Dynamics of the Landscape Patches in the Old Growth Forest on Mt. Graham (Pinaleno Mountains), Arizona

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Abstract.—The old growth forest on Mt. Graham (Pinaleno Mountains) of eastern Arizona is comprised of forest patches rather than being homogeneous in composition. These patches reflect the heterogeneity of disturbances that occur on the mountain. The two primary disturbances have been fire and wind, although clearing for road construction and recently for an astronomical observatory also are important. The forest patches represent different stages in forest succession following disturbance. Patches can be described as open, forest edge, and mature and old growth forest. With these categories, composition and demography of dominant tree species varies and creates smaller patches within the general categories. Variability results from the relative success of pioneer species and the consequent invasion of other species. There appear to be four recovery patterns following disturbance within the Engelmann spruce-corkbark fir (*Picea engelmannii-Abies lasiocarpa* var. *arizonica*) forest. These include (1) initial spruce invasion closely followed by fir with a second surge of fir recruitment in about 80 years, found more on level topography sites; (2) initial invasion by spruce with fir establishment about 40 years later and a second surge of spruce recruitment about 100 years after recovery initiation, found on moderate topography sites; (3) initial spruce invasion with fir following in about 40-80 years with no second recruitment surge by either species, found on moderate to steep topography sites; and (4) initial spruce invasion with fir recruitment following in about 120 years and surging only in the past 50-60 years, found on steep topographic sites. For all locations there is a conifer recruitment period initiating about 140 BP and lasting about 50 years. This closely corresponds with a wet climatic period following a drought period. Sites with similar recovery patterns are clustered together indicating the forest is composed of large patches rather than a heterogeneous mix of small patches. The locations of large forest patches with particular recovery patterns could be used to project possible successional patterns of recently reforested areas on the mountain.

INTRODUCTION

Many mountains of the Southwest are isolated peaks surrounded by contiguous desert ecosystems. These peaks, often referred to as "sky islands" (Gelbach 1981), have functioned as refugium for the montane and subalpine flora and fauna during climatic fluctuations over the past 10,000 years (Martin 1963). Climatic changes have caused vertical migrations of the mountain flora resulting in extirpation of species. For example, the Engelmann spruce (*Picea engelmannii* Parry)-corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemmon) forest association found on Mt. Graham (Pinaleno Mountains) does not occur on any other sky island in southern Arizona al-

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though the species may be found separately on other mountain tops. Many of the high elevation forests of the sky islands have not been lumbered because of their limited area and therefore have attained "old growth" status.

Old growth forests are becoming increasingly rare in the Southwest. The old growth spruce-fir forest on the Pinaleno Mountains only covers about 360 ha, and occurs primarily above 3,100 m. This is a very small portion of the thousands of hectares of forest on the mountain, most of which has been impacted by timbering. The remainder of the conifer dominated forest communities on the Pinalenos include, in descending order, mixed conifer forest immediately below the spruce-fir forest with the upper stands part of the old growth forest characterized by Douglas fir (*Pseudotsuga menziesii* var. *glauca* (Breissn.) Franco), southwestern white pine (*Pinus strobiformis* Engelm.) and white fir (*Abies concolor* (Gordon et Glendinning) Hoopes); ponderosa pine (*Pinus ponderosa* Laws.) forest; and pinyon-juniper forests. These forests have been described by Johnson (1988) for the Pinalenos and Whittaker and Niering (1965) for the Santa Catalina Mountains near Tucson, Arizona. Whittaker and Niering used the top of the Pinalenos to complete their description of vegetational zonation on a southwestern mountain because the spruce-fir forest did not occur on the Santa Catalinas. In this description they demonstrated how different environments found at different elevations and aspects, and within drainages greatly influenced the pattern of vegetation on the mountain. This was an extension of the early work of Shreve (1915) in his description of distribution of vegetation in relation to climate on a desert mountain.

