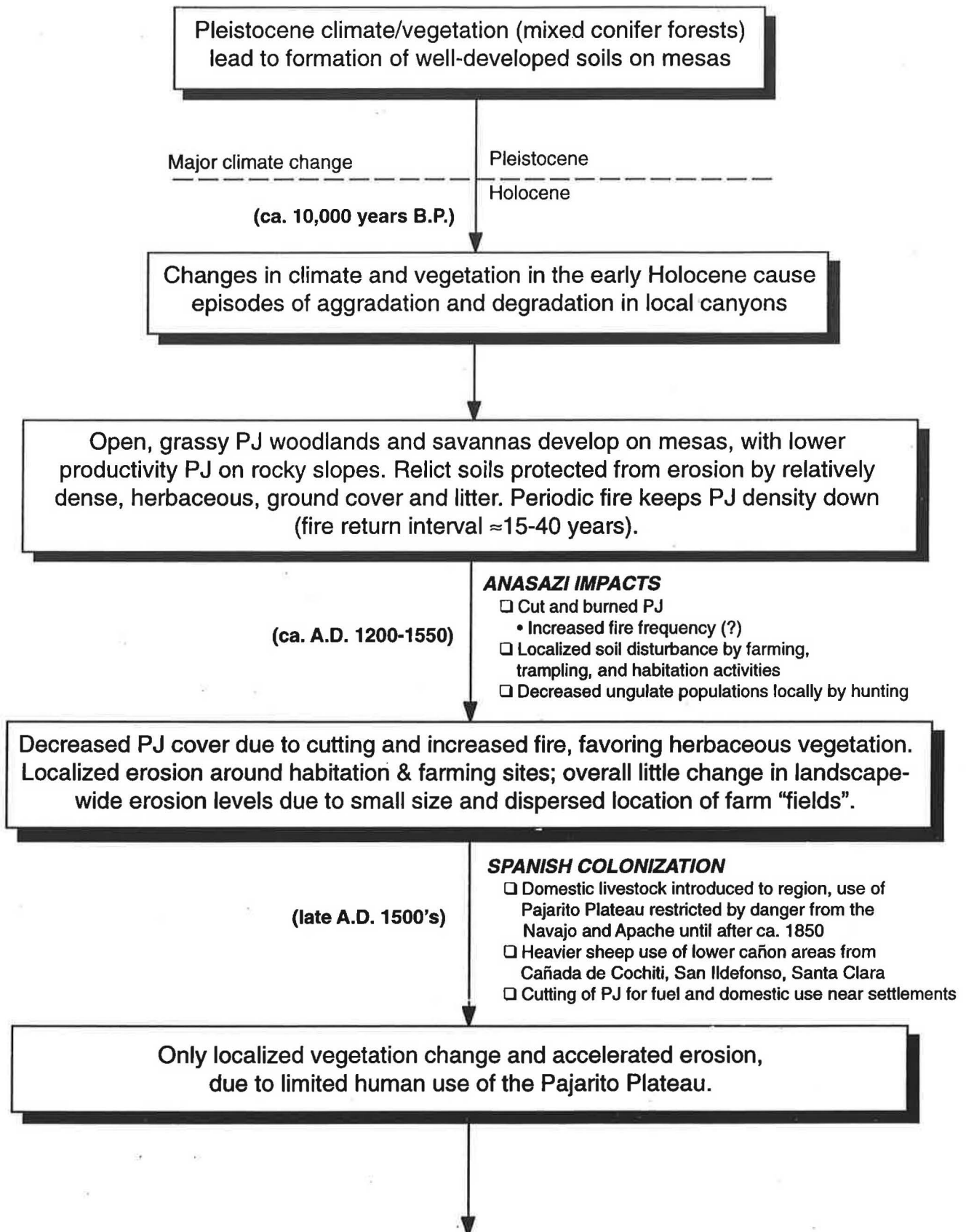


Conceptual Model of Piñon-Juniper (PJ) Ecosystem Changes on the Pajarito Plateau



ANGLO SETTLEMENT

- ☐ Continued increased in livestock numbers, especially in 1880's after railroads access area, large numbers of sheep and cattle are brought to the Pajarito Plateau; widespread use of the plateau for intensive grazing through 1930's
- ☐ Extreme droughts in 1890's and 1950's
- ☐ Selective cutting of PJ becomes more extensive through 1930's
- ☐ Widespread fires eliminated by intensive grazing; active fire suppression initiated and institutionalized ca. 1910
- ☐ Large numbers of feral burros in Bandelier National Monument from 1940's until 1983
- ☐ High deer numbers in Bandelier since 1940's
- ☐ Elk reintroduced, local population grows to thousands

