Vegetation Changes within the Subalpine and Mixed-Conifer Forest on Mt. Graham, Arizona

Proxy Evidence for Mt. Graham Red Squirrel Habitat

R. Scott Anderson and Susan J. Smith

Though important as habitat for the endangered Mt. Graham red squirrel, and increasingly important as a recreational resource, little is known about the antiquity of the spruce-fir forests on the Pinaleño Mountains (but see Swetnam et al. in this vol.). In this chapter we address further aspects of the vegetation history of the range, first investigated by Anderson and Shafer (1991). Our goals are threefold. First, we seek to clarify the Late Holocene vegetation history of the mixed-conifer and spruce-fir forests of the range. Second, we explore the history and importance of fire within the spruce-fir forest over the course of the post-glacial period. Third, we speculate on the antiquity of the habitat of the endangered Mt. Graham red squirrel, one of two subspecies of red squirrel found in Arizona (Hall 1981). Currently, the Pinaleño Mountains are the only habitat of the Mt. Graham red squirrel (Hoffmeister 1986).

Because the Mt. Graham red squirrel has an incomplete fossil history, a realistic approach to determining the antiquity of the squirrel’s habitat is to examine proxy evidence of its occurrence. Using this paradigm, we have obtained sediment cores from cienegas (small marshes) on Mt. Graham and have analyzed pollen and plant remains from the sediments to determine long-term forest history, and charcoal particles to reconstruct forest fires.

Considerable change in vegetation distribution within the southwestern United States has occurred in the last 15,000 years (Betancourt et al. 1990). During the last glacial period, elevational limits of most high-elevation conifers were depressed as much as 1,000 m (Cole 1982; Anderson
et al. 2000). In southeastern Arizona, areas that now support desert grassland, desert scrub, or Sonoran Desert vegetation previously supported juniper (*Juniperus* sp.) woodland (Van Devender 1990a, 1990b). The transition to modern communities occurred during the Early Holocene in most parts of the region, with less substantial changes occurring over the last ca. 8,500 years. Our records from the Pinaleños do not include the late glacial period, but do include most of the Holocene.

**Study Sites**

Sediments from four sites in the Pinaleño Mountains—Emerald Springs Cienega, High Peak Cienega, Soldier Creek Meadow, and Hospital Flat Meadow—were analyzed. The sites are located within a ca. 6 km radius of each other, approximately 20 km southwest of Safford, Arizona (fig. 11.1; table 11.1).

Emerald Springs Cienega is a wet meadow located in a small, freeze-thaw–generated nivation hollow. The vegetation surrounding the cienega is dominated by Engelmann spruce, with minor amounts of corkbark fir. Understory growth is sparse and consists of currant (*Ribes wolfii*), orange gooseberry (*Ribes pinetorum*), cranesbill (*Geranium richardsonii*), and blueberry (*Vaccinium myrtillus*; nomenclature follows Johnson 1988). Grasses (Poaceae) and sedges (Cyperaceae) cover the cienega proper.

High Peak Cienega is also a wet meadow located in a nivation hollow. Upland vegetation around this site is dominated by Engelmann spruce, though corkbark fir is more abundant here than at Emerald Springs Cienega. Bearberry honeysuckle (*Lonicera involucrata*), currant, strawberry (*Fragaria* sp.), raspberry (*Rubus* sp.), wintergreen (*Pyrola picta*), cow parsnip (*Heracleum lanatum*), and members of the sunflower family (Asteraceae) grow in open areas of the understory. Corn lily (*Veratrum californicum*), violet (*Viola* sp.), cranesbill, grasses, and sedges grow on the marsh surface.

Soldier Creek Meadow is a small, open meadow within the mixed-conifer forest of the range. Trees are dominated by variable amounts of Engelmann spruce, white fir, and Douglas-fir, as well as southwestern white and ponderosa pines.