These studies of desert mountain vegetation along with ours on the Pinalenos (Stromberg and Patten 1991) describe the high elevation forest communities not as one homogeneous forest stand, but rather as a heterogenous stand of forest patches, each a consequence of site conditions and external disturbance factors. Old growth spruce-fir forests in Colorado have also been shown to be a function of the interaction of these factors (Rebertus et al. 1992). Most landscapes are affected by natural or anthropogenic disturbances which operate in a heterogenous manner resulting in a heterogenous landscape. Frequency and severity of disturbance events are often controlled by site conditions, resulting in a mosaic of forest patches, each a consequence of the resistance and resilience of the community to the type of disturbance.

The forest on the top of the Pinaleno Mountains is a mosaic of patches resulting primarily from two natural disturbance factors and one anthropogenic disturbance. These are fire (lightning strikes), wind, and strip clearing for fire roads (now abandoned). Very limited cutting has occurred along the edges of cienegas, and more recently road building and clearing has occurred for an astronomical observatory. These disturbances have created (1) burned areas of various sizes in which some trees may have survived, (2) windthrow areas with down timber, (3) openings with no trees, and (4) edge communities. There are also a few open areas for which the cause is not known, although fire is suspected. The topography of the mountain top varies in aspect, with all aspects represented. Soil development appears to be the result of topographic steepness and aspect.

The objectives of this paper are to describe the demographics of different forest patches in the old growth spruce-fir forest of the Pinalenos and to show how they are a result of the temporal and spatial influences of the various disturbance factors acting in concert with site conditions and recovery processes of the different communities.

METHODS

Thirty sites were delineated for study within the high elevation old growth forest area on the Pinaleno Mountains . Of these, 15 were in the spruce-fir zone (3,130 to 3,270 m) and 15 in the spruce-fir, mixed conifer transition zone (2,930 to 3,100 m). Five of the sites were open stands recovering from disturbance and 5 were edges between forest and recently disturbed areas. At each site, trees were sampled for density, dbh and basal area, and cover using ten 20 m^2 plots on randomly placed transects within about a one hectare forest stand. A representative sample of trees was cored for age determination. Shrub and herbaceous cover was determined. The forest floor was sampled for rock and litter cover. Slope and aspect were measured for each site.

RESULTS AND DISCUSSION

Results presented here are limited to spruce-fir stands, especially old growth stands. A more detailed description of all of the study sites has been presented in earlier papers (Stromberg and

Patten 1991, 1994) including cone and seed productivity (Stromberg and Patten 1993).

The oldest spruce-fir stands were about 340 years old. In most cases the oldest trees were Engelmann spruce, while in only a few cases did the corkbark fir achieve nearly this age. Old stands were located throughout the old growth spruce-fir study area. Interspersed among the old stands, where there had been road building or recent windthrow, were younger stands of various ages depending on the time of the disturbance.

The density of different age classes of spruce and fir differs between locations. The pattern of age classes over time is an indicator of the recruitment dynamics of each stand. Because the oldest age of the trees within the spruce-fir forest is about 340 years for most of the old growth stands (an age younger than the maximum age reported for Engelmann spruce of 500-600 years (Alexander 1987)), we assume that there was a major disturbance at that time; most likely an extensive fire. The presence of a few younger stands indicates there also have been more recent disturbances, and road building and winds have created very recent disturbances.

We have suggested that there are two general patterns of recovery from disturbance within the old growth spruce-fir forest depending on the disturbance mechanism (Stromberg and Patten 1994). For a major disturbance that clears a site, for example fire or timber cutting, initial recovery results from invasion of spruce. This is followed in time by either a second spruce recruitment period, or establishment of a young population of fir. In areas that are only partially cleared (e.g., windthrow), both spruce and fir may invade the site but fir more commonly is the pioneer species. Other studies of spruce-fir forests in the Rocky Mountains have shown similar staggered or bimodal recovery patterns following disturbances (Aplet et al. 1988, Rebertus et al. 1992).

