

Thema: **A comparison of vegetation structure on three different soils at Bandelier National Monument, New Mexico, U.S.A.**

(Vergleichende Untersuchungen über die Vegetationsstruktur auf drei verschiedenen Böden in Bandelier National Monument, New Mexico, U.S.A.)

Diplomarbeit
für die
Diplomprüfung
zur

Erlangung des Grades: Diplom-Agraringenieur (Dipl.-Ing.agr.)
der
Landwirtschaftlichen Fakultät
der
Rheinischen Friedrich-Wilhelms-Universität
zu
Bonn

Vorgelegt am: 27.04.1999

von

cand. agr.: Christian Julius

1. Prüfer: Prof. Dr. Wolfgang Schumacher
2. Prüfer: Prof. Dr. Dieter Wittmann

Table of contents

Introduction	p. II
1. Study Area	p. 1
1.1. Geography	p. 1
1.2. Geology	p. 3
1.3. Soils	p. 6
1.4. Climate	p. 8
1.5. Vegetation	p. 9
2. Historical use of land	p. 14
3. Introduction of the “Watershed Restoration Project”	p. 17
4. Methods	p. 20
4.1. Selection, location, and size of plot units	p. 20
4.2. Vegetational studies	p. 23
4.2.1. Tree studies	p. 23
4.2.2. Studies of shrubs, forbes, cacti, and grasses	p. 28
5. Results	p. 33
5.1. Soils	p. 33
5.1.1. Structure of most prominent soil types	p. 33
5.1.2. Comparison of soil characteristics	p. 38
5.2. Trees	p. 38
5.2.1. Density	p. 38
5.2.2. Age class structure	p. 40
5.2.3. Ground cover (analysis of aerial photo)	p. 43
5.3. Shrubs, forbes, cacti, and grasses	p. 44
5.3.1. Ground cover by Braun-Blanquet	p. 44
5.3.2. Ground cover by line-intercept method	p. 46
5.3.3. Biomass	p. 48
6. Comparison of soil groups	p. 52
6.1. Trees	p. 52
6.2. Shrubs, forbes, cacti, and grasses	p. 56
7. Discussion	p. 59
8. Summary	p. 62
Acknowledgements	p. 64
Bibliography	p. 65
Appendix: List of figures	p. 69
List of tables	p. 70
Plant list	p. 71

Introduction

Accelerated soil erosion causes major natural and cultural problems across the landscape of Bandelier National Monument. Development of soil instability made it imperative to formulate further requirements of research.

The main goal of experimental revegetation work at Bandelier is to be able to implement a parkwide piñon-juniper woodland restoration program in order to stop erosional processes.

Present studies focus on the reduction of tree density combined with the leaving of slash in the treated area in order to reestablish herbaceous ground cover.

A possible influence of soil profile towards vegetation structure has been neglected so far.

The object of the current study is to find out whether there is a significant difference in vegetation structure corresponding to some specific soil characteristics on South Mesa at Bandelier National Monument.

Both the presence of a pumiceous surface layer and a clay horizon (argillic horizon) in a soil depth of up to 120 cm (48 inches) is supposed to favor the development of a grassland structure due to a higher amount of soil water available for forbes and grasses.

On both deep, pumiceous soils without an argillic horizon and shallow, rocky soils a predominance of *Pinus edulis* (Colorado piñon pine) and *Juniperus monosperma* (one-seed juniper) is assumed.

Ground cover and density of trees as well as biomass and ground cover of shrubs and herbaceous plants were measured to get an idea about possible differences of vegetation structure in the present environment.

In the past century, most vegetation types in the landscape of Bandelier National Monument have undergone major changes caused by the often intertwined effects of grazing history and fire suppression (ALLEN 1989).

Hence, the age class structure of the existing tree population of one-seed juniper and Colorado piñon pine was estimated to compare potential changes of vegetation structure in times past.

To know whether some specific soil characteristics favor the development of a herbaceous cover significantly can be useful for further procedure of experimental revegetation work at Bandelier National Monument.

1. Study area

1.1 Geography

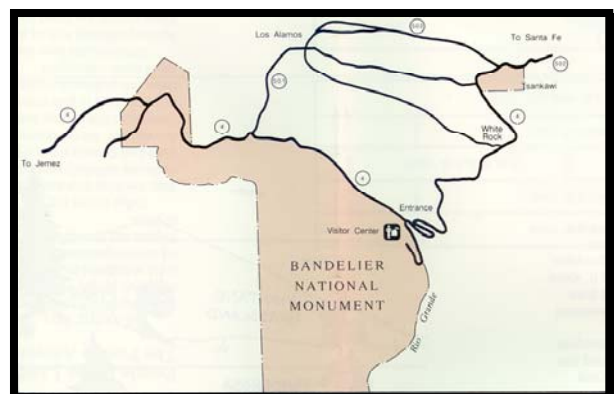
The State of New Mexico is located in the Southwest of the United States of America. The states of Arizona, Colorado, Oklahoma and Texas border New Mexico on the west, north and east, respectively (Fig. 1). New Mexico's southern border is split with the western half shared with the country of Mexico and the eastern half with Texas.



Location of
New Mexico
within the
U.S.A.



Location of Bandelier National
Monument (red star) within New
Mexico



Border of Bandelier National
Monument

Figure 1: Location of study area

Bandelier National Monument lies in north central New Mexico about 15 miles northwest of the state capital, Santa Fe. The monument is part of the National Park System and the Preservation System and covers an area of 13,250 hectares. It is part of the Pajarito Plateau that is situated on the southeastern flank of the Jemez Mountains. Sloping towards the Rio Grande, the plateau is dissected by five canyons. The Rio Grande passes Bandelier National Monument as a natural border in the Southwest.

Within the boundaries of Bandelier National Monument the Watershed Restoration Project is located. The project is situated on South Mesa, which is a part of the Pajarito Plateau south of Bandelier National Monuments Headquarters. It covers an area of about eighty hectares.

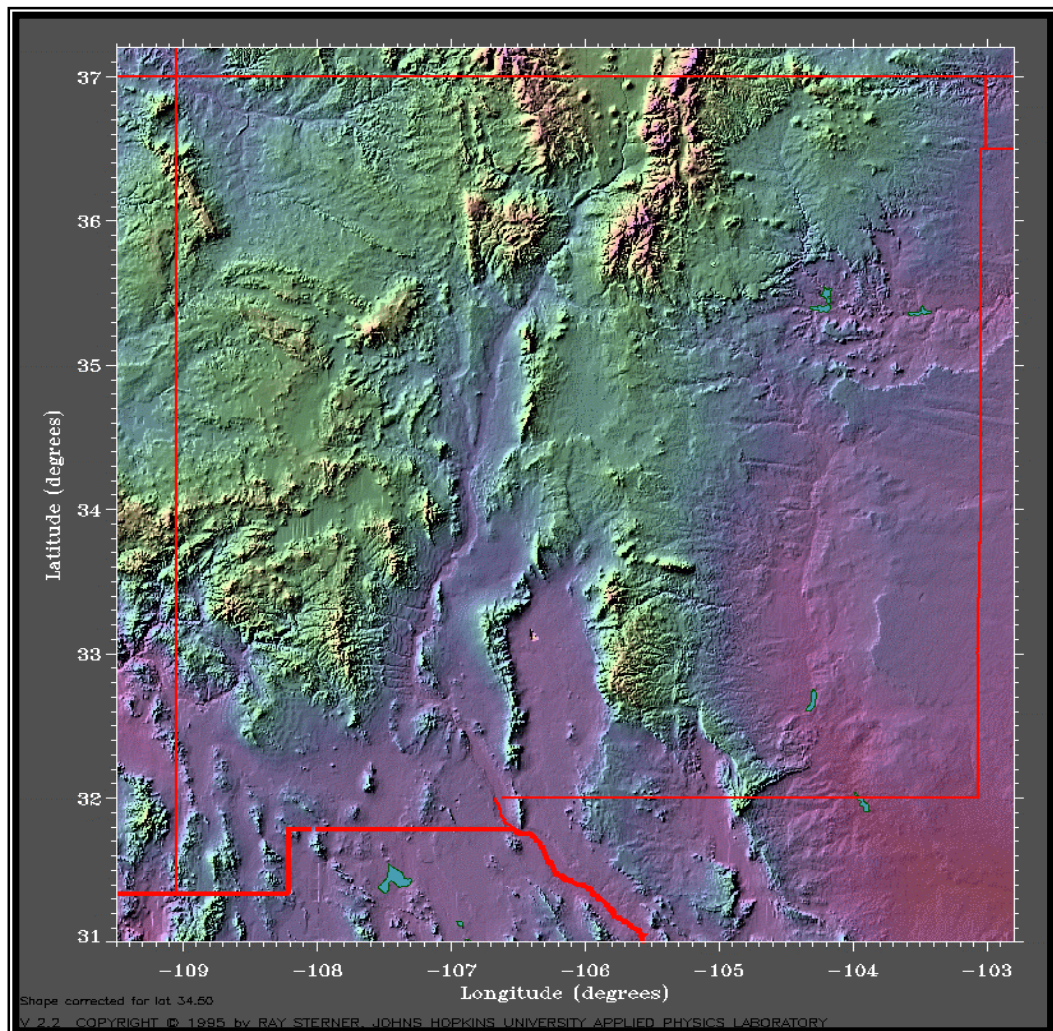


Figure 2: Topographic map of New Mexico

Found in STERNER, RAY: Color Landform Atlas of the United States. John Hopkins University Physics Laboratory. 1995.

In general elevation changes within New Mexico from south to north. Starting south at about 870 m (2850 ft) at the point where the Pecos River crosses the border of the state into Texas, elevation rises up to 4015 m (13161 ft) (Wheeler Peak) in the Sangre De Cristo Mountains, which are part of the southern foothills of the Rocky Mountains and are situated in north-central New Mexico (Fig. 2).

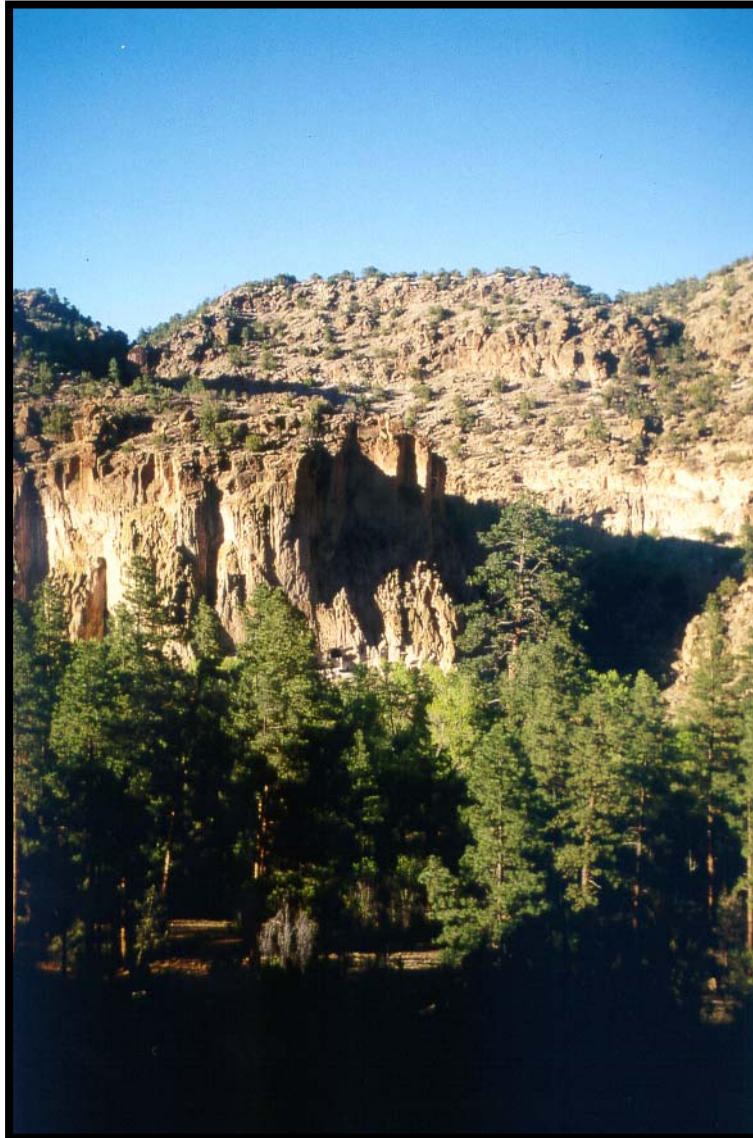
Likewise, change in elevation is perceptible in Bandelier National Monument. Moving upward from the Rio Grande at about 1615 m (5300 ft) elevation rises up to 3110 m (10199 ft) at the summit of the Cerro Grande, which is located at the northwestern border of Bandelier.