(post A.D. 1880)

PJ ecosystems, especially understory/soil subsystems, forced into disequilibrium:

- ☐ Decreased ground cover by grazing and hoof action from ungulates, rodents, rabbits, and ants
 - Decreased vegetation and litter cover, particularly in the interspaces between trees
 - Soil surface microclimate becomes more extreme
- ☐ Increased bare soil → thresholds reached where precipitation becomes surface runoff instead of infiltration
 - Less water available for shallow-rooted herbs
- ☐ Increased soil erosion → leading to further increase in bare soil and surface runoff in a positive feedback cycle (note: the same magnitude rainfall event causes more erosion than before)
- ☐ Increased precipitation intensity (?) from ca. 1880-1930 may have further increased surface runoff
- ☐ Decreased fire frequency (as inadequate ground fuels remain to carry fire) allows unimpeded tree establishment
- ☐ Increased PJ tree density and PJ invasion of former grasslands downslope and ponderosa forests upslope
 - ↳ • Increased tree competition with herbs for water, nutrients, light, space (and allelopathic effects?)
 - ↳ – Further decreases in herbaceous vigor and cover reducing herbaceous controls on tree establishment
- ☐ Droughts may have further reduced herbaceous vegetation, perhaps triggering erosion on additional sites by causing thresholds of exposed soil to be exceeded
- ☐ Herbaceous plant re-establishment becomes very difficult, even after livestock are removed, due to dominance of physical processes in the desertified interspaces:
 - Loss of organic matter litter/mulch at soil surface (therefore, drier surface soil and difficult surface microclimate), increased freeze/thaw soil displacement (disrupting seedling roots), nutrient/texture problems for seedling establishment in exposed clay-rich B-horizons, nutrients translocated and concentrated beneath trees, decreased seed sources, depleted soil seed pools, animal use of herbs and their limited seed sources (by ungulates, rodents, and ants)
- ☐ Soil erodes from uplands → canyons → Rio Grande/Cochiti Reservoir
- ☐ Bare soil → bare rock, with even further increases in surface runoff and attendant erosion down-drainage

Today: most local PJ woodland ecosystems are unstable from a soils perspective, with many moving towards "PJ rocklands"

LAND USE HISTORY AND ECOSYSTEM CHANGES IN PINON-JUNIPER AND JUNIPER WOODLANDS OF THE PAJARITO PLATEAU, JEMEZ MOUNTAINS, NEW MEXICO

While definitive research on ecological changes in piñon-juniper woodlands (*Pinus edulis*, *Juniperus monosperma*) has yet to be conducted in the Jemez Mountains, much work has been done (and is ongoing) on the ecology (Barnes 1983 and 1986, Padien 1990, Padien and Lajtha 1992, Lajtha and Getz 1993, Allen and Parmenter 1993, Breshears 1993, Chong 1994), hydrology (Wilcox 1994, Wilcox and Breshears - in press, Wilcox *et al* - in press) archaeology (Mathien *et al.* 1993, Kohler and Linse 1993, Powers and Orcutt - manuscript), and general land use histories (Allen 1989, Rothman 1989, Scurlock and Johnson 1994) of local woodlands.

Synthesizing existing information with published research from other areas (e.g. Tausch *et al* 1981, Rogers 1982, West and Van Pelt 1987, Evans 1988, Cartledge and Propper 1993, Betancourt *et al* 1993, Miller and Wigand 1994) and consultations with local resource managers and researchers leads to the following general scenario of changes in local piñon-juniper woodlands (Figure 1).

Modern woodland soils on the Pajarito Plateau likely formed to a significant degree under the cooler, moister conditions of the late Pleistocene, when mixed conifer forests likely blanketed the mesa tops. Los Alamos National Laboratory geomorphologist Steve Reneau is finding evidence in local canyon sediments that changes in climate and vegetation in the early Holocene (ca. 8500-6000 years ago) led to at least localized episodes of soil erosion on adjoining uplands. During this time the dominant climatic and associated vegetation patterns of the modern Southwestern U.S. developed, including PJ woodlands and savannas. It seems that these woodlands were relatively open with well-developed herbaceous understories which: a) protected the soils from excessive erosion during intense summer thunderstorm events; and b) provided a largely continuous fuel matrix which allowed surface fires to spread through the woodland zone from the adjoining ponderosa pine and grassland types.