A review of age class data for each site indicates that, although each site has its individual pattern that follows the general patterns we have described, there are secondary patterns among sites (fig. 1). The following patterns are based on existing age class densities. We recognize, however, that present trees only represent survivors from past recovery cycles and recruitment events.

Pattern A (fig. 1) shows initial spruce establishment about 340 years BP with a fir establishment surge from about 200 to 100 years BP. Spruce shows another small surge from 100 years BP to near present. This pattern is exemplified by sites 11 and 14 in our study (Site 11 presented).

Pattern B shows spruce establishment about 260 years BP with a second spruce recruitment surge about 180 to 100 years BP. A fir recruitment period occurred in this latter period with most recruitment of fir occurring in the past few decades. This pattern is exemplified by sites 10 and 12 (Site 10 presented).

Pattern C shows a low to moderate level of recruitment of spruce starting about 300 years BP with very limited fir recruitment. About 140 years BP fir had a high recruitment surge which has lasted until the present. This pattern is exemplified by sites 7 and 9 (Site 9 presented).

Pattern D has a low level of spruce recruitment starting about 340 years BP. Fir did not have any recruitment for nearly 160 years until 180 to 140 years BP and has shown a moderate to high establishment rate in the past century. This pattern is exemplified by sites 15 and 16 (Site 15 presented).

In an attempt to explain the different patterns of forest patch development over time, we looked at general site conditions for each pattern (fig. 2). The number of sites for each pattern were too limited to permit statistical analysis, however, there were some differences among the recovery patterns. The pattern with nearly synchronous early recruitment for spruce and fir occurred on sites with nearly level topography (Pattern A). This pattern also had the earliest surge of fir recruitment. The pattern with delayed fir recruitment following spruce initiation occurred on the steepest sites (Pattern D).

To determine what factors might influence seedling establishment of spruce and fir, we ran a correlation between seedlings and various site conditions, especially those that influence the microenvironment near ground surface (Table 1). The presence of an existing canopy, especially of older trees (i.e., high basal area), appears to have the greatest positive relationship with establishment of spruce and fir seedlings. As expected, a dense spruce canopy cover and/or basal area improved conditions for fir. In open sites where herbaceous cover had established, spruce and fir seedling recruitment was low. Steeper slopes also played a negative role in conifer seedling recruitment.

There are common trends among the recovery patterns. Spruce initiates establishment of the spruce-fir forest following an area-clearing disturbance. A few of the study sites that were open meadows now have scattered spruce trees, in most cases less than 60 years old. There also are periods which show higher recruitment rates,