Within the Watershed Restoration Project elevation ranges from 1900 to 2000 m (6230 to 6560 ft).

1.2 Geology

The Jemez Mountains are volcanic in origin. About 1.6 and 1.2 million years ago massive eruptions had a great impact on the further evolution of today's landscape in this area (IZETT and OBRADOVICH 1994).

The Pajarito Plateau, being one of the most prominent landforms of the Jemez Mountains, developed as a consequence of this volcanic activity. The plateau consists of a number of various tuff deposits caused by pyroclastic flows (ALLEN Unpublished manuscript). These deposits stratify up to 300 m and cover a variety of older geologic units, like sandstones of the Santa Fe group, coarse alluvial deposits of the Puye Formation, and a diversity of igneous rocks from the Cerro del Rio volcanic field (DETHIER 1996; RENAULT and DETHIER 1996). Beside the above mentioned tuff deposits, pumice was deposited on the Pajarito Plateau from the last major eruption(s) near the Valle Grande caldera about 50,000 to 60,000 years b.p. (SELF 1988). Today patches of this coarse-textured material are easily found all over the Pajarito Plateau, increasing in thickness and extent towards the West (ALLEN Unpublished manuscript).



Tuff deposits exposed at a canyon wall of Frijoles Canyon near Bandelier National Monument Headquarters.

Multiple episodes of both soil formation (relative landscape stability) and erosion (relative landscape instability) created a soil landscape that is marked by long, narrow mesas and steep canyons (DAVENPORT 1997). DAVENPORT (1997) pointed out that according to the distribution of soils on the South Mesa watersheds and on the Pajarito Plateau a relatively long period of landscape stability (prior to the deposition of “El Cajete pumice” about 50 000 to 60 000 b. p.) allowed a significant soil development.

A characteristic feature of soil development is given by the occurrence of an argillic horizon within the soil profile of several soil units on South Mesa.

The presence of an argillic horizon with its accessory properties may give an important insight into age and formation of a specific soil. Hence, it is appropriate to give a brief description of this horizon.

An argillic horizon is defined as “an illuvial horizon in which layer-lattice silicate clays have accumulated by illuviation to a significant extent” (U.S. DEPARTMENT of AGRICULTURE 1975).

Since the formation of an argillic horizon is relatively slow and therefore ordinarily requires a few thousand years, its occurrence is a useful means to determine soil age.

An argillic horizon is formed by dispersed clay that is believed to move with percolating water. Once the percolation of water stops, the clay deposits on the walls of the noncapillary voids (U.S. DEPARTMENT of AGRICULTURE 1975).

It is likely to believe that presently the amount of rain at Bandelier National Monument in most years does not suffice to allow a development of an argillic horizon. This probably indicates a soil and surface of such great age that climate has changed through the years (U.S. DEPARTMENT of AGRICULTURE 1975).

In sands and loamy sands an argillic horizon consists of a series of lamellae which effect the water holding capacity of the soil by damming up the percolating water (U.S. DEPARTEMENT of AGRICULTURE 1975). The explanation of this phenomenon is “that pores slightly larger than those in the next layer above cause water to hang in the soil” (U.S DEPARTMENT of AGRICULTURE 1975).

SCHEFFER and SCHACHTSCHABEL (1998) support this hypothesis by describing the circumstances caused by an unsaturated water movement resulting in the creation of backwater.

The decline of the saturation of soil water within a soil causes two effects:

First, the tension of soil water within fine-textured material increases and second, the ability of water conduction within coarse-textured material is getting very low (SCHEFFER and SCHACHTSCHABEL 1998).

Hence, coarse-textured material that is covered by a layer of fine-textured material will not participate in the conduction of soil water to a bigger extent until the soil profile is flooded (SCHEFFER and SCHACHTSCHABEL 1998).

1.3 Soils

Soils characterized below are classified by the U.S. Comprehensive Soil Classification System. BUOL, HOLE, and McCracken (1980) give a precise description of the main differences between this system and others.

In 1997, Davenport identified and described the different soil profiles situated on three watersheds on South Mesa in Bandelier National Monument. The area of his research included the location of the Watershed Restoration Project. Within the border of this project, Davenport distinguished twelve different soil units. These soil units can be classified into three great groups:

The Ustorthents, the Ustochrepts, and the Haplustalfs.

The Ustorthents are described as Entisols on recent erosional surfaces that have an ustic soil moisture regime (U.S. DEPARTMENT of AGRICULTURE 1975). They mostly occur in soft sedimentary deposits and have moderate to steep slopes.

The Ustochrepts are classified as reddish or brownish Ochrepts of subhumid to semiarid regions and are most commonly formed in Holocene deposits or on steep slopes. Like the Ustorthents, the Ustochrepts have an ustic soil moisture regime, and most of them are calcareous at a shallow depth (U.S. DEPARTMENT of AGRICULTURE 1975).

The Haplustalfs are reddish Alfisols of warm, subhumid to semiarid regions that are located on recent erosion surfaces or deposits, most of them from late Pleistocene (U.S. DEPARTMENT of AGRICULTURE 1975). They are provided with an argillic horizon that has a gradual or clear but not abrupt upper boundary. Haplustalfs also have an ustic soil moisture regime and occur as associated soils or as inclusions in areas of the great groups of Entisols and Inceptisols (U.S. DEPARTMENT of AGRICULTURE 1975).

In the map shown below all soil units distinguished by DAVENPORT are represented as map units. The abbreviations **PG** and **PM** stand for soil units that belong to the great group of the Ustorthents. Accordingly **CJ**, **LR**, **PO**, **PP** and **VU** are part of the Ustochrepts and **NJ**, **NR**, and **OH** belong to the Haplustalfs.

The abbreviations **RM** and **RS** stand for mesic and steep rock outcrop and therefore are not considered as soil units.

A more detailed description of the most common soil units found in this part of South Mesa can be found in chapter 7.

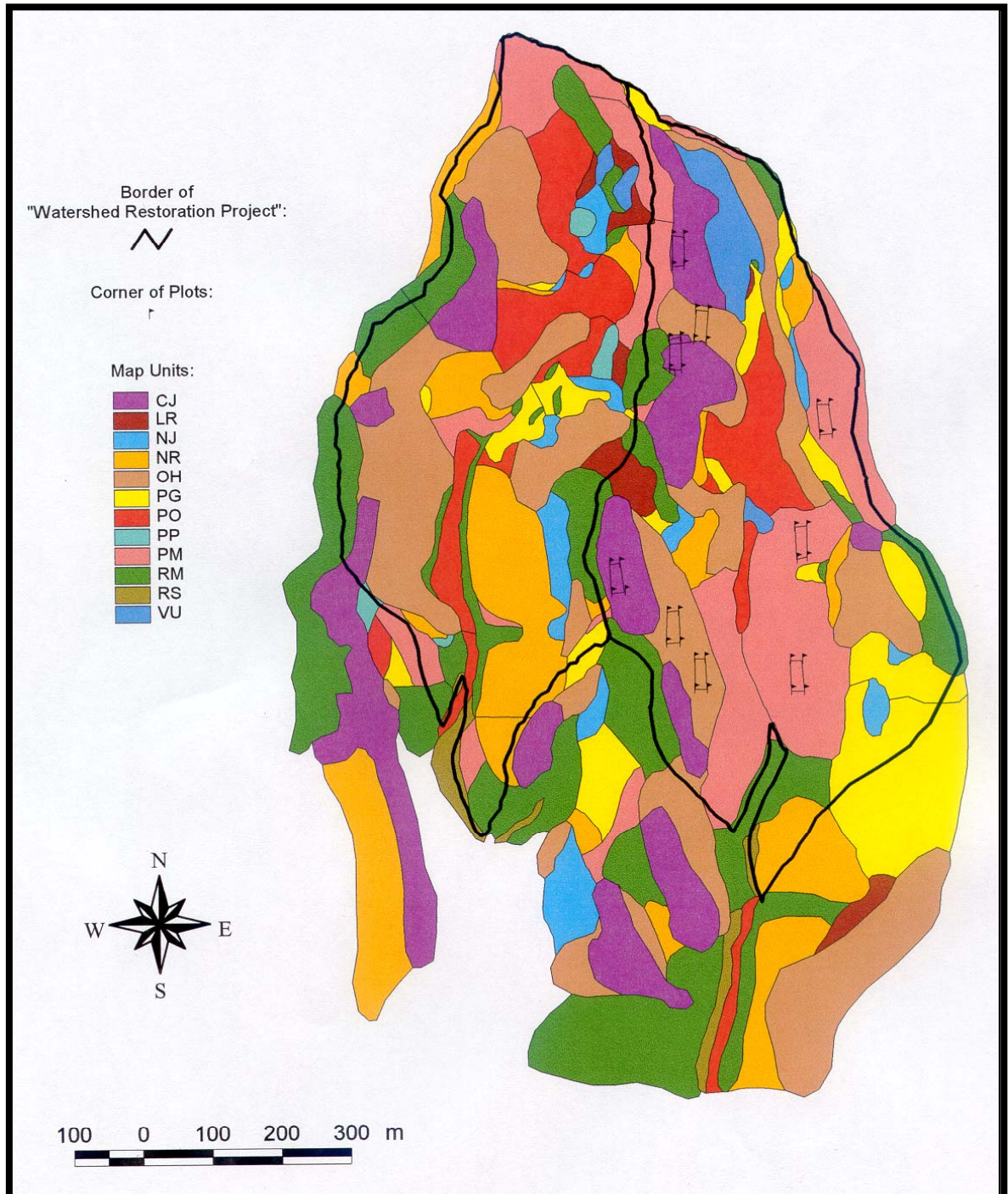


Figure 3: Different map units at the Watershed Restoration Project on South Mesa

Based on DAVENPORT, DAVID W.: Soil Survey of Three Watersheds on South Mesa, Bandelier National Monument. 1997.

At Bandelier National Monument a major natural and cultural resource problem is caused by accelerated soil erosion. Sheet, rill, and especially gully erosion can easily be observed all over the Pajarito Plateau.

The reduction of herbaceous cover associated with an increasing establishment of Colorado piñon pine (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) is assumed to form the basis for the occurrence of soil erosion at Bandelier. The passing of soil erosion thresholds triggers the beginning of accelerated soil erosion (DAVENPORT et al. 1998).

Several field studies have been set up to get an idea about the processes of runoff and erosion on South Mesa. Weather, microtopography, land survey, and runoff data have been collected by WILCOX et al. (1996) since 1993. According to this data, ongoing erosion rates of about 4 mm/year can be suggested.

Beside the alarming loss of topsoil, thousands of archeological sites located all over Bandelier have been or are in danger of being damaged.

1.4 Climate

The north-central part of New Mexico is subjected to a semiarid continental climate.

Sea surface temperature regimes in the eastern Pacific Ocean and the seasonal position of the polar and subtropical jet streams, the Pacific anticyclone, and the Bermuda High influence the seasonal distribution of precipitation in the Middle Rio Grande Basin (GOTTFRIED et al. 1995).

Focusing on the Pajarito plateau, average temperature ranges from -1.6°C in January to $+20^{\circ}\text{C}$ in July (29°F to 82°F) and mean annual precipitation is 41.3 cm (16.5 inches) (ALLEN 1989). One has to keep in mind that temperature and the amount of rainfall throughout the year differ with elevation significantly.

Rain in the fall and spring as well as snow in winter are caused by cyclonic storms associated with the polar jet stream (ALLEN Unpublished manuscript).

