forest habitat types within southeastern Arizona that are found at a variety of elevations and in different mountains. For example, a partial list of spruce-fir habitat types would include:

Abies lasiocarpa / Carex foenea	3,050 m	Pinaleno
A. lasiocarpa / Erigeron eximius	2,865-3,110 m	Pinaleno
A. lasiocarpa / Jamesia americana	2,650 m	Catalina
A. lasiocarpa / moss	2,985-3,505 m	Pinaleno
Picea engelmannii / Acer glabrum	2,745 m	Chiricahua

Some other common habitat types are *Pseudotsuga menziesii/ Quercus hypoleucoides,* which is found in the Chiricahua, Pinaleno, Huachuca, and Animas Mountains between 1,980 to 2,620 m, and *Pinus ponderosa/ Quercus hypoleucoides,* which is found in the Chiricahua, Pinaleno, Santa Rita, Santa Catalina, and Galiuro Mountains between 2,100 and 2,450 m.

Amount of Area Covered by Forest

Almost all of the forests within the United States portion of the Madrean Archipelago are administered by the Coronado National Forest. There are about approximately 2,020 ha in the Santa Catalina and 4,050 ha in the Chiricahua Mountains that could be classified as commercial forest based on stand conditions and accessibility (Shupe and Solether 1973). The Pinaleno Mountains contain 3,410 ha of operable commercial forest land, including 440 ha of ponderosa pine, 2,260 ha of mixed conifer, and 710 ha of spruce-fir; in addition, there are 1,920 ha of commercial forest that is inoperable (Shupe and Solether 1973). The Pinaleno Mountains also contain pockets of forest vegetation and forested steep slopes and rocklands that are not commercially operable.

Stand Characteristics

A typical spruce-fir stand in the Pinaleno Mountains contains approximately 2,773 conifer and aspen trees/ha that are 2.5 cm dbh and larger; 95 percent of the stand consists of corkbark fir and spruce, in almost equal proportions (Niering and

Lowe 1984). However, the proportions of spruce and fir vary depending on the stage of development following major disturbance (Stromberg and Patten 1991). In old-growth stands, spruce will have a greater basal area and density of large trees, while corkbark fir will dominate the smaller trees and sapling size classes (Niering and Lowe 1984, Stromberg and Patten 1991). Thirteen percent of the spruce in the Niering and Lowe sample, for example, were greater than 30 cm, while only 2 percent of the fir was in the larger size classes.

The mixed conifer forest in the Pinaleno Mountains contained about 2,330 trees per hectare (Niering and Lowe 1984). Over 50 percent of the average stand consisted of white fir, mainly because of the large number of trees in the smaller dbh classes (less than 15 cm). Spruce and fir comprised 34 percent of the density, and Douglas-fir was about 10 percent. Some of the old-growth Douglas-fir had diameters of 152 to 178 cm (Shupe and Solether 1973).

The Douglas-fir and white fir forest in the Santa Catalina Mountains only contained 455 conifers/ha but supported an additional 425 trees/ha of *Acer* spp., *Jamesia americana*, and *Robinia neomexicana*. The ponderosa pine forest contained 1,375 conifers/ha, 74 percent ponderosa pine and the other being southwestern white pine, Douglas-fir and white fir. Oaks and *Robinia* made up an additional 450 trees/ha.

SILVICULTURE

Silviculture Prescriptions

One part of the definition of silviculture states that it is the application of a knowledge of silvics to the treatment of a forest or woodland (Gottfried and Ffolliott 1993). One key objective of traditional silviculture is to ensure adequate tree regeneration for the future. There is growing interest and public demand for ecosystem management that will create and maintain healthy and sustainable forest and woodland ecosystems. Health is defined as the ability of a forest to recover from natural or human-caused stressors (Haack and Byler 1993), while sustainability refers to the long-term production of all forest values. Silviculture is a tool for ecosystem or multiresource management of any forest or woodland ecosystem. Silvics or tree ecology must serve as the basis for management activities if ecosystem management goals are to be achieved. Managers, with public input, must determine the desired future condition and mix of resources to be favored on a site, and modify their prescriptions.

Encinal Woodlands

Ecological research to support silvicultural prescriptions in the encinal woodlands, is relatively limited (McPherson 1992). Natural regeneration from seed is apparently episodic; oak seedlings were 19 percent of the regeneration in one study; sprouting from roots and stumps was a more common regenerative mechanism (Borelli et al. 1994). Only nine percent of the plots contained any tree regeneration, and, as a consequence, the encinals might not be reproducing in sufficient numbers to sustain themselves if they continue to be heavily harvested (Borelli et al. 1994). On many sites, encinal stands sprout vigorously after cutting, indicating that coppicing might form a basis to obtain regeneration in silvicultural prescriptions. Furthermore, harvesting cycles can be reduced through proper thinning of the resultant coppice (Touchan et al. 1992). Sustainability of vegetative reproduction is unknown, however.