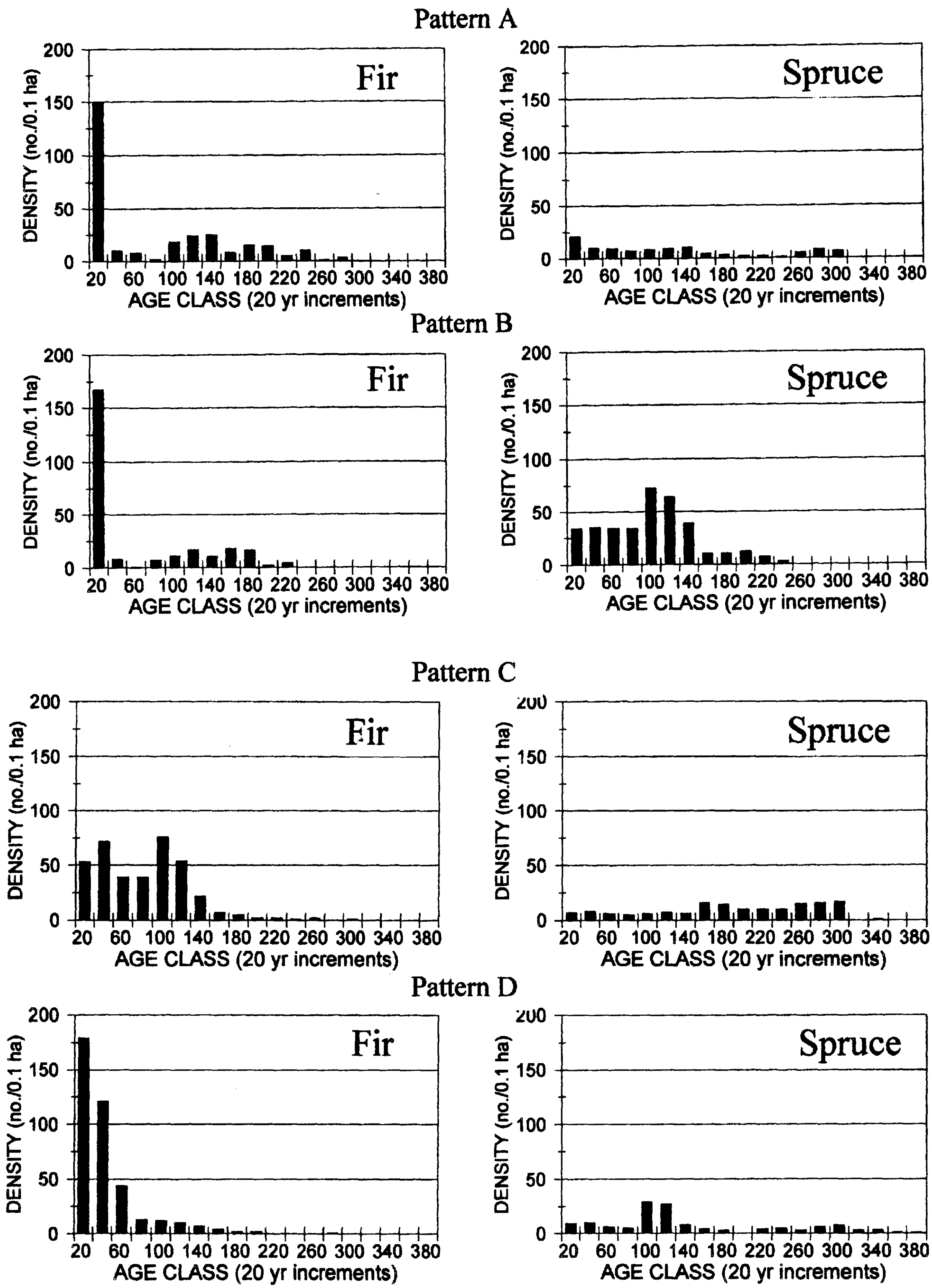

Figure 1.—Four recovery patterns of spruce-fir old growth forest showing different time responses of corkbark fir and Engelmann spruce based on age class demographics of representative forest stands on the Pinaleno Mountains.

often for both spruce and fir. The most obvious of these is the period 140 to 100 years BP, and the last 40 years (see fig. 2). The latter period may just represent short-term survival of young trees; however, the first period may be tied to past climatic cycles. The initiation of many of the present forest stands, around 300 to 350 years BP, also may be climatically influenced.

A study on "severe, sustained drought" funded by the State Department Man and the Biosphere Program and the U.S. Geological Survey in the late 1980s and early 1990s, reviewed tree ring chronologies of the West and Southwest, using studies by H.C. Fritts of the University of Arizona Tree Ring Laboratory (see Fritts 1991), to determine periods of severe drought over the past 400 years. The chronologies for the Southwest indicate several drought periods, but only two that where considered severe and sustained. These were 1667-1670 (ca. 320 years BP) and 1822-1826 (ca. 165 years BP). The drought period of the late 1980s was not included. Wet periods identified through tree ring chronologies (e.g., Buckley's 1989 spruce tree-ring chronology from Mt. Graham) included 1740-1750 (ca. 250 years BP), 1830 to 1840 (a very wet period ca. 150 years BP), 1850-1860 (ca. 130 years BP) and 1904-1934 (ca. 70 year BP). In general, Buckley's chronology indicates that the period 1755-1825 (ca. 245-165 years BP) had below normal tree-rings, while the period 1825-1870 (ca. 165-120 years BP) had above normal tree-rings.