April, May and June are typically the driest months of the year.

This season of dryness is followed by the “Mexican monsoon” season, which most commonly starts at the beginning of July.

Monsoonal rains associated with a high frequency of summer thunderstorms characterize this time of year. These thunderstorm events bring about 30% of the total annual precipitation. (ALLEN Unpublished manuscript).

Fluctuations of atmospheric mass between the southeastern and western Pacific/Indian Ocean influence the distribution of precipitation in north-central New Mexico on a longer time scale. These fluctuations are a main feature of the ENSO (El Niño-Southern Oscillation) cycle, including wet years during El Niño episodes and dry years during La Niña conditions throughout the Southwest (BETANCOURT et al. 1993).

In the 1950s La Niña conditions caused one of the most severe droughts occurring in the 20th century in New Mexico.

1.5 Vegetation

Three major vegetation types cover the landscape of New Mexico: forest, shrub, and grassland.

Considering the strikingly different plant and animal communities existing in each of them, CASTETTER (1956) divided these major vegetation types into several biomes.

To give an idea about how the vegetative character of a landscape is connected with total annual precipitation, elevation, temperature, and soil conditions, some of these biomes are introduced briefly in the following chapter.

The description of these biomes is based on Castetter, Edward F.: The Vegetation of New Mexico. 1956.



Typical grassland found in the southern parts of New Mexico. The picture was taken from highway 54 north of Three Rivers looking towards the San Andres Mountains.

The Grassland Biome occupies a large part of New Mexico and is subdivided into two associations: the desert plain grassland and the mixed grassland or mixed prairie.

The desert plain grassland association ranges from about 870 m to 1675 m (2850 to 5500 ft) in altitude. Black grama (*Bouteloua eriopoda*) is a prominent grass of this association. One of the most characteristic features of the mixed grassland is the occurrence of blue grama (*Bouteloua gracilis*) as a climax dominant grass.

The Woodland Biome is characterized by small trees usually not much more than 10 m (about 30 ft) tall. It usually consists of one-seed juniper (*Juniperus monosperma*) and Colorado piñon pine (*Pinus edulis*) and carries an understory of grassland and forbes.



Picture of *Pinus edulis* (Colorado piñon pine) north of plot unit PA3.

In New Mexico, woodland ranges from about 1370 to 2290 m (4500 to 7500 ft), with an average annual precipitation rate between 32.5 to 50 cm (13 to 20 inches).

GOTTFRIED et al. (1995) mention that “piñon-juniper woodlands constitute the most common vegetation type in Arizona and New Mexico.”



Piñon-juniper woodland at Bandelier National Monument on South Mesa. The picture was taken within the borders of the Watershed Restoration Project looking east towards Boundary Peak.

The Coniferous Forest Biome is subdivided into the Petran subalpine and Petran montane association. The latter ranges from 2135 to 2900 m (7000 to 9500 ft), and average annual precipitation is 40 to 55 cm (16 to 22 inches). The Petran montane association covers extensive areas of New Mexico and is dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*).



Coniferous forest in the Sangre de Cristo Mountains north of Taos. The picture was taken at an elevation of approximately 2700 m (about 8850 ft).

At Bandelier National Monument various aspects of the above mentioned biomes can be found. ALLEN (1989) describes a zonation of communities on the Pajarito Plateau that is based on elevation and slope exposure.

Starting at an elevation of 1600 to 1900 m (5250 to 6230 ft), one passes through juniper grassland which is replaced by piñon-juniper woodland at about 1900 to 2100 m (6230 to 6885 ft). Ponderosa pine forest exists at 2100 to 2300 m (6885 to 7540 ft), whereas mixed conifer forest dominates the landscape at about 2300 to 2900 m (7540 to 9500 ft). Finally one can find spruce-fir forest above 2900 m near the Cerro Grande.

Livestock grazing and an associated reduction in fire frequency during the late 19th century are assumed to form the basis of a significant change in vegetation structure at Bandelier National Monument (ALLEN 1989). Herbaceous ground cover decreased and Colorado piñon pine and one-seed juniper were able to establish in the existing grasslands and ponderosa pine forests. The reduction of herbaceous cover was exacerbated by the presence of a large feral burro population around 1940 and the occurrence of a severe drought during the 1950s.



Juniper grassland heavily invaded by one-seeded juniper at the southern borders of the Watershed Restoration Project.

On South Mesa vegetation is dominated by piñon-juniper woodlands, with Colorado piñon pine and one-seeded juniper being the most prominent trees. Understory biomass within this woodland type generally is low. A diverse flora can still be found on the Pajarito Plateau. JACOBS (1989) identified 720 species in 347 genera representing 86 families of the vascular plant flora at Bandelier National Monument.

2. Historical use of land

The first indication of people living on the Pajarito Plateau can be traced back to the early Holocene. Using radiocarbon dating, RENEAU et al. (1995) determined the age of three hearths located on Pajarito Mesa to be about 9,000 to 10,000 years old.

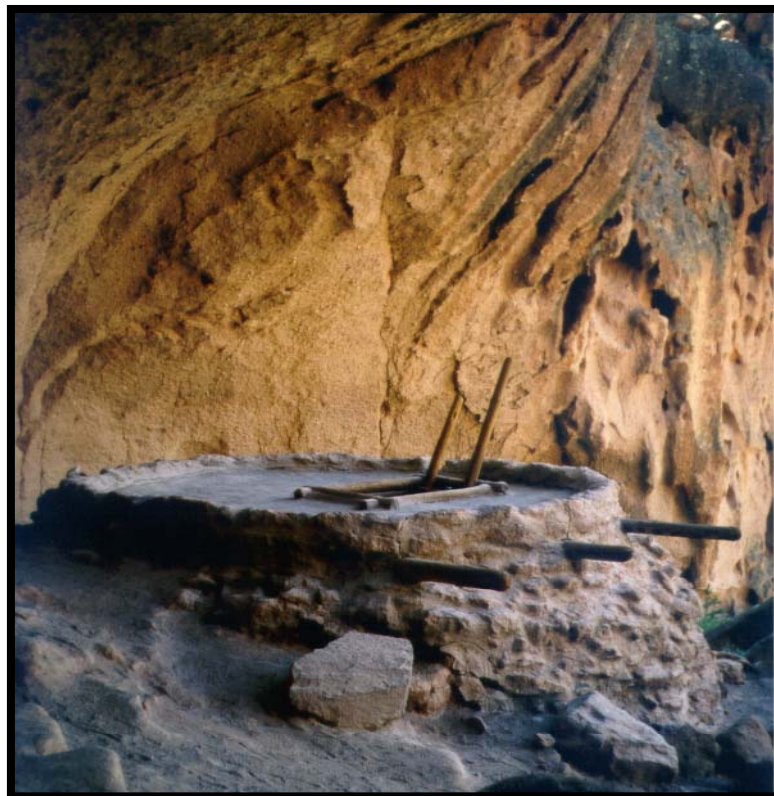
Population during the Paleo-Indian Period (about 9500 to 5500 B.C.) was small and people lived a nomadic lifestyle, following seasonal migration of big game (TRAILS ILLUSTRATED 1994).

As the climate warmed through the centuries, hunting and gathering played a less important role and small farming settlements were established.

During the Development Period (A.D.600 to 1175), social organization became more complex.

Material culture, like the making of pottery, the building of multiple-roomed pueblos or the construction of underground rooms called kivas for religious and ceremonial activities, began to grow into a very rich and elaborate tradition (TRAILS ILLUSTRATED 1994).

People living in these communities are known as the Anasazi, the ancestors of the Pueblo Indians.



Picture of Anasazi pueblos at Frijoles Canyon in Bandelier National Monument.

Between A.D. 1175 and 1325, large Pueblo communities in the areas of Chaco and Mesa Verde disintegrated and people migrated into the northern Rio Grande drainage.

At the height of occupation, BRACKER (1996) estimates at least 3000 people lived in the Bandelier area from about A.D. 1235 to 1250 and circa A.D. 1290 to 1375.

An intense use of timber and the cultivation of land for agriculture resulted in an expansion of herbaceous vegetation at the expense of the existing trees (ALLEN Unpublished manuscript). During the following two centuries people abandoned the Mesas and settled along the Rio Grande. It is suggested that by the end of the 16th century most of the Anasazi had left the Pajarito Plateau.

In 1598, the first Spanish settlement was established by Don Juan de Oñate in the upper Rio Grande Valley at the foot of the Pajarito Plateau. By conquering and colonizing these valley regions, the Spanish influence grew, and for the first time domestic livestock were introduced into the area (CARLSON 1969).

Initially, Apache and Navajo raiding parties prevented settlers from inhabiting the interior portions of the Jemez mountains (ALLEN Unpublished manuscript). Therefore the impact of livestock-grazing on the Pajarito Plateau was low until the Apache and Navajo were confined to reservation in the 1860s.

The area of today's Bandelier National Monument experienced a dramatic change in land use caused by the entry of railroads to the region at about 1880. With the connection to external markets provided by the railway, livestock industry established and boomed.

ALLEN (Unpublished manuscript) mentions that "spreading surface fires ceased in the late 1800s across the landscapes of Bandelier National Monument (ALLEN 1989), the Jemez Mountains (TOUCHAN et al. 1996), and the Southwest as a whole (SWETNAM and BAISAN 1996), as the intensive and extensive grazing of livestock (especially sheep) removed the grassy fuels which carried the fires."

Intensive livestock-grazing associated with the suppression of the natural fire cycle left little space for grasses and forbes to compete with the invading piñon and juniper trees on the Pajarito Plateau. This was the first step triggering a vegetative shift away from existing grasslands toward piñon-juniper woodlands.

In 1916 Bandelier National Monument was created.

One main reason for the establishment of this Monument was the work of Adolph Bandelier, an enthusiastic and adventurous southwestern scholar. Bandelier was working on an expedition in New Mexico when people of the Pueblo of Cochiti guided him to Frijoles

Canyon on October 23, 1880 (TRAILS ILLUSTRATED 1994). Being fascinated by the beauty and the variety of archeological sites, Bandelier described this place as “the grandest thing I ever saw.” His work and his novel *The Delight Maker* sparked interest and ultimately lead to the creation of Bandelier National Monument (TRAILS ILLUSTRATED 1994).

The main goal of its establishment in 1916 was the protection of a number of prominent Anasazi ruins.

U.S. Forest Service operated Bandelier National Monument until control was transferred to the National Park Service in 1932 (ALLEN Unpublished Manuscript).

Under the supervision of the National Park Service commercial livestock-grazing within the borders of this monument was permitted. However, the impact of intensive grazing was already perceptible.

Presently Bandelier National Monument is part of the National Park and National Wilderness Preservation System. The preservation of archeological sites as well as the protection of environment and wilderness are the main goals of this monument today.



Picture of Bandelier National Monument Headquarters from South Mesa.

3. Introduction of the “Watershed Restoration Project”

Accelerated soil erosion causes major natural and cultural problems across the landscape of Bandelier National Monument. In addition to the alarming loss of topsoil, thousands of archeological sites have been or are in danger of being damaged (see chapter 3.3).

In order to maintain cultural and natural resources it is imperative to develop methods to decrease erosional processes.

In 1992 experimental revegetation work was initiated in Bandelier National Monument by CHONG (University of New Mexico) and ALLEN (USDI National Biological Service). The goal of their research was to find a best working solution to reestablish native grasses and forbes on a degraded piñon-juniper site in order to reduce soil erosion. Reduction of tree density, application of slash and straw mulch, summer seeding and fertilization are the elements of their investigation.

Exclusion of livestock-grazing alone tends to be insufficient to promote recovery of herbaceous plants in degraded piñon-juniper woodland (CHONG 1993). Apart from that CHONG (1993) pointed out, that favorable microsites are critical for herbaceous plants to establish from seed on degraded piñon-juniper sites.

Based on the results of this research, additional revegetation work was set up by JACOBS (Bandelier National Monument) and LOFTIN (Rocky Mountain Experiment Station) in 1994. Reduction of tree density combined with the leaving of slash in the treated area, and the spreading of native seed material turned out to be an effective way to reestablish native grasses and forbes.