Hospital Flat Meadow is the lowest-elevation site in this study and is presently being incised by an intermittent stream. The coring site was
located on the west side of the meadow, near the upland forest, which is composed of ponderosa pine, with minor amounts of Douglas-fir, Engelmann spruce, southwestern white pine, white fir, and quaking aspen (*Populus tremuloides*). Herbs include yarrow (*Achillea lanulosa*), thistle (*Cirsium* sp.), goldenrod (*Solidago* sp.), and grasses. Blue wild rye (*Elymus glaucus*) grows on the moist meadow surface.
Methods

At least one sediment core was collected from each site. Cores were taken from Emerald Springs Cienega in October 1986 and 1987; cores were taken from the High Peak, Soldier Creek, and Hospital Flat sites in November 1990. Cores were collected with either a Livingstone piston corer (Wright 1980) or a modified Dachnowsky corer.

Sediments of each of the records were described in the laboratory. Depending upon sediment type, pollen was concentrated from raw sediment by using modifications of standard techniques (Fægri and Iversen 1989). Sediments from Emerald Springs core #1 included treatments with dilute potassium hydroxide (KOH), hydrochloric acid (HCl), hydrofluoric acid (HF), and acetolysis solution, with suspension in silicone oil. *Lycopodium* spore tracers were added for calculation of pollen concentration. KOH treatment was eliminated and acetolysis was limited for core #2 because of poor pollen recovery. Samples from the other three sites were processed with additional steps, including pollen separation using a heavy liquid (zinc bromide). The pollen assemblages were counted to ca. 300 terrestrial grains at 400X. Grains were identified using the reference collection at the Laboratory of Paleoecology (LOP), Northern Arizona University.

Plant macrofossils were isolated by water sieving larger portions of core sediments through soil sieves after suspension in water. Macrofossils were identified under a stereoscope at 10 to 70X, with reference to plant materials deposited at the LOP.

Sedimentary charcoal was identified from High Water core #1 only. The technique consisted of embedding each continuous 5 cm long core

Table 11.1. Location of the four Mt. Graham study sites

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Elevation m</th>
<th>Latitude</th>
<th>Longitude</th>
<th>USGS Quad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emerald Springs Cienega</td>
<td>3,143</td>
<td>32° 42' N</td>
<td>109° 53' 30&quot; W</td>
<td>Webb Peak 7.5'</td>
</tr>
<tr>
<td>High Peak Cienega</td>
<td>3,118</td>
<td>32° 42' N</td>
<td>109° 52' 00&quot; W</td>
<td>Mt. Graham 7.5'</td>
</tr>
<tr>
<td>Soldier Creek Meadow</td>
<td>2,860</td>
<td>32° 42' N</td>
<td>109° 55' 00&quot; W</td>
<td>Webb Peak 7.5'</td>
</tr>
<tr>
<td>Hospital Flat Meadow</td>
<td>2,750</td>
<td>32° 42' N</td>
<td>109° 52' 32&quot; W</td>
<td>Webb Peak 7.5'</td>
</tr>
</tbody>
</table>
section with epoxy resin, mounting the resulting section on a microscope slide, and grinding the preparation to a thin section (Smith and Anderson 1995). The thin-section slide was scanned for charcoal at an interval of 1 mm, providing a near-continuous record of sedimentary charcoal for large sections of the core. However, due to difficulties in preparing sandy sediment, several gaps occur in the record.

Chronology of the resulting record was provided by bulk radiocarbon dating, performed by Beta Analytic, Inc. (Miami, FL).

Results

Chronology and Sedimentology

Seven radiocarbon dates were obtained for four cores (table 11.2). Only the record from Emerald Springs Cienega extends back to the Early Holocene, with a bottom date exceeding 9,200 years ago (Anderson and Shafer 1991).

Emerald Springs Cienega. Three radiocarbon dates were obtained from the two Emerald Springs Cienega cores. In addition, we assign the age of AD 1685 to a large charcoal peak at 21.2 cm depth in the core, corresponding to the most recently documented fire in the vicinity of Emerald Springs, as determined by stand origination data (Grissino-Mayer et al. 1995). The 134 cm long core #1 consists mostly of homogeneous organic silt, with varying amounts of sands, to a depth of 128 cm. Sediments below 128 cm are tan, oxidized, sandy silts.

High Peak Cienega. One radiocarbon date was obtained from the single sediment core. The top 3 cm of this 42 cm core consisted of dark brown peat. Dark-brown silty clays, with little visible organics, extended from ca. 3 to 40 cm. The bottom 2 cm consisted of light brown sands.