The drought period in the 1600s may have created conditions for initiating forest disturbance and recovery such as enhancing the potential for extensive fires. Apparently, the only extensive evidence of fires in the spruce-fir zone of the Pinalenos is about 340 BP (Thomas Swetnam, pers. comm.). On the other hand, the wet period in the 1800s may have triggered extensive masting of the conifers and thus seedling recruitment. If this wet period followed a relatively dry period, the masting could be extensive as occurred with the breaking of the drought of the late 1980s (Stromberg and Patten 1993). The lengthy wet period in the early 1900s might also have maintained a moderate level of conifer recruitment following the recruitment surge in the 1860s.

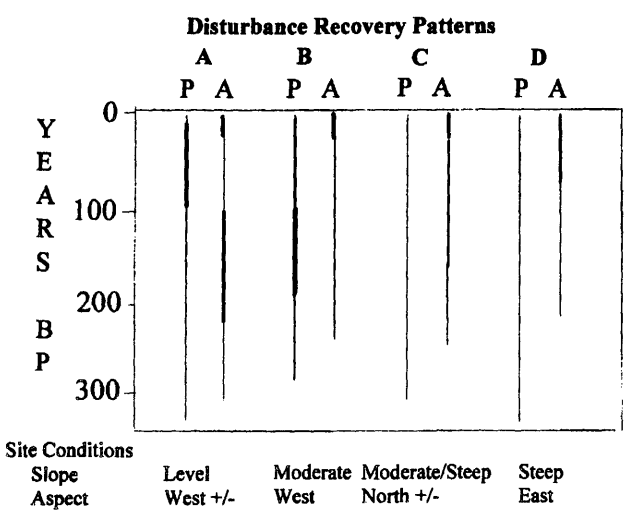

Figure 2.—Comparison of disturbance recovery patterns indicating recruitment initiation and "surges" of spruce (P) and fir (A). Line thickness indicates relative rates of conifer recruitment.

Table 1.—Correlation coefficients between densities of conifer seedlings (plants <1.5 m tall) with selected site factors.

	Picea engelmannii	*Abies lasiocarpa*
Rock cover	-0.31	-0.09
Slope	-0.36*	-0.33
Litter depth	0.23	0.21
Herbaceous cover	-0.46**	-0.47**
Shrub cover	0.03	0.03
P. engelmannii canopy cover	0.62**	0.37
A. lasiocarpa canopy cover	0.18	0.59**
Total canopy cover	0.37	0.43**
P. engelmannii basal area	0.61**	0.50**
A. lasiocarpa basal area	0.34	0.73**
Total basal area	0.40*	0.50**

Sample size n=30
*Significant at P<0.05
**Significant at P<0.01

CONCLUSIONS

Although each site in the old growth spruce-fir forest on the Pinaleno Mountains has its own recovery pattern, we have shown what appears to be four general patterns. Our hypothesis is the forest is not composed of a highly heterogenous mix of forest patches, but that there is some spatial relationship among those patches with similar recovery patterns. There were not enough sites within the old growth spruce-fir forest area of our Pinaleno Mountain study area to test these relationships through ordination; however, through aggregating sites with similar recovery patterns (including younger recovery sites), we found that similar sites do occur in groups (fig. 3). This appears to indicate that areas of the mountain top with similar environmental conditions will give rise to similar disturbance recovery patterns. Disturbance history may also play a role, however, it appears as though much of the mountain top, with exception of recent disturbances, experienced extensive fires at about the same time period.

The spruce-fir forest, with its limited area on the Pinaleno Mountains, is composed of a few large patches within which the environmental conditions are causing similar responses of the two dominant forest species to produce predictable compositional changes following major disturbances. Using these recovery patterns, it might be possible to project future forest age class composition on sites where reforestation was initiated with transplants of young spruce trees, such as near the astronomical observatory site.