In 1996 GATEWOOD (Bandelier National Monument), JACOBS and ALLEN continued this experimental revegetation work by initiating the Watershed Restoration Project.

The intention of this project is to test former developed restoration methodology at a functional ecosystem scale.

The Watershed Restoration Project is located on South Mesa, south of Bandelier National Monuments Headquarters. It covers an area of about eighty hectares. Within this area there are two drainages, running north to south and define two watersheds draining into Loomis Canyon.

The west drainage serves as the control watershed, whereas the east drainage represents the treatment watershed. Both are about the same size.

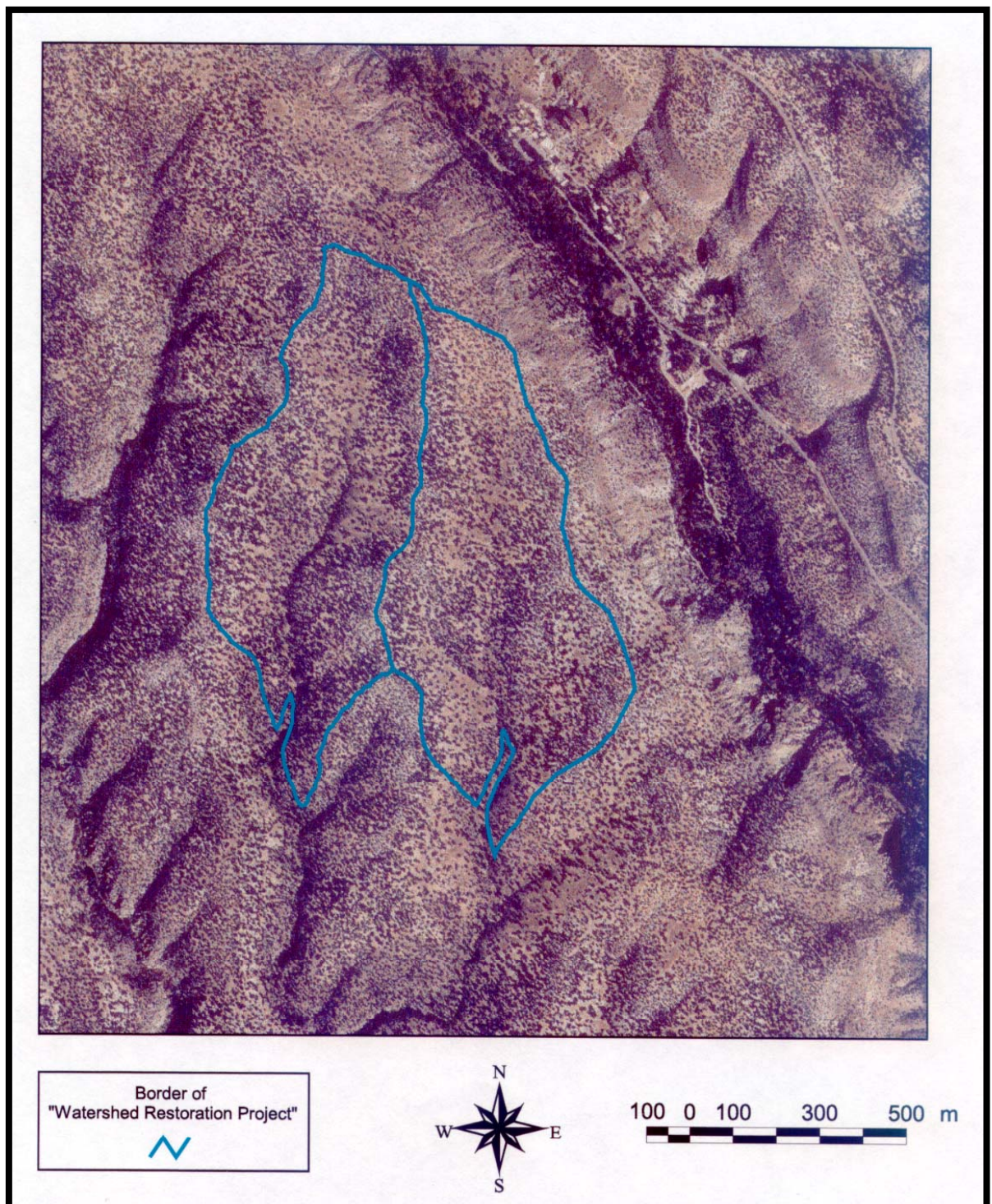


Figure 4: Aerial photo of Bandelier National Monument Headquarters and South Mesa including the borders of the Watershed Restoration Project prior to treatment.

In the treatment area all one-seeded juniper and Colorado piñon pine that are less than 18 cm in diameter at breast height have been cut down and broadcast into the inter-canopy areas. As a standard of comparison no treatment was made in the control area.

In both control and treatment watersheds twenty 100 m vegetation transects were established and data is collected once a year using the line-intercept procedure. With this procedure changes in percentage herbaceous ground cover can be estimated.

Pitfall traps are used to document ground dwelling arthropod populations. This documentation and the observation of avian and ungulate species are used to assess ecosystem response to the treatment.

Additionally 206 soil erosion bridges were set up in order to estimate changes in soil erosion rates and 27 soil moisture probes were installed in both treatment and control watershed.



Impression of vegetative response within the treatment area of the “Watershed Restoration Project”. The picture shows a high ground cover of *Lotus wrightii* (Wright’s deervetch), *Erigeron flagellaris* (trailing fleabane), and *Artemisia campestris* (Sagebrush) due to the lack of tree competition.

4. Methods

In the following chapter the procedure of selecting the most prominent soil types and the location and size of research plots will be illustrated.

In addition, the methods of measuring vegetation structure within these research plots will be explained. The measurement focuses on density, age class structure, and ground cover of trees as well as biomass and ground cover of shrubs and herbaceous plants.

4.1 Selection, location, and size of plot units

The study site is located on South Mesa, within the treatment area of the “Watershed Restoration Project”.

The prominent soil types of this area have been divided into four groups by using the criteria

- existence or absence of pumice and
- existence or absence of an argillic horizon

within the soil profile.

These four groups are:

Group A: (PA)	existence of both pumice and an argillic horizon within the soil profile
Group B: (PNA)	existence of pumice but absence of an argillic horizon within the soil profile
Group C: (NPNA)	absence of both pumice and an argillic horizon within the soil profile
Group D: (NPA)	existence of an argillic horizon but absence of pumice within the soil profile

The current study focuses on the soils of group A, B, and C. The soil types of group D can be neglected, because their extent is relatively small compared to the extent of each of the other groups in the treatment area of the Watershed Restoration Project (Fig. 3).

In each of the remaining groups A, B, and C, three research plots have been established. The extent of each research plot is 20 by 50 meters. All of them are east or west exposed and are orientated north to south.

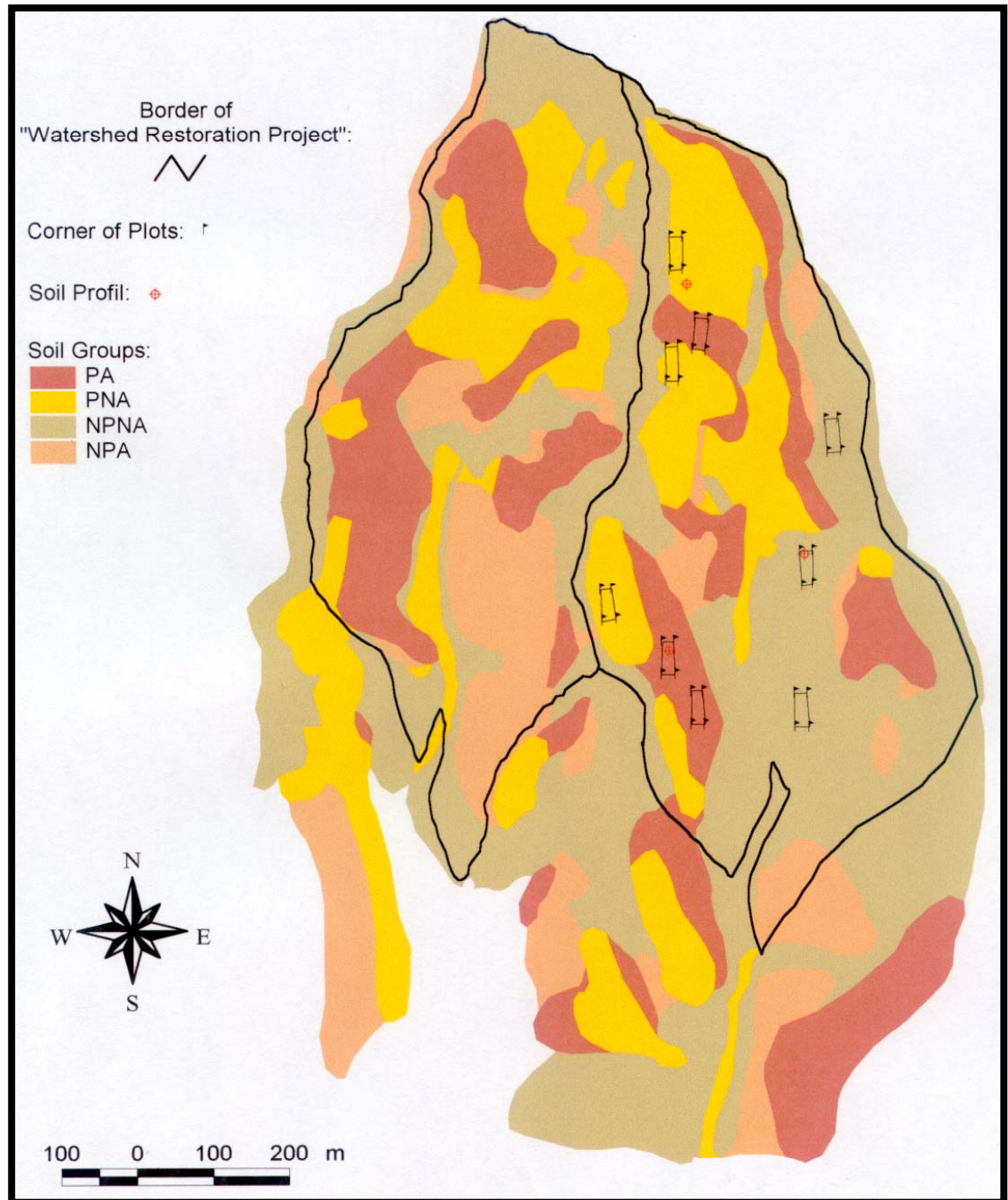


Figure 5: Four different soil groups on South Mesa including the location of research plots and soil profiles.

Each research plot is located within a homogeneous map unit (Fig. 3) which is assigned to a certain group (Fig. 5).

The selection of a map unit for putting up a research plot was made by means of extent and density. The location of a research plot within a map unit was selected randomly.

Using the Global Positioning System (GPS) helped to locate the position of a plot unit within the field. The coordinates of each corner of a plot unit have been determined with GPS. GPS made it possible to ascertain the position of each corner with an inaccuracy of less than one meter.

Drilling auger holes on each corner and in the center of every research plot was necessary to ensure the existence or absence of an argillic horizon in a depth of less than 120 cm (48 Inches) within the soil profile.



Using an auger to ensure the existence or absence of an argillic horizon in a certain depth of a soil profile.

Each corner of a research plot has been marked with an aluminum stake of about 50 cm (20 Inches) length. Each aluminum stake has been labeled with the abbreviation of the soil group (PA, PNA, NPNA), a number (1- 3), and its cardinal point from the center of the research plot (NW, NE, SW, SE).

4.2 Vegetational studies

4.2.1 Tree studies

Density

In each research plot density of one-seed juniper (*Juniperus monosperma*) and Colorado piñon pine (*Pinus edulis*) was estimated. To get a precise idea about the number of these two tree species per plot unit, each research plot was grid into several paths.

Starting at the southwestern corner, a tape measure of 50 m (164 ft) length was pulled towards the northwestern corner. The same procedure was repeated with another tape measure running parallel to the one before every 5 m to the East, until the whole research plot was gridded into four paths of 5 m width and 50 m length.