A silvicultural prescription for sustained productivity of fuelwood, based largely upon on the studies mentioned above and management procedures of the USDA Forest Service in southeastern Arizona, might involve the following scenario. Trees to be harvested are marked for removal by managers (Bennett 1992). A subsequent thinning of the resultant coppice to retain 1, 2, or 3 of the largest and most vigorous residuals is scheduled for 5 years after harvesting. Delaying thinning beyond this time can reduce growth of the residuals (Touchan et al. 1992). Residual trees are selected for harvesting after they attain a specified size. For example, a diameter of 15 to 20 centimeters drc (diameter at root collar) likely can be reached in 20 to 30 years after the coppice thinning on some sites. The USDA Forest Service specifies a 15-centimeter stump height and about a 45-centimeter slash height in southeastern Arizona. Other silvicultural prescriptions based upon clearcutting, shelterwood, seed tree, and selection cuttings have not been widely tested.

Removal of trees in any silvicultural treatment changes landscape diversity, which can affect habitats for wildlife. Unfortunately, there have been no studies on the effects of harvesting in encinal woodlands on deer habitats (Smith and

Anthony 1992) or those of other big game species, although an increase in diversity might be beneficial if sufficient cover is retained. Encinal woodlands provide resources for unique assemblages of neotropical migratory birds (Block et al. 1992), and it is likely that different management approaches will be needed for different situations. Actual impacts of silvicultural treatments on nongame bird and many other wildlife species remain to be evaluated.

Although livestock production is important, encinal woodlands have not been subjected to large-scale range improvement practices (Ffolliott and Guertin 1987, McClaran et al. 1992). Haworth and McPherson (1994) indicated that production levels and species compositions of herbaceous plants might not be affected greatly by range improvement practices consisting of the removal of trees in fuelwood harvesting. However, more research is necessary to assess overstory-understory relationships over the broad range of sites found in the encinal woodlands (McPherson 1992).

Pinyon-juniper Woodlands

Although knowledge of pinyon-juniper woodland ecology is increasing, it still is incomplete (Gottfried and Ffolliott 1993). However, managers recognize that heavy, wingless seeds of pinyons and junipers, and dryland environmental conditions require special consideration when preparing silvicultural prescriptions. It would be ideal if treatments could be linked to good seed crops, but this is difficult considering the relatively long period between good years, and the inability to confidently forecast them. Silvicultural prescriptions must be linked to habitat type in order to succeed.

Bassett (1987), in reviewing the potential applicability of common silvicultural prescriptions to pinyon-juniper woodlands in the Southwest, concluded that single-tree selection and two-step shelterwood methods best sustain stand health and productivity for tree products or for a mix of resources. These cutting methods are compatible with the dispersal patterns of heavy tree seed, provide protected micro-sites for regeneration, and are esthetically acceptable. The single-tree selection method reduces stand density, but still retains the uneven-aged structure and horizontal and vertical diversity important for some wildlife species. Initial harvesting by the shelterwood method, which leaves the best trees for seed production, also tends to retain a diverse cover. However, there are some disadvantages with both methods, especially the costs associated with intensive management and potential damage to residual trees during subsequent harvests. Bassett (1987) discussed the trade-offs that must be evaluated in preparing a silvicultural prescription. Success from a forestry perspective will depend largely upon achieving satisfactory regeneration.

The shelterwood method is used to regenerate even-aged stands and can be used in existing even-aged and uneven-aged pinyon-juniper woodlands. Bassett (1987) recommended the two-step shelterwood method. A modified one-cut shelterwood method, which removes the entire overstory, can be used where advance tree regeneration is satisfactory. However, it is important to protect the younger trees from harvesting damage.

Bassett's (1987) recommendations are valid for stands within the Madrean Archipelago, especially if regeneration of pine or non-sprouting juniper species is important. The clearcut or seed-tree methods would favor alligator juniper and oak regeneration, but generally result in unsatisfactory regeneration of species with short seed dispersal distances.

Current management is attempting to integrate livestock and wildlife with tree production (Gottfried and Severson 1993). Silvicultural methods can also be used to enhance forage production for livestock and forage and cover for wildlife. A common treatment is designed to clear small dispersed areas of trees. This practice has been shown to benefit elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) (Short et al. 1977). However, care must be taken to insure that openings are not too large (Gottfried and Severson 1993) or that the woodlands not become too fragmented. Wildlife and other needs must be assessed to ensure tradeoffs in resource allocation are acceptable. Openings create a more diverse landscape that should favor other wildlife species such as small mammals (Gottfried and Severson 1993). In many cases, the size of the openings might not be critical, if continuous corridors of adequate width are maintained. Managers must decide if cleared wildlife-livestock openings should be maintained, or trees should be allowed to reoccupy the sites. A management scheme could be created which would involve a variety of seral stands in space and time. This strategy would enhance biological diversity within woodland landscapes.