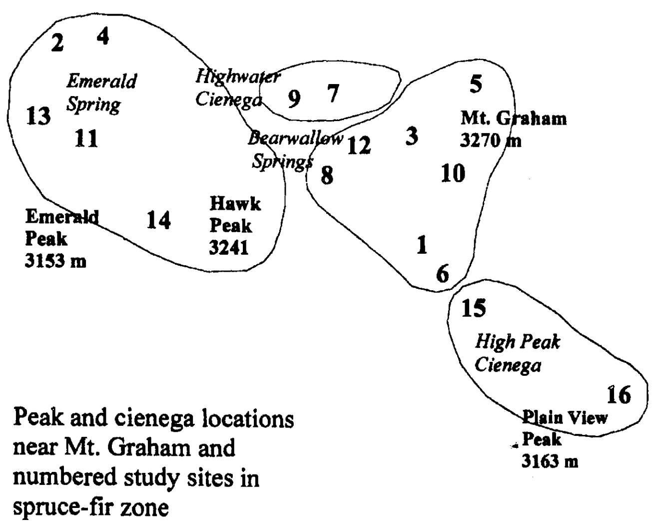

Figure 3.—Groupings of study sites with similar recovery patterns in the Mt. Graham area.

LITERATURE CITED

Alexander, R.R. 1987. Ecology, silviculture, and management of the Engelmann spruce-subalpine fir type in the central and Southern Rocky Mountains. USDA Forest Serv. Agri. Handbook 659, v+144 p.

Aplet, G.H., R. D. Laven and F.W. Smith. 1988. Patterns of community dynamics in Colorado Engelmann spruce-subalpine fir forests. Ecology 69:312-319.

Buckley, B.M. 1989. Dendroclimatic aspects of Engelmann spruce in southern Arizona and New Mexico. M.S. Thesis, Arizona State University, Tempe. 131 p.

Fritts, H.C. 1991. Reconstructing large-scale climatic patterns from tree-ring data: a diagnostic analysis. University of Arizona Press, Tucson. 286 p.

Gelbach, F.R. 1981. Mountain islands and desert seas: a natural history of the U.S.-Mexico borderlands. Texas A&M Univ. Press, College Station, 298 p.

Johnson, W.T. 1988. Flora of the Pinaleno Mountains, Graham County, Arizona. Desert Plants 8:147-162, 175-191.

Martin, P.S. 1963. The last 10,000 years. The University of Arizona Press, Tucson. 87 p.

Rebertus, A.J., T.T. Veblen, L.M. Roovers, and J.N. Mast. 1992. Structure and dynamics of old-growth Engelmann spruce-subalpine fir in Colorado. pp. 139-153 *in* Kaufmann, M.R., W.H. Moir and R. L. Bassett (tech. eds.) 1992. Old-growth forests in the Southwest and Rocky Mountain regions: Proceedings of a workshop. USDA Forest Service Gen. Tech. Report RM-213. 201 p.

Shreve, F. 1915. The Vegetation of a Desert Mountain Range as Conditioned by Climatic Factors. Carnegie Institute of Washington, Washington, D.C. 112 p.

Stromberg, J.C. and D.T. Patten. 1991. Dynamics of the spruce-forests on the Pinaleno Mountains, Graham County, Arizona. Southwestern Naturalist 36:37-48.

Stromberg, J.C. and D.T. Patten. 1993. Seed and cone production by Engelmann spruce in the Pinaleno Mountains, Arizona. Journal of the Arizona-Nevada Academy of Sciences 27:79-88.

Stromberg, J.C. and D.T. Patten. 1994 (in press). Islands within islands: vegetation dynamics of the spruce-fir forests of the Pinaleno Mountains. Part III, Chapter 1, *in* Istock, C. (ed.) Storm over a mountain island: conservation biology and the Mt. Graham affair. University of Arizona Press, Tucson.

Whittaker, R.H. and W.A. Niering. 1965. Vegetation of the Santa Catalina Mountains, Arizona. Gradient analysis of the south slope. Ecology 46:429-452.