Controlling each path from South to North, every Colorado piñon pine and one-seed juniper found has been labeled.

The coordinates of each single tree were registered by adding the northerly distance of each tree to the latitudinal, and the easterly distance to the longitudinal coordinate of the southwestern aluminum stake.

The number of trees per research plot was multiplied by factor ten in order to estimate tree density per hectare. All information given about tree density refers to number of trees per hectare.

Age class structure

The age class structure of Colorado piñon pine (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) was estimated by counting tree rings.

Both tree species differ in the way of growing annual increments.

Colorado piñon pine grows with a relatively small amount of false, missing, and discontinuous tree rings and has a single, nearly circular main stem.

One-seed juniper produces several main stems from a single rootstock, although trees with a single main stem may occur (JOHNSON 1962).

Aging one-seed juniper by counting tree rings is very difficult because of the prevalence of false, discontinuous, and missing rings.

Hence, the goal of constructing an age class structure was not to determine the precise age of every single tree, but to estimate the time of establishment of each tree per decade.

Colorado piñon pine grows annual increments with relatively clear boundaries, which benefits the procedure of measuring the age class structure of this tree.

A correlation between diameter and number of tree rings for a piñon population of a specific soil group is feasible.

Hence, the diameter outside bark of every living Colorado piñon pine found in the research plots was determined close to soil surface. Measuring diameter at breast height (dbh) in this case was inappropriate because of the possibility of missing tree rings.

Next, the precise number of tree rings of 25% of the existing piñon trees per research plot was determined. The selection of piñon trees was realized in a random way and considered the whole range of diameter sizes.

If practicable, a tree core of every selected tree was taken and glued into a core mount. A core was collected by drilling an increment borer horizontally towards the center of the tree. In order not to miss any tree rings, the borer was drilled into the tree as close to the soil surface as possible.

PHIPPS (1985) gives a graphic description of collecting, preparing and measuring tree increment cores.

If the diameter of a tree was too small for collecting an increment core or the tree already had been cut down, a horizontal wooden slice (“cookie”) was cut off the tree close to the soil surface by using a pair of hedge clippers or, if necessary, a chainsaw.

The surfaces of both tree cores and wooden slices were polished with a belt sander.

Using a microscope helped determining the number of tree rings per tree core or per wooden slice.

The existing piñon population of all research plots was distinguished by affiliation to a soil group. A significant correlation between diameter and number of tree rings of the analyzed piñon trees per soil group was determined.

The correlation was used to establish a regression coefficient (a) per soil group in order to estimate age.

Using the equation

$$y = x \cdot a \quad \text{with}$$

y = estimated number of tree rings

x = diameter outside bark

a = regression coefficient

helped to estimate the number of annual increments per tree. In order to get comparable values, this estimation was realized for the total piñon population per soil group including the 25% of trees for which the precise number of tree rings already had been measured.

The estimated number of tree rings was used to determine the decade in which a piñon tree established.

In the case of one-seed juniper, the unsteadiness of growing annual increments with clear boundaries made it necessary to measure age class structure in a different way. The large number of missing, discontinuous, and false tree rings complicates the discovery of the center of a living one-seed juniper tree.

Hence, the method of tree coring is inappropriate for aging one-seed juniper.



Picture of some wooden slices (“Cookies”) after preparation with a belt sander. The three wooden slices on the left have been cut out of several different one-seed juniper trees, whereas the slice on the right originates from a Colorado piñon pine.

In order to get the most accurate idea about the number of tree rings, a horizontal wooden slice was taken from every one-seed juniper found in the nine research plots. The slice was taken close to the soil surface by using a hedge clipper or, in most cases, a chainsaw.

The surfaces of all wooden slices were polished with a belt sander and tree rings were counted under a microscope. In order not to miss any discontinuous tree rings, the broadest distance between growing center of the tree and bark was chosen to count rings.

It turned out that the stem with the biggest diameter on a multiple-stem one-seed juniper is not necessarily the oldest one. Sometimes the number of tree rings is highest on a stem with a smaller, or even the smallest diameter (personal observation).

Hence, if a juniper tree grew three or more stems out of the same rootstock, a wooden slice of the smallest, the medium, and the biggest stem was collected and prepared. If the number of stems growing out of the same rootstock was two, a sample of both stems has been taken.

The number of tree rings of each slice of a multiple-stem juniper tree was counted and the average value was measured in order to receive the most accurate idea about the exact number of tree rings.

The age of every Colorado piñon pine and one-seed juniper found in the research plots was estimated by subtracting the tree ring value from the present date (1998). The determined value helped to locate the decade in which the tree established.

Ground cover (analysis of aerial photo)

Tree canopy cover above ground was estimated in each of the nine research plots.

The experiment did not try to distinguish the canopy cover by tree species. Both Colorado piñon pine (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) have been regarded as one tree population.

The area of the Watershed Restoration Project got partly cleared of the existing tree population during the realization of experimental revegetation work in 1997 (see chapter 5).

Hence, in four of the nine research plots all piñon and juniper trees with a diameter of less than 18 cm at breast height already had been cut down.

Still the measurement of canopy cover was feasible by using an aerial photo (Fig. 4) of this area.

To get a more accurate idea about the difference between bare soil and herbaceous cover respectively and tree canopy cover, the aerial photo has been scanned into a computer and the area of each research plot has been zoomed in to full extent (Fig. 6).

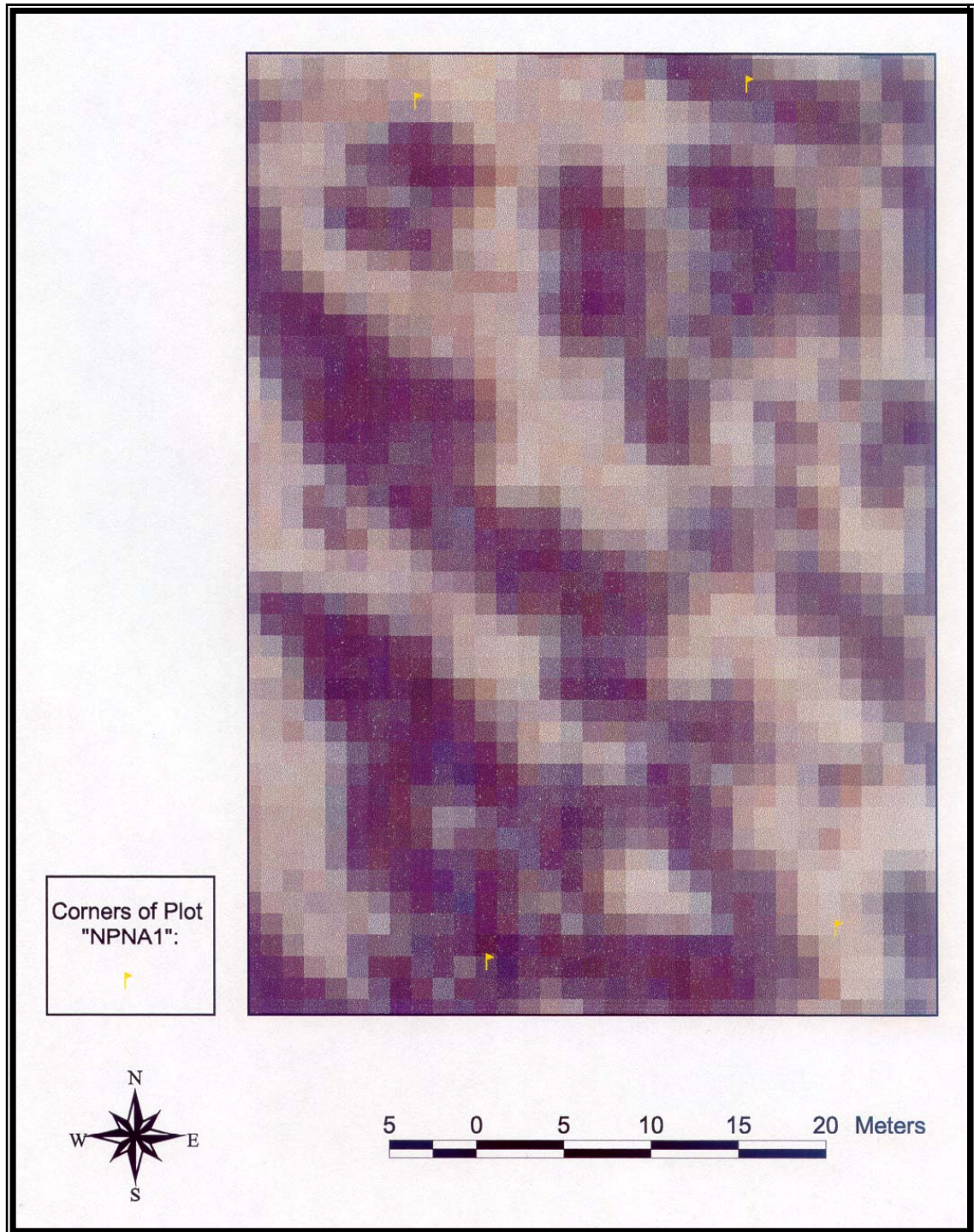


Figure 6: Location of research plot NPNA 1 shown on an aerial photo and zoomed in to full extent.

The aerial photo was taken at 11:00 AM, so the projection of shadow has been neglected. After the location of a research plot had been zoomed in, both dark and light pixels within the border of the research plot have been counted. A pixel was only registered if more than 50% of its extent was situated within the border of a research plot. The dark pixels were considered to represent tree canopy cover, whereas the light pixels were supposed to show bare soil and herbaceous cover respectively. The number of dark pixels in proportion to the total number of pixels counted within the border of a research plot was considered to represent percentage canopy cover of both Colorado piñon pine and one-seed juniper.

4.2.2. Studies of shrubs, forbes, cacti, and grasses

In order to conduct studies of shrubs, forbes, cacti, and grasses, two field units each 10 by 10m (ca. 33 by 33ft) in size have been established in each of the nine research plots. The fields both have the shape of a quadrat and are situated in the northern and southern half of a research plot respectively (Fig. 7). The border of a field unit runs parallel to the surrounding border of a research plot. The distance of the northwestern corner of the northern field is 5m to the northern and the western border of the research plot, and the distance of the southeastern corner of the southern field measures 5m to the southern and the eastern border of the enclosing plot unit.

Studies conducted in these field units focus on ground cover and biomass of shrubs, forbes, cacti, and grasses. Two methods have been used in order to estimate ground cover:

The line-intercept method and the method developed by Braun-Blanquet.

The process of estimating herbaceous vegetation structure was complicated by the fact that tree population within the area of the Watershed Restoration Project partly has been cleared in 1997 (see chapter 3). Hence, five research plots are situated in an area where piñon pines and one-seed junipers have been cut down. Three out of these five plots are located on soil group PNA. The remaining two research plots are situated on soil group PA and NPNA respectively.

Results of experimental revegetation work at Bandelier already have shown that lack of tree competition has a significant effect on ground cover and total amount of biomass of herbaceous plants.