Soldier Creek Meadow. Two radiocarbon dates were obtained from this core. We also found a charcoal layer at a depth of 18–19 cm, which may correspond to the last major fire in the vicinity of Soldier Camp Meadow at ca. AD 1871 (Grissino-Mayer et al. 1995). The 95 cm long record consists largely of a homogeneous dark-brown peaty colluvium
to 53 cm depth. Sandier sections occur from depths of ca. 7–21 cm and 30–35 cm. Below 53 cm the color becomes darker, and the clay content increases.

_Hospital Flat Meadow._ One radiocarbon date occurs near the bottom of this 61 cm core. Although Hospital Flat Meadow does not lie within the study area of Grissino-Mayer et al. (1995), we assign the age of AD 1871 to a charcoal layer that occurred at a depth of 8.5 cm depth. The core top is silty peat with large organic fragments from its top to a depth of 30 cm. From ca. 30 to ca. 49 cm, the core is a gray, sandy unit. Finer sands and colluvium occurs from 49 to 61 cm.

_Pollen and Plant Macrofossils_

_Emerald Springs Cienega._ Anderson and Shafer (1991) reported on this record, though additional data are added here. The Emerald Springs Cienega record is the only one from the Pinaleños that extends back to the Early Holocene, with a bottom age exceeding 9,200 years old. Pollen was analyzed from 13 samples from core #1, with a minimum of 29 pollen and spore types identified. The concentration and preservation of pollen was excellent in the top 10 cm of the core, but declined rapidly with depth. This was true for all major pollen types (spruce, fir, pine, oak,
The dominant identifiable plant remains found were Engelmann spruce needles (Anderson and Shafer 1991). Needle fragments of cork-bark or subalpine fir and achenes of sedge were also found. All fragments had been burned, which probably enhanced their preservation.

High Peak Cienega. This record extends back to ca. 4,200 years ago. Twenty pollen samples were analyzed from the single core, but only the top (surface) sample contained enough well-preserved pollen to yield a 300-grain count. That sample contained 73 percent spruce, 10 percent pine, 5 percent fir, 4 percent ragweed (Ambrosia sp.), and 2 percent each of grass and goosefoot family (Chenopodiaceae) pollen, with smaller amounts of other types. Wetland pollen included 8 percent lily family (Liliaceae) and 5 percent sedge. Such percentages of pollen are characteristic of the spruce-fir forest in the Southwest (R. S. Anderson et al., Northern Arizona University, unpublished data).

The macrofossil data complements the pollen data. Spruce remains occur in four of the five macrofossil samples analyzed, while fir needle fragments were found in only one of the samples. Moreover, the concentration of spruce remains increased toward the top of the core, indicating either (1) an actual increase in the local abundance of spruce, or (2) an increase in preservation toward the surface.

Soldier Creek Meadow. The record from Soldier Creek extends back to over 1,300 calendar years ago and, along with that from Hospital Flat, provides the most complete record of vegetational change for the Late Holocene in that mountain range. Eighteen pollen samples were analyzed from this core, with good pollen preservation in 17 samples.

Changes in the pollen assemblage during this period reflect changes in both the upland forest community as well as in the meadow environment itself. Periods of little change in the pollen assemblages, perhaps corresponding to periods of relative stability, occur from ca. 750 to 1,300 years ago and from ca. 100 to 375 years ago. Periods of rapid change in the record occur ca. 375 to 750 yr BP, and within the last 100 years.

Prior to ca. 750 years ago, pine, grass, and goosefoot (Cheno-Am) pollen types dominate the pollen assemblage (fig. 11.2). Other conifers,
including spruce and fir, are a minor component of the assemblage, although Douglas-fir pollen increases by ca. 1,000 years ago. Pollen characteristic of the piñon-juniper woodland at lower elevations (piñon pine, *Pinus edulis*; Cupressaceae, mostly junipers; oaks [*Quercus*]; ragweed; and sagebrush [*Artemisia* sp.]) is present in small but consistent quantities. The dominant riparian pollen type is alder (probably *Alnus incana*), while sedge pollen is also abundant.