Treatments that reduce tree densities should benefit livestock and native ungulates by providing additional forage while maintaining thermal and hiding cover. However, the impacts of residual trees on understory dynamics are unclear. Some questions concern the quantity and quality of herbaceous vegetation which can be achieved, and the longevity of any increases. Relationships among overstory cover, tree regeneration, and forage yields need better definition.

Conifer Forests

The only remaining commercial forests in the United States portion of the Madrean Archipelago are found in the Santa Catalina, Chiricahua, and Pinaleno Mountains (Shupe and Solether 1973). However, because of conflicting land uses in the Santa Catalina Mountains and poor site and low stand densities in the Chiricahua Mountains, these two areas could not support a commercial timber management program. The Pinaleno Mountains contain commercial stands of spruce-fir, mixed conifer, and ponderosa pine. The silviculture of these forest types in the central and southern Rocky Mountains has been reviewed by Alexander (1974). This review covered the various even-aged and uneven-aged systems that are applicable to achieve satisfactory regeneration of these forests. Silviculture for multiple-use was covered, but in less detail.

Shupe and Solether (1973) indicated that the most successful regeneration prescriptions on Mount Graham were light selection cuts or small patch clearcuts of from 0.8 to 2.0 ha. Blowdown was a problem in some stands if overstory removals were heavy, and dwarf mistletoe (*Arceuthobium vaginatum* var. *cryptopodum*) was a problem in some ponderosa pine stands. Ice damage has been a periodic problem. Multiple-use silviculture for a variety of resources and for sustained stand health is the main concern in the Sky Islands today. The USDA Forest Service overall management objective for Mount Graham is to maintain and enhance esthetics and outdoor recreational values (Shupe and Solether 1973).

Silvicultural treatments anticipated in 1973 were: salvage of poor risk and overmature trees; light commercial thinning of sawtimber and subsawtimber stands; overstory removal (simulated shelterwood) where satisfactory regeneration has become established under overmature trees; and stand regeneration according to a single-tree or group selection prescription (Shupe and Solether 1973). Many of the Mt. Graham stands are fairly old and natural mortality is increasing; individual tree growth is also lower in dense stands. The goal was to maintain tree vigor and reduce insect and disease damage. These prescriptions may not be feasible today unless there is a market for the timber. More importantly, public attitudes do not support commercial harvesting solely for wood products; harvesting would have to be related to forest health considerations.

Slash cleanup to reduce fire hazard was an important component of most treatments (Shupe and Solether 1973). Slash disposal policies are under review, since ecosystem benefits must be compared to increased fire and insect hazards. However, Moody et al. (1992) indicate that a high percentage of the forest on the Coronado National Forest is at high risk of catastrophic wildfires because of high fuel loading and lack of management to alleviate the situation. If conditions have changed drastically since 1973, the Forest Service may have to evaluate the need for fuel reduction activities, sanitation or salvage logging, and eventually, prescribed fire. The latter would be difficult because of the fuel loading and fuel ladders. Any activities to correct the condition would draw public comment.

Insect and fire control activities in the old-growth stands within non-wilderness areas will also have to be evaluated. The public may endorse natural forest dynamics in a remote wilderness area but be less tolerant when they can see its effects on their way to a favorite campground. Large areas of dead and dying trees or of burned snags often are the results of unhealthy stand conditions. Silvicultural treatments may become necessary to open dense stands where tree vigor, and resistance to insects and diseases, has been reduced or where unacceptable insect and disease damage has been identified. Regeneration or improvement treatments would be used to improve stand health prior to insect or disease attack, while sanitation treatments would be used to prevent a pest from spreading.

The roundheaded pine beetle (*Dendroctonus adjunctus*) currently is causing considerable mortality in ponderosa pine forests on Mount Graham, especially adjacent to Riggs Lake. Coronado National Forest crews have cut infected and dead trees in hopes of removing potential hazards and containing the problem. Many cut trees have been bucked and left as firewood for recreational visitors. Some were sold to a sawmill in Alamogordo, New Mexico.

CONCLUSIONS

The mountains of the Madrean Archipelago or Sky Islands support a diverse mixture of forest and woodland ecosystems representing the Rocky Mountain and Madrean floras. Regional and local climatic conditions over last 24,000 years have influenced the present distribution of vegetation communities. These lands have been used by humans since prehistoric times.

Demands for the forest and woodland resources have changed over time. However, there currently are conflicts among different interest groups as to how intensively the land should be managed. To this end, silvicultural prescriptions, matched to habitat type, provide one tool for ecosystem management in the Madrean Archipelago. The Coronado National Forest is charged with ecosystem management that will ensure sustainability and health of the region's forests and woodlands. The various interest groups should work together to achieve these goals.

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