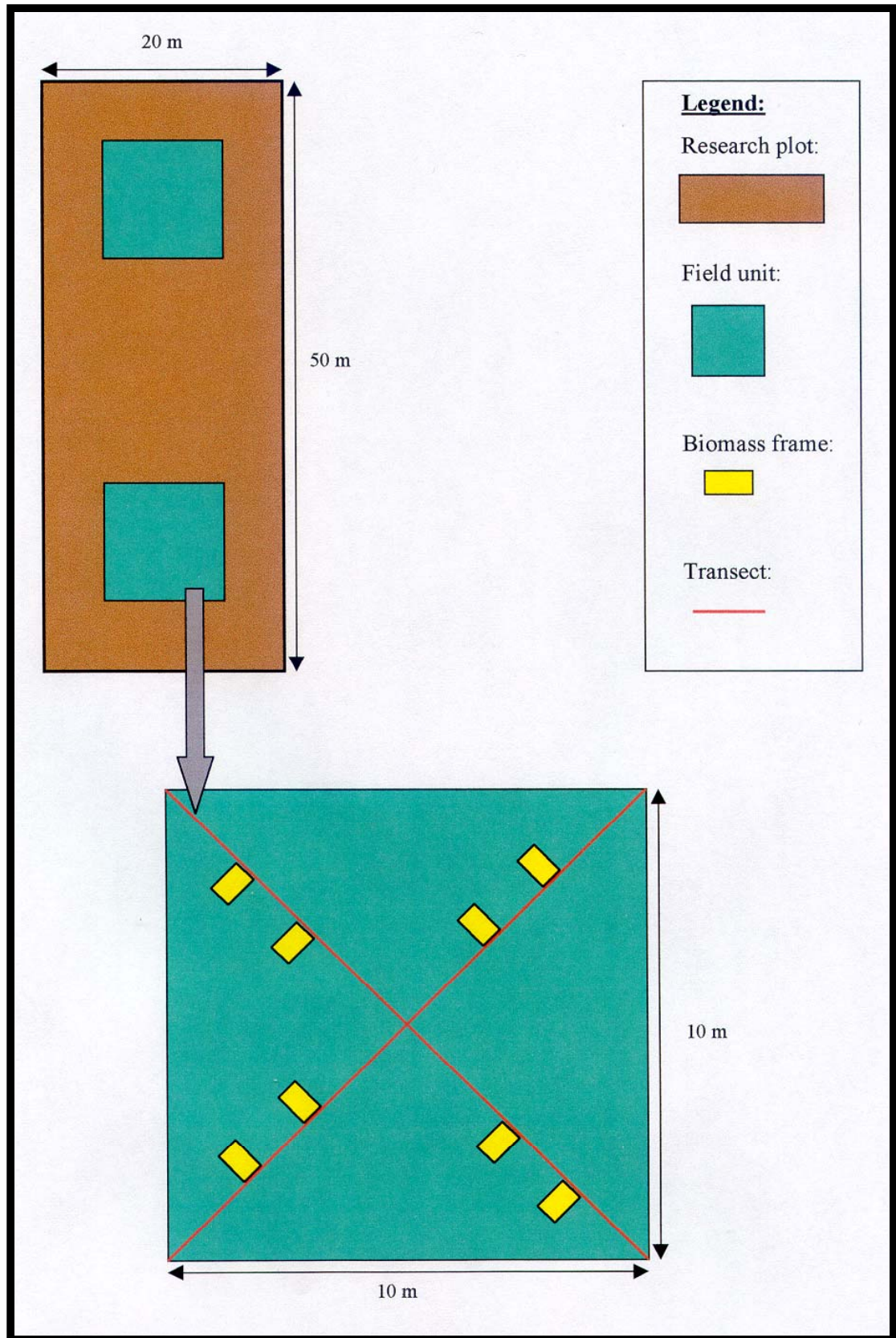


Figure 7: Arrangement of field units, vegetation transects, and biomass frames within a research plot.

In order to get comparable values of pre-treatment conditions of shrubs and herbaceous plants on soil group PNA, two additional field units have been established in an untreated area south of research plots PNA2. The field units have been labeled as PNAc.

Braun-Blanquet

Ground cover of shrubs, forbes, cacti, and grasses has been estimated in both field units of a research plots. This estimation is based on the method invented by BRAUN-BLANQUET (1964). The Braun-Blanquet method is a prominent way of measuring ground cover throughout Europe.

In each field unit elevation, exposition, and slope gradient were determined.

Next a plant list of all plant species affiliated to the life form shrub, forb, cactus, or grass has been established and the total number of plant species per field unit has been counted. Unknown plants have been sampled and a detailed identification was realized in the herbarium of Bandelier National Monument Headquarters.

The common and scientific naming of the recorded plants is based on MARTIN, W.C., and C.R. HUTCHINS: A Flora of New Mexico. Vol. 1+2.

Ground cover of all plant species found within a field unit was estimated by using an estimate scale based on Braun-Blanquet:

- r: 1-2 individuals
- +: sparsely or very sparsely present, cover very small
- 1: plentiful but of small cover value
- 2: covering 5- 25% of the area
- 3: covering 25- 50% of the area
- 4: covering 50- 75% of the area
- 5: covering 75- 100% of the area

Next, percentage of total ground cover caused by all shrubs, forbes, cacti, and grasses within a field unit was estimated.

A table representing the collected data has been established for each soil group.

In order to get an idea about the continuity of plant species throughout the field units of a soil group, all data were divided into five continuity classes.

The arrangement of these continuity classes is based on KNAPP (1971):

- I: 1-20% continuity
- II: 21-40% continuity
- III: 41-60% continuity
- IV: 61-80% continuity
- V: 81-100% continuity

Line-intercept method

Another way of estimating ground cover of shrubs, forbes, cacti, and grasses was realized by using the line-intercept method. Line-intercept is a prominent method to measure ground cover throughout the United States of America. It is done in one dimension by using a line transect. This transect could be viewed as a plot that is stretched out to a line. That is the areas lost from the plot is gained as the line is stretched out.

Along a line transect percentage cover of all species affiliated to the life forms mentioned above was evaluated.

Starting at the northern corners of each field unit, two tape measures were stretched towards the southern corners in a diagonal way in order to create two line transects (Fig. 7).

The length of ground cover of every plant species along these transects was measured and the collected data was recorded by using portable computers.

Next, all data collected of each plant species was arranged by field unit. The total length of ground cover estimated for each specific plant species was put in proportion to the total length of both transects per field unit.

A table showing the results of percentage cover was established for each soil group. In addition comparable values of ground cover estimated by using Braun-Blanquet is presented in each table.

Biomass

Biomass of herbaceous plants was collected and measured in all research plots. This part of research is focusing on all grass and forb species. No species of any shrub or cacti was taken into consideration.

The collection of biomass was done along both transects located within each field unit.

A frame of quadrature shape measuring 0,5 square meter was placed on the 2m, 4m, 8m, and 12m mark of the westerly side of a tape measure, thus marking a transect. All frames were lined up with the tape measure (Fig. 7).

All above ground biomass within a frame was clipped close to soil surface by using a pair of pruning shears. Biomass of each grass species and of the five most prominent forb species was collected separately. The selection of these forb species was done by personal observation of occurrence and density of herbaceous plants throughout the area of the Watershed Restoration Project.

The selected forb species are:

Sagebrush (*Artemisia campestris*), wormwood (*Artemisia carruthii*), yellow ragweed (*Bahia dissecta*), golden aster (*Chrysopsis villosa*), Wright's deervetch (*Lotus wrightii*), and mullein (*Verbascum thapsus*).

The remaining forb species were collected without separation and labeled as "rest forbes".

Next, the collected biomass was dried in an oven for at least 24 hours at 140° F. Dried organic matter was weighed using a calibrated balance with an accuracy up to a hundredth gram.

The weight of dried biomass of each collected herbaceous species was summed up per soil group. The recorded data being defined as gram per 24 meters square was converted into kilogram per hectare.

5. Results

In the following chapter the results of the collected data will be presented.

The abbreviations Jumo (Juniperus monosperma) and Pied (Pinus edulis) stand for one-seed juniper and Colorado piñon pine respectively.

The chapter is divided into three aspects. The first part introduces the most prominent soil types of the research area. Each soil type represents a soil group.

The second part focuses on tree studies. Results of density in trees per hectare, percentage ground cover, and age class structure will be shown.

The third aspect of this chapter informs about studies of shrubs and herbaceous plants.

5.1. Soils

5.1.1. Structure of most prominent soil types

To convey an idea about the different soil structure of groups PA, PNA, and NPNA, a typical soil profile was excavated. The position of these soil profiles within the area of the Watershed Restoration Project is illustrated in figure 5.

The most prominent soil type of each soil group will be introduced below. The description of these soils is based on DAVENPORT, D. W.: Soil Survey of Three Watersheds on South Mesa, Bandelier National Monument. 1997.

Group PA

Unnamed Soil B (OH): (Ashy-skeletal, mixed, mesic Ochreptic Haplustalf)

Soil B formed in alluvial/colluvial pumice over alluvial/colluvial material derived from tuff. It is mostly found on mesa top slopes with a gradient of 5 to 15 %. The surface of Soil B is covered with pumice, which gives it a well drained and rapidly permeable character. Buried by this pumiceous layer a soil similar to the Hackroy or Nyjack Series can be found, containing an argillic horizon.

The argillic horizon most commonly is situated at a depth of about 100 cm below the soil surface (personal observation).



Picture of soil profile located in plot PA2. In this picture the root system of *Schizachyrium scoparium* (little bluestem) can be observed.

Soil profile:

- | | |
|----------------------|---|
| A (0-8 cm): | very gravelly loam;
about 50 % pumice gravel;
many fine and medium roots; |
| CB (8-55 cm): | extremely gravelly loam;
about 70 % pumice gravel;
common fine and medium, few coarse roots; |
| 2Btk/Cr: (55-85 cm): | silty clay loam;
few medium roots;
many continuous distinct clay films on ped faces and pore walls; |
| 2R (85+ cm): | tuff; |

Group PNA

Cajete Series (CJ): (Ashy-skeletal, frigid Mollic Vitrandepts)

The soils of the Cajete Series formed in pumice on low hills, terraces, and mountain side slope with a gradient of 0 to 30 %. Similar to the Unnamed Soil B, the characteristics of soils belonging to the Cajete Series can be described as well drained with a slow run-off and a rapid permeability.

The biggest difference to the Unnamed Soil B is the lack of a buried Nyjack or Hackroy soil within the subsoil.



Picture of soil profile located close to plot PNA1.

Soil profile:

- A1-A2 (0-38 cm): extremely gravelly coarse sandy loam or gravelly loam;
15 to 80 % pumice pebbles, by volume;
many fine and medium roots;
neutral;
- Bw (38-83 cm): very gravelly sandy loam;
35 to 60 % pumice pebbles, by volume;
many fine and medium roots;
neutral;
- C1-C2-C3 (83-150 cm): very gravelly sand or very gravelly sandy loam;
35 to 60 % pumice pebbles;
neutral to mildly alkaline;

Group NPNA

Pogna Series (PG/PM): (Loamy, mixed, frigid Lithic Ustorthent)

Soils of the Pogna Series (**PG**) formed in material weathered from tuff. Mostly they are situated on gently to strongly sloping mesa tops and are characterized as well-drained soils with medium run-off and a moderately rapid permeability. The Pogna Series is most commonly connected to rock outcrop. The abbreviation (**PM**) stands for Pogna-rock outcrop complex and refers to soils of the Pogna Series that are situated in an area of up to 40 % rock outcrop.

The Pogna Series are classified as Lithic Ustorthent. They are assigned to the Entisol order.

Soil profile:

- A1 (0-13 cm): fine sandy loam;
many medium roots;
neutral;
- C (13-30 cm): fine sandy loam;
many medium and coarse roots;
slightly acid;
- R (30+ cm): tuff bedrock;



Picture of soil profile located in plot NPNA1

5.1.2. Comparison of soil characteristics

Amount of total annual precipitation and the time of year in which such precipitation occurs does much to determine vegetative cover in a given area of New Mexico (CASTETTER, 1956).

Hence, it is appropriate to inspect and compare soil characteristics that influence the water holding capacity of a soil significantly.

One of these soil characteristics found in the soil types of the research area is the presence of pumice as a top soil (PA, PNA). DAVENPORT (1997) describes soil types belonging to the PA or PNA group as soils with a well drained, rapidly permeable character and a slow run-off.

In contrast, soil types of the NPNA group have a moderately rapid permeability and a medium run-off.

Hence, a relatively higher amount of water is able to infiltrate into deeper layers of soil group PA and PNA compared to group NPNA.

Another important soil characteristic is the presence of an argillic horizon up to a depth of 120 cm within a soil profile. Soil water infiltrating into a soil profile of a PA soil is likely to be dammed up by this clay horizon (see chapter 3.2). In contrast, most soil water percolating through a soil profile of a PNA soil will infiltrate into deeper soil layer.

Hence, a relatively higher amount of soil water will be stored in a soil depth of up to 120 cm within a soil of the Pa group. This circumstance favors herbaceous plants to assimilate soil water.