Native American effects on local woodlands are thought to have been insignificant or highly localized until the late 12th Century, when the Anasazi population began to build markedly (Orcutt - manuscript). Recent archeological survey and excavation work at Bandelier shows evidence of extensive Anasazi impacts on woodland resources during the peak occupation period of ca. 1200-1500 A.D. Cutting and burning of piñon and juniper trees for cooking, heating, building, and agricultural activities likely led to significant deforestation of upland mesas during this time, and local ungulate (primarily mule deer) and rabbit populations were reduced by hunting pressure (Kohler - 1992). The overall ecological effect of several centuries of Anasazi occupation of the Pajarito Plateau may have been to favor herbaceous vegetation at the expense of the woodland trees. Intensive soil disturbance certainly occurred in farmed areas and around habitations, but there was likely little net change in landscape-wide erosion rates due to the small size and dispersed location of farm "fields" and habitations, and the effectiveness

of herbaceous vegetation at protecting soils from erosion. Perhaps the lack of well-developed, old-growth PJ woodland in the Bandelier area can be partly traced to the slow recovery of woodlands from the effects of Anasazi deforestation.

European settlement of the adjoining Rio Grande Valley, and the introduction of domestic livestock grazing, began in 1598 at today's San Juan Pueblo. During most of the historic period livestock use of the Pajarito Plateau was apparently restricted by danger from Athapascan raiders (Navajo, Apache, Ute), although lower elevation areas near the valley communities may have been heavily utilized by livestock (Smith - manuscript). This constraint on use of the Pajarito Plateau eased by ca. 1850 but was not eliminated until the final suppression of Navajo raids in the 1860's. Still, at the time the Ramon Vigil Grant in the heart of the Pajarito Plateau was surveyed by the U.S. General Land Office in 1877 herbaceous vegetation was abundant, and livestock use was apparent (Appendix 1).

Cutting of PJ for fuelwood and building materials was important in many areas on the Pajarito Plateau in the late 19th and early 20th Centuries. For example, after the National Park Service acquisition of the Tsankawi area in 1932 a NPS inspector wrote that it was easy to follow "the approximate boundaries of this 7.5 square mile section by the areas slaughtered by woodcutters" and "the entire area has been checkerboarded with wagon roads where the Mexicans have been hauling wood"; this report includes a photograph of "one of the thousand wood roads that crisscross the Monument" (Atwell 1933). The stubs of axe-cut junipers remain obvious in most PJ woodlands north of Frijoles Canyon on the Plateau.

Prior to the 1860's surface fires likely burned through local piñon-juniper woodland sites roughly every 15 to 40 years (Allen 1989:117-118), favoring the maintenance of open woodlands, savannas, and grasslands by killing young piñon and juniper trees and promoting the growth of competing grasses. Relatively dense grasses, herbs, and associated organic litter protected the soils from erosion and carried the fires which restricted the density of piñon and juniper. Once established, older pinyon and juniper trees may have been protected by their rather nonflammable litter from most direct fire effects by growing in clumped islands amidst the grassier matrix of overall woodland sites.

The development of railroad links to external commercial markets during the 1880's led to marked increases in the numbers of domestic livestock grazed on the Pajarito Plateau, beginning in 1880 on the Ramon Vigil Grant (Rothman 1989). The resultant high intensity grazing apparently triggered a number of ecological changes in local woodlands. Overgrazing caused sharp reductions in the herbaceous ground cover and associated organic litter, effectively suppressing the previously widespread fires. Cool season grasses which green up early in the growing season are thought to have been most affected by this grazing pressure, so that today they largely found only beneath the crowns of older woodland trees or on steep slopes. Reduced cover of herbaceous plants and litter led to decreased water infiltration and increased surface runoff from the typically intense local

rainfall events - thresholds were reached which initiated accelerated erosion. An increase in the intensity of extreme storm events in the late 1800's may have further exacerbated erosional processes (see reviews of climate **vs.** grazing theories in Hastings and Turner 1965, Denevan 1967, and Bahre 1991). In any event, by 1913 grass cover was considered "scant", and a 1937 surveyor identified inadequate water infiltration as a cause (Appendix 1). Current PJ woodland conditions in Bandelier, as inventoried by over three kilometers of line transect data, display tree canopy coverage ranges of 12% to 45%, herbaceous plant coverage (basal intercept) of only 0.4% to 9%, and exposed soils covering between 38% and 75% of ground surfaces.