The period 750 to 375 years ago shows variable pollen assemblages, perhaps indicating a period of adjustment in the local vegetation. Pine remains the dominant conifer; spruce, juniper/cypress, and oak pollen increase; fir pollen reaches its maximum then declines slightly; and Douglas-fir pollen percentages remain steady. However, the pollen of dwarf mistletoe (*Arceuthobium vaginatum*) begins a steady increase. Since this parasitic plant produces little pollen and is poorly dispersed, its increase probably signifies its abundance within host pine trees surrounding the meadow. Alternatively, this may represent a period of tree encroachment upon the meadow, nearer the coring site. A decline in percentages of grass pollen, with an increase in thistle, provides support for this hypothesis. Declines in alder, meadow rue (*Thalictrum*), and lily family pollen may also indicate a drying of the meadow.

Sediments deposited ca. 375 to 100 years ago show a steady increase in spruce and grass, and a decline in Douglas-fir. Towards the end of this period, riparian and wet meadow pollen indicators, including alder, walnut (*Juglans*), dock (*Rumex*), and meadow rue, increase, while sedge pollen remains prominent. These changes suggest that water tables in the meadow were higher than previously, perhaps corresponding to increased effective precipitation.

Changes in the pollen assemblages in the top portion of the core are undoubtedly associated with local modification of the forests on Mt. Graham and vicinity. Most prominent among these changes is a further decline in pine, associated with local logging operations, and its replacement in the assemblage by spruce pollen. Oak pollen also reaches its highest percentage in the record at this time.

*Hospital Flat Meadow.* The record from Hospital Flat covers the last 1,200 years. Although the core was 60 cm long, pollen was not recovered below 50 cm depth. Eleven pollen samples were analyzed, and due to
poorer preservation than at the Soldier Creek site, the average pollen sum was less (ca. 225 grains) than for the higher site. Changes in the pollen assemblages suggest a somewhat simpler story here than for Soldier Creek. Pollen assemblages older than ca. 725 years are dominated by pine, which varies from 40 percent to over 60 percent, contrasting with samples from Soldier Creek that never exceed 40 percent. Small amounts of other conifer pollen were also found (fig. 11.3), with the most abundant of these being the piñon type. Dominant shrub and herb species include members of the sunflower, grasses, and goosefoot families, as well as alder.

A transition in the pollen assemblage at ca. 725 years ago is shown by declines in herbs (e.g., sunflower family, grasses), alder, and the carrot family (Apiaceae). Pollen from sedge increases to over 80 percent of the pollen sum. Pine pollen also increases, reaching a maximum of 75 percent between ca. 500 and 350 years ago. Dwarf mistletoe is common at this time and, as at Soldier Creek, suggests either a heavy infestation of the pines surrounding the meadow or tree encroachment on the meadow.

Figure 11.2. Summary pollen percentage diagram for Soldier Creek Meadow.
By ca. 300 years ago, grasses had replaced sedges as the dominant herbs of the meadow. The dominant grass at the location today is wild blue rye, which prefers moist soils (Kearney and Peebles 1951). Pine dominates at this site, and other conifers such as spruce, Douglas-fir, and fir are not as important in the fossil pollen record as they are at Soldier Creek (figs. 11.2 and 11.3). The macrofossil record complements the pollen evidence. The dominant plant macrofossil is ponderosa pine, and macrofossils in general are most abundant during the time of maximum pine-pollen percentages. This also suggests tree encroachment upon the meadow, and if so, zone II-time should have been the driest period of the sequence.

**Sedimentary Charcoal**

The occurrence of sedimentary charcoal in cores is a proxy record of forest fire. Our technique (Smith and Anderson 1995) has allowed us to identify the amount of charcoal in each successive centimeter of sedi-
ment of a core. Charcoal data are available only for the Emerald Springs site (fig. 11.4).

Many factors are responsible for the abundance of charcoal in sediment cores (Whitlock and Larsen 2001; Whitlock and Anderson 2003). Previous studies on charcoal sedimentation suggested that the smallest charcoal sizes are probably produced by sub-continental to global sources (Clark 1988). This “background” charcoal can be found at nearly all levels, and probably does not represent local fires (those burning at or very near the site). Large increases in charcoal above background levels within the core probably represent nearby fires, or even fires that burned across the meadow surface (Whitlock and Anderson 2003).