5.2. Trees

5.2.1. Density

The total number of both Colorado piñon pine (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) counted in all research plots is 965. About 43% of these trees are one-seed juniper and 57% are Colorado piñon pine.

Table 1: Number of trees per research plot

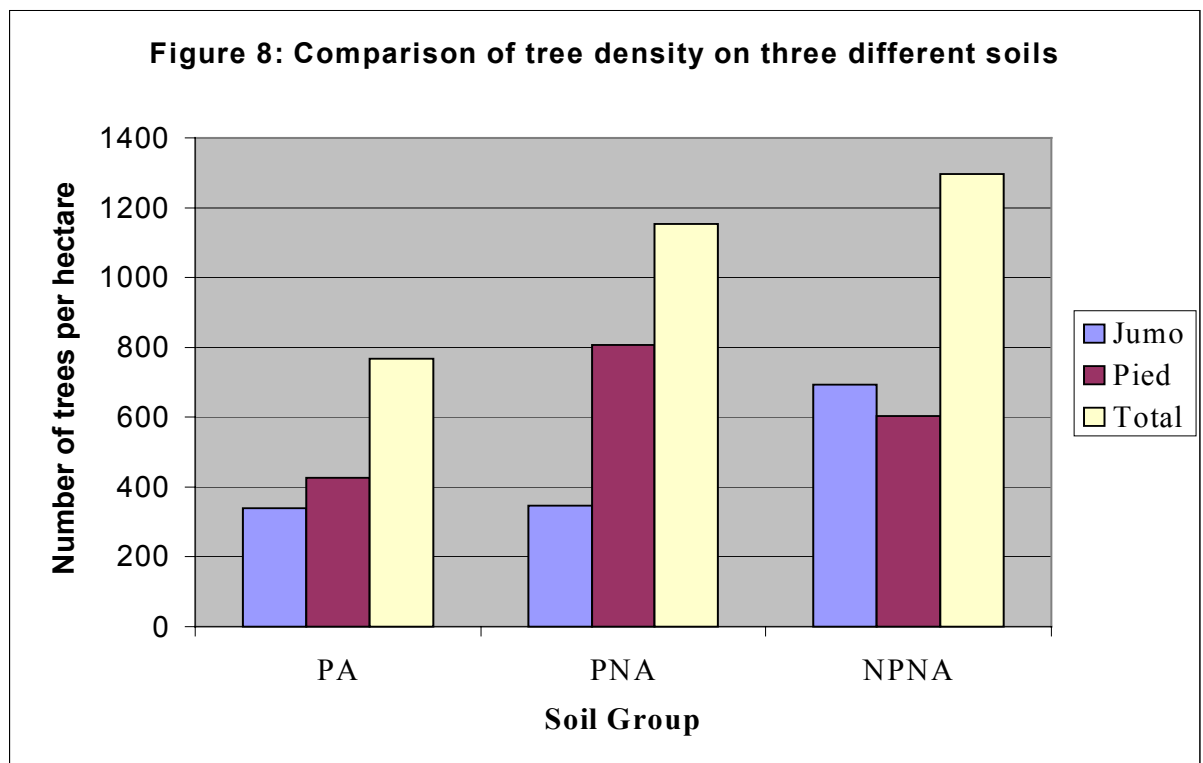
	PA 1	PA 2	PA 3	PNA 1	PNA 2	PNA 3	NPNA 1	NPNA 2	NPNA 3
Jumo	37	31	34	46	31	27	83	69	56
Pied	35	38	55	75	63	104	56	61	64
Total	72	69	89	121	94	131	139	130	120

The table shows a significant difference between the total number of trees in the research plots of soil group Pa and NPNA.

The total number of 965 trees counted in all research plots ties up with an average density of about 1072 trees per hectare.

Tree density was highest in research plot NPNA1 with 1390, and lowest in research plot PA2 with 690 trees per hectare.

Comparing average tree density per soil group, the highest value is found at soil group NPNA with about 1296 trees per hectare. The second highest result is estimated for soil group PNA with 1154, and the lowest value is measured for soil group PA with 767 trees per hectare (Fig. 8).



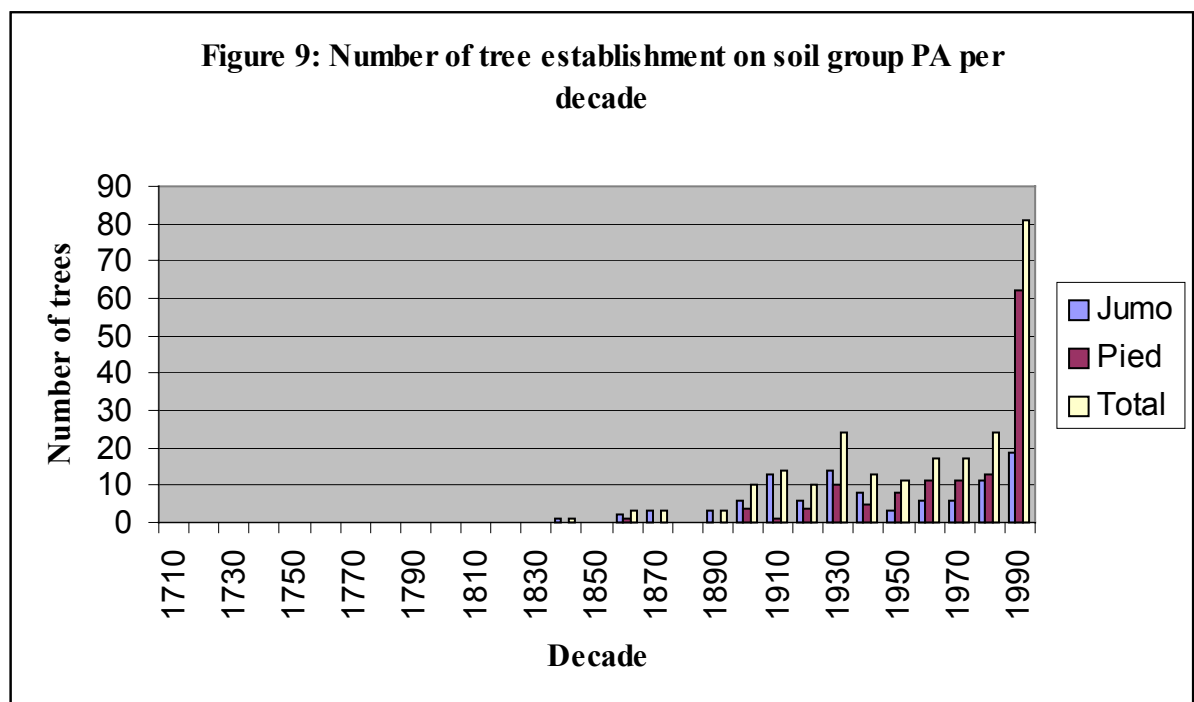
Total tree density of soil group PNA and NPNA is clearly above the estimated average of 1072 trees per hectare, whereas tree density of soil group PA is noticeably below this value. Both on soil group PA and NPNA, distribution of tree density per species is about equal. A predominant density of *Pinus edulis* in contrast to *Juniperus monosperma* can be detected on soil group PNA.

Comparing tree density per species of soil group PA and PNA, one fact is strikingly perceptible. Tree density of one-seed juniper in both cases is about equal, whereas number of piñon trees per hectare on soil group PNA nearly doubles the value of soil group PA.

5.2.2. Age class structure

On soil group PA, first tree establishment can be traced down between 1840 and 1849 (Fig. 9). Tree establishment on this soil group is low to non-existent till the turning of the century. Between 1900 and 1909 total number of tree establishment is higher than ten for the first time.

After tree establishment peaks during the 1930s with a total of 24 trees, the tendency of an increasing tree population declines until the 1950s.



The highest number of tree establishment on soil group PA is recorded in the 1990s with a total of 81 trees.

From the time of the first tree detection until the 1940s number of one-seed juniper establishing on this soil group per decade is higher than the comparable value of Colorado piñon pine. This tendency changes in the 1950s and in the 1990s for the first time number of Colorado piñon pine establishing on this soil group is about three times as high as the number of tree establishment of one-seed juniper.

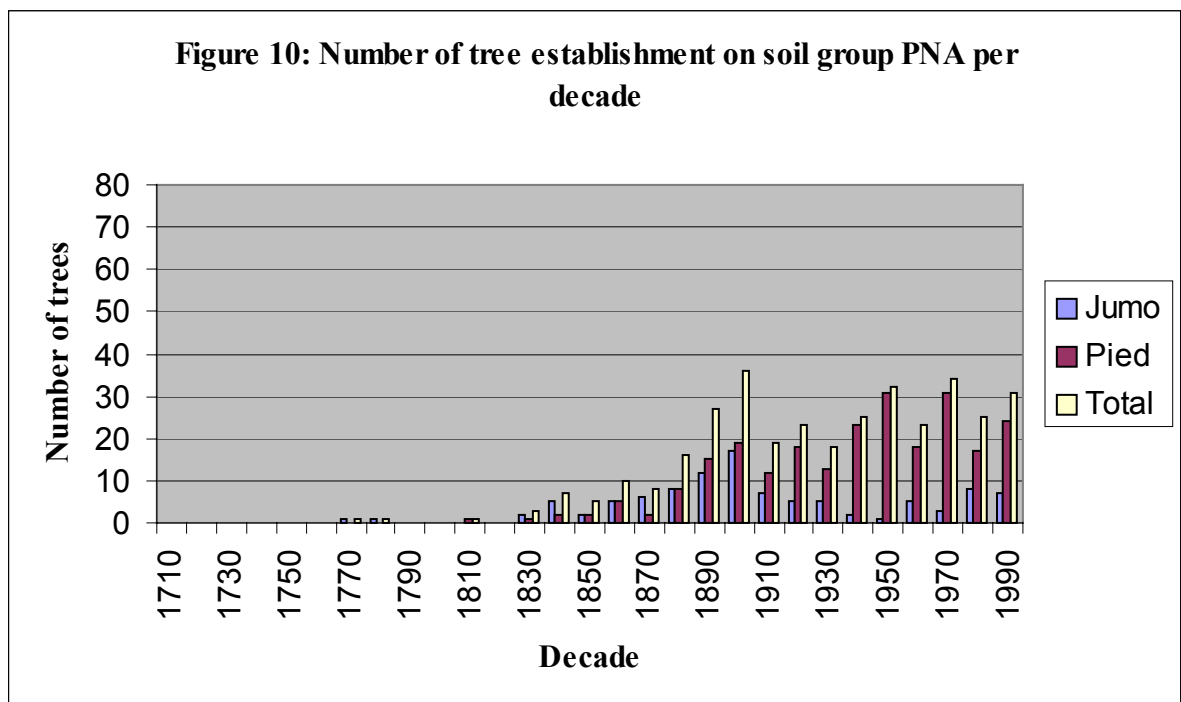
The oldest tree species found on soil group PNA is a one-seed juniper, which established between 1770 and 1779 (Fig. 10).

Tree establishment started to increase in the 1880s and peaked between 1900 and 1909 with a total number of 36 trees establishing. Interestingly, the total number of trees establishing during this decade is even higher than the total number of trees establishing in the 1990s.

A decline of tree establishment can be detected during the 1930s and 1940s. From 1950 to 1998 the total number of tree establishment on soil group PNA is about 30 trees per decade.