Over the past century many young piñon and juniper trees became established in the absence of thinning fires and competing herbaceous vegetation, with increases in tree density continuing to the present on mesic sites. Thus tree density increased within PJ woodlands, while piñon and juniper expanded their ranges upslope into ponderosa pine forests and juniper moved downslope into former grasslands. As these trees grew they became increasingly effective competitors for water and nutrients in the shrinking tree interspaces, directly limiting herbaceous plant establishment and growth and keeping much bare soil exposed; allelopaths in juniper needle litter may augment this process. These changes apparently interacted as a positive feedback cycle in which decreased herbaceous ground cover promoted tree invasion and erosion, which in turn fostered further decreases in ground cover. As a result, large portions of Bandelier are becoming piñon-juniper "rocklands" as the soil mantle erodes away - this is most evident on the southerly, low elevation mesas of the park where shallower soils were already present before this erosion cycle began.

The locally severe 1950's drought, and associated bark beetle outbreak, killed many piñon on dry sites in the Bandelier area (Allen 1989:124-126). Field data indicate that the piñon mortality associated with this outbreak caused the ecotone between piñon-juniper and juniper woodlands to shift sporadically about 1 km upslope in the Frijoles watershed. This intense drought may have further reduced the ground cover of herbaceous plants enough to initiate or exacerbate desertification and erosion processes on some PJ sites. In addition, the presence of water-competing clumps of PJ beneath ponderosa pine trees may have contributed to the extensive, concurrent, drought-induced mortality of ponderosa pine which displaced the lower ecotone of ponderosa pine forests upslope one to two kilometers in the Bandelier area (Allen 1989:121-124)

Overall, the most significant ecological changes in local PJ woodlands in historic times involve diminished and altered herbaceous ground vegetation, fire suppression, increased tree densities, and accelerated soil erosion.

The re-establishment of herbaceous ground cover under today's desertified mesa-top conditions is difficult. Heavy utilization of the current herbaceous vegetation by animals ranging from harvester ants (e.g. Pogonomyrmex occidentalis) and mice (Peromyscus spp.) to increasing numbers of elk may be

limiting the availability of seed sources in many woodland areas (cf. Carlson 1987). Decreases in organic matter litter as a mulch, and reduced water infiltration, have caused the soil surface microenvironment to become more xeric and experience more extreme temperatures, inhibiting seedling establishment. The relatively porous, organic matter-rich, surface soil horizons have been eroded from many sites, leaving relatively impermeable clay-enriched horizons exposed; these subsoils present more difficult nutritional and water-balance challenges for prospective seedlings. Winter freeze-thaw activity churns the top soil layer and creates polygonal cracking patterns in bare soils in the local piñon-juniper zone that must damage or kill the roots of seedlings that managed to establish successfully the previous summer.

Once initiated, this pattern of desertification is apparently difficult to break (Evans 1988). Physical rather than biological processes now dominate these sites, as the biological capital which once moderated the elemental forces has been significantly dissipated, leaving harsh sites for plant establishment. Soils which likely formed under more mesic climate and vegetation conditions during the Pleistocene are obviously eroding at unsustainable levels in many piñon-juniper woodlands on the Pajarito Plateau today. For example, in 1993 erosion bridge measurements at 360 points in a 1 ha. PJ watershed in Bandelier revealed a mean degradation in the soil surface level of 0.34 cm between July and November (Wilcox et al 1993). Also, herbaceous vegetation cover continues to decline in some areas (Potter 1985).

Simply eliminating the livestock grazing that apparently triggered the development of the current situation is not sufficient to halt the erosion. Livestock grazing ceased in 1932 over most of the Bandelier area in which erosion is currently occurring, although burro populations were building up south of Frijoles Canyon by this time which certainly furthered subsequent erosion. North of Frijoles Canyon, where burros were never a significant factor, removal or reduction of domestic livestock was accomplished by 1943, with absolute exclusion of trespass livestock since the early 1960's, yet serious erosion occurs here too and may even be worsening in areas like the detached Tsankawi unit. Interestingly, in Bandelier today herbaceous vegetation is generally far more vigorous and dense on canyon walls than on the adjoining, eroding uplands, even on dry southerly aspects, as rock cobbles on the canyon slopes apparently create a relatively stable, mulching substrate where adequate moisture and nutrients are available to the interspersed plants.