In the Emerald Springs record, distinct periods of high charcoal abundance alternate with periods of low charcoal abundance. We believe, however, that our chronology is inadequate for calculation of fire-event frequency (e.g., Millspaugh and Whitlock 1995; Long et al. 1998; Brunelle and Anderson 2003). Nevertheless, charcoal deposited in three core segments far exceeds background values in this record—91.2 to 91.3 cm, 73.2 to 76.2 cm, and 19.4 to 21.6 cm. Based on interpolation between radiocarbon dates, the first and second periods correspond to ca. 5,825 to 5,850 and 4,850 to 5,000 m median calibrated years BP. Given the origination age of the modern spruce forest there, we believe the uppermost charcoal peak originated from the AD 1685 fire that was widespread across the range (Grissino-Mayer et al. 1995). Though four core sections were too sandy to permit our sediment epoxy technique (the largest being from ca. 27.0 to 55.0 cm depth), sedimentary charcoal was identified from nearly all other levels. These data suggest that major fires, such as the AD 1685 conflagration, have probably been rather rare near Emerald Springs during the Holocene, but fire has been a regular factor in the disturbance of local forests over the period of record.

**Discussion and Conclusions**

Perhaps less is known regarding the history of the spruce-fir forest type than any other forest association in the Southwest. Much of our knowledge of vegetation history comes from packrat (*Neotoma* sp.) middens, preserving a record of change in lowland vegetation. During much of the last glacial period, until ca. 11,000 to 10,000 yr BP, spruce grew at eleva-
Figure 11.4. Charcoal area (mm²) for individual levels in a core from Emerald Springs Cienega.
tions lower than today. Englemann spruce grew as low as 2,222 m near Flagstaff, Arizona (Anderson 1993), and at 2,000 m in the Guadalupe Mountains, Texas (Van Devender 1990a). Spruce was also found at 2,285 m within the White Mountains of Arizona (Jacobs 1983), and at 2,780 m within the Chuska Mountains of New Mexico (Wright et al. 1973). With the increasing temperatures of the Early Holocene, spruce retreated to its present elevational range.

Even fewer data exist for the region closer to Mt. Graham. Pluvial Lake Cochise sediments from Willcox Playa show higher percentages of spruce pollen during the late glacial period than today (Martin 1963). Packrat middens have not been identified from the area, so we are unsure of the species of spruce present at that time. However, results from Emerald Springs Cienega led Anderson and Shafer (1991) to conclude that Englemann spruce has grown on Mt. Graham for at least the last 9,200 calendar years.

The records from the Mt. Graham sites do not provide us with a continuous vegetational history for the Holocene. However, it is clear that Engelmann spruce dominated at the highest elevations for much of that time. This contrasts with the record from Soldier Creek and Hospital Flat, where mixed-conifer dominated, at least for the last 1,200 to 1,400 years. Pines, both ponderosa and southwestern white, were dominant at Hospital Flat, while spruce was more important at the slightly higher Soldier Creek site. Pollen data also suggest that vegetational changes were largely synchronous at these two sites, even though the individual characteristics of the mixed-conifer forest were different, due to elevational differences. Vegetational changes occur at ca. 750 and 375 years ago, and within the last century. Moist conditions are inferred for the first period, followed by drier climates, succeeded by wetter conditions again. A general cooling trend is noted with a long-term increase in spruce in the Soldier Creek record and an increase in fir and Douglas-fir in the Hospital Flat record.

Based on these data, it is likely that the habitat of the Mt. Graham red squirrel existed essentially in variants of its present form for much of the Holocene (also see Swetnam et al. in this vol.). This gives us confidence in concluding that habitat requirements were present for the squirrel during that period.
Acknowledgments

We thank the following for their help with this project: administrative support, L. Fitzpatrick (U.S. Fish and Wildlife Service); fieldwork, P. Anderson, P. Chouinard, N. Giggy, P. Koehler, D. Shafer, and R Sweeney; and logistical assistance, T. Newman (U.S. Forest Service) and C. Duncan (U.S. Forest Service). Funding was provided by the University of Arizona through the Mt. Graham Red Squirrel Study Committee, which is comprised of representatives from the Arizona Game and Fish Department, the University of Arizona, the U.S. Forest Service, and the U.S. Fish and Wildlife Service (USFS contract 40–8197–0–0499). Laboratory of Paleoecology Contribution No. 80.

Literature Cited