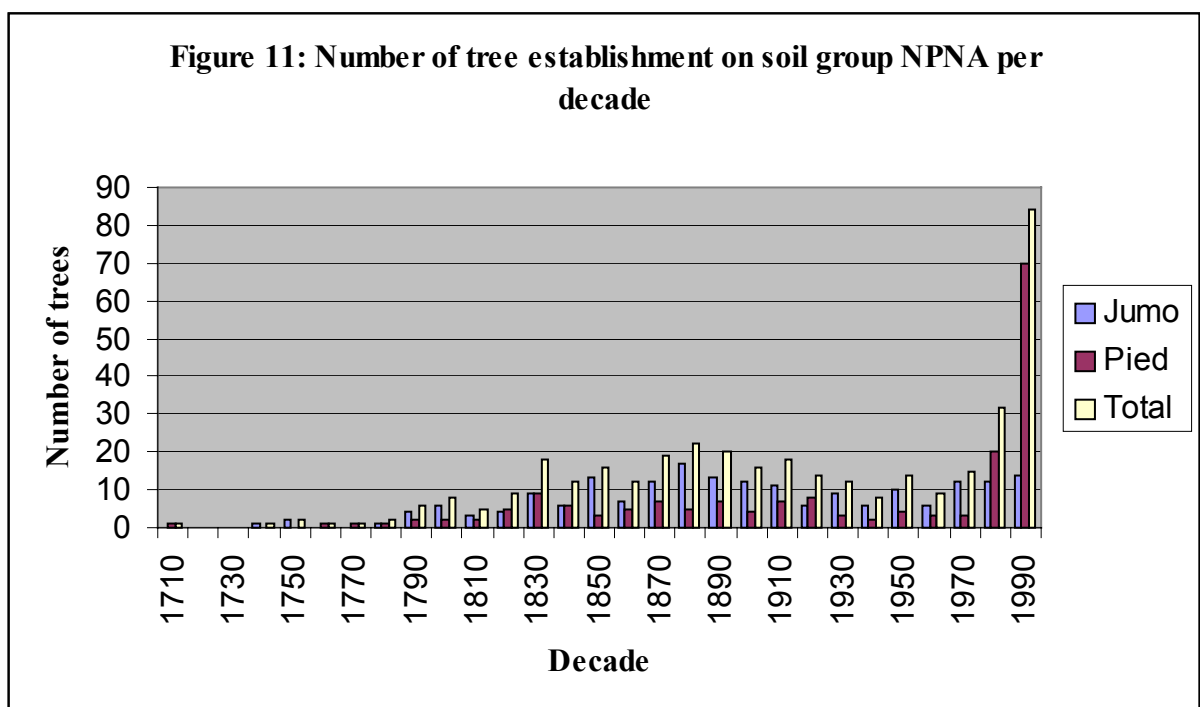
Since the 1890s tree establishment is dominated by Colorado piñon pine.

The difference in the number of tree establishment of the two species is highest in the 1950s, when number of Colorado piñon pine is about thirty times as high as the comparable value for one-seed juniper.



While number of Colorado piñon pine per decade increases from the 1930s until the 1950s, the opposite of this tendency is perceptible for one-seed juniper.

Both the oldest Colorado piñon pine and one-seed juniper were found on soil group NPNA (Fig. 11).



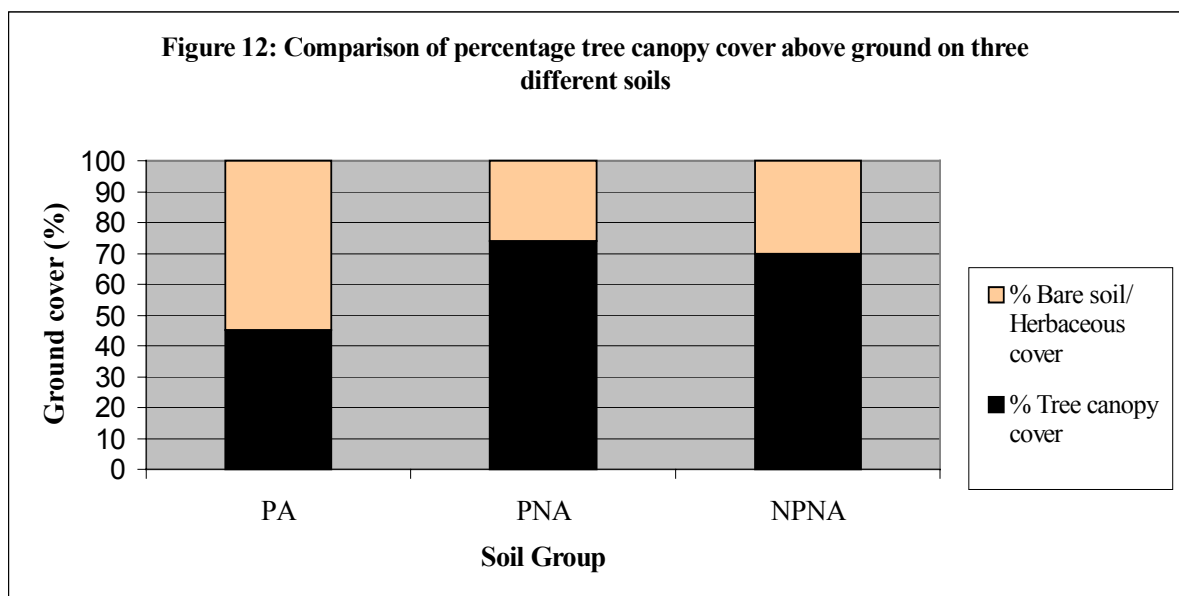
Tree establishment on this soil group is constantly perceptible since the 1740s, with a first slight peak in the 1830s.

Number of trees establishing on soil group NPNA is definitely increasing during the turning of the century. Between 1880 and 1889 for the first time number of tree establishment is higher than 20 trees per decade.

Until the 1940s a decline of tree establishment per decade on soil group NPNA is perceptible. In the 1980s and in particular the 1990s, establishment of trees is increasing dramatically. Until the 1980s in most cases number of one-seed juniper establishing per decade is higher than number of Colorado piñon pine. This fact changes in the 1980s and especially the 1990s. Between 1990 and 1998, number of Colorado piñon pine establishing on soil group NPNA is five times as high as the comparable value for one-seed juniper.

5.2.3. Ground cover

The highest value of tree canopy cover was found in research plot PNA3 with about 87% ground cover. The research plot with the smallest value is PA1 with approximately 33% tree cover.



Percentage tree canopy cover estimated in all research plots of soil group PA ranges from about 33 to 51%. On this soil group, average tree canopy cover is the smallest with about 45% (Fig. 12).

The highest average value of tree canopy cover can be found on soil group PNA with about 74% ground cover. Percentage tree cover estimated in all research plots of this soil group ranges from about 58 to 87%.

Average tree canopy cover estimated on soil group NPNA is about 70%. Tree cover above ground ranges from approximately 63 to 82% in all research plots of this soil group.

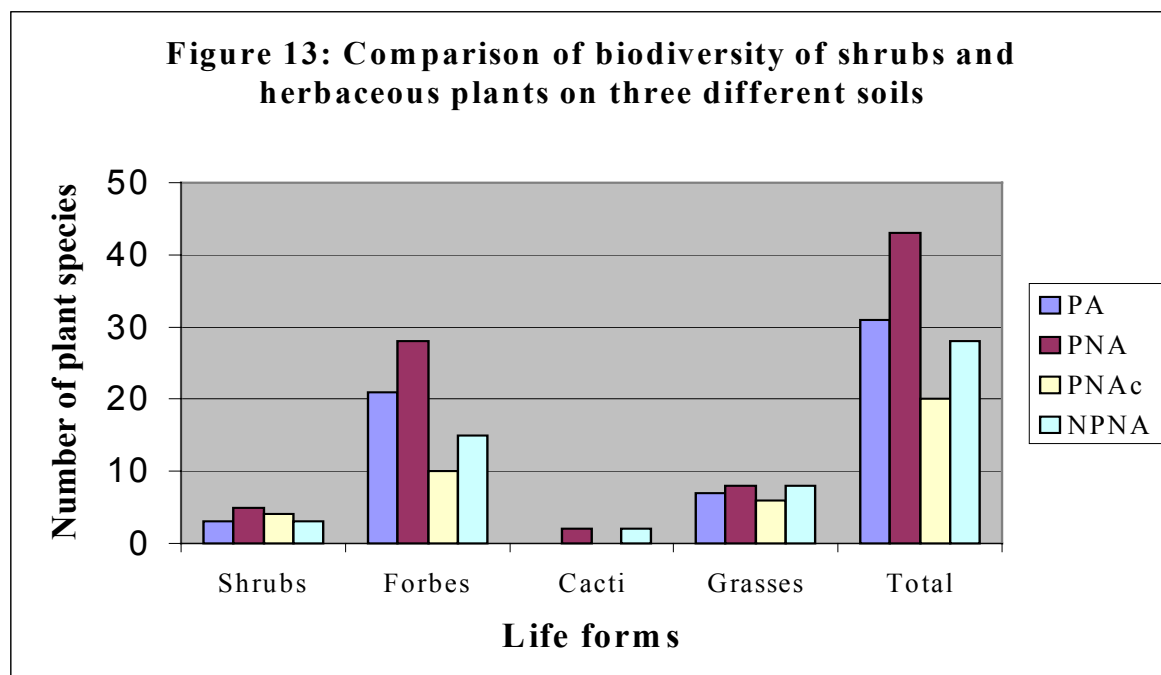
Comparing average tree canopy cover of all soil groups, no significant difference can be determined between soil groups PNA and NPNA. Additionally the range of estimated tree canopy cover on both soil groups is similar.

Both average tree canopy cover and range of estimated ground cover of soil group PA differ from the comparable values of soil groups PNA and NPNA respectively. Values estimated for this soil group are relatively small.

5.3. Shrubs, forbes, cacti, and grasses

5.3.1 Ground cover by Braun-Blanquet

Total number of plant species recorded in all research plots is 56, with 3 trees, 5 shrubs, 36 forbes, 2 cacti, and 10 grasses.



This figure is based on data recorded by using the Braun-Blanquet method.

Highest number of shrubs and herbaceous plants was found on soil group PNA with a total of 43 species. The lowest number was recorded within the two field units of PNAc. Hence, it is likely, that high biodiversity recorded within the research plots of soil group PNA is primarily caused by lack of tree competition.

With 31 and 28 species respectively, the total number of plants on soil group PA and NPNA are similar.

Estimated total ground cover on soil group PA is relatively high with 5 to 20%.

21 forb and 7 grass species were recorded on this soil group. Starting with the highest estimated value, *Artemisia campestris* (sagebrush), *Artemisia carruthii* (wormwood), *Lotus wrightii* (Wright's deervetch), *Bahia dissecta* (yellow ragweed), *Verbascum thapsus* (mullein), and *Cryptantha jamesii* (hiddenflower) are the forb species showing the most spacious ground cover. Additionally, all of these forbes appear with a continuity of more than 80% through all field units affiliated to soil group PA.

Schizachyrium scoparium (little bluestem), *Bouteloua gracilis* (blue grama), and *Koeleria cristata* (junegrass) produce the highest ground cover of all grass species on this soil group, with little bluestem and junegrass being assigned to continuity class V. Blue grama appears with a continuity of more than 60%.

Little bluestem attracts attention by producing the highest ground cover of all plant species found on this soil group. This grass is the only plant that is assigned to ground cover class 2 (cover value of 5- 25%).

On soil group PNA recorded number of forb and grass species are 28 and 9 respectively. Though all field units of soil group PNA are located within the clearing area of the Watershed Restoration Project and hence competition for water by trees is minor, total ground cover is relatively small with 5 to 15%.

Forb species with most spacious ground cover and a continuity of more than 80% on soil group PNA are similar to the comparable plants of soil group PA. Starting with the highest ground cover value, these species are: *Lotus wrightii*, *Bahia dissecta*, *Artemisia campestris*, *Senecio multicapitatus* (ragwort groundsel), *Verbascum thapsus*, *Cryptantha jamesii*, and *Croton texensis* (Texas croton).

No such similarity can be found comparing grass species of these two soil groups. *Sitanion hystrix* (bottlebrush squirreltail) is the only grass species on soil group PNA that can be assigned to continuity class V, though its ground cover value is very small. A grass recorded in more than 60% of all affiliated field units and a cover value of up to 5% is *Bouteloua gracilis* (blue grama).

Smallest total ground cover is estimated for the field units of soil group NPNA. Cover ranges between <5 to 10%. *Artemisia campestris*, *Bahia dissecta*, *Chrysopsis villosa* (golden aster), and *Lotus wrightii* have the highest ground cover values and are existent in more than 80% of all field units.

The most prominent grass species are *Schizachyrium scoparium*, *Bouteloua gracilis* and *Poa fendleriana* (muttongrass). All of these species appear with high continuity, but are sparsely to very sparsely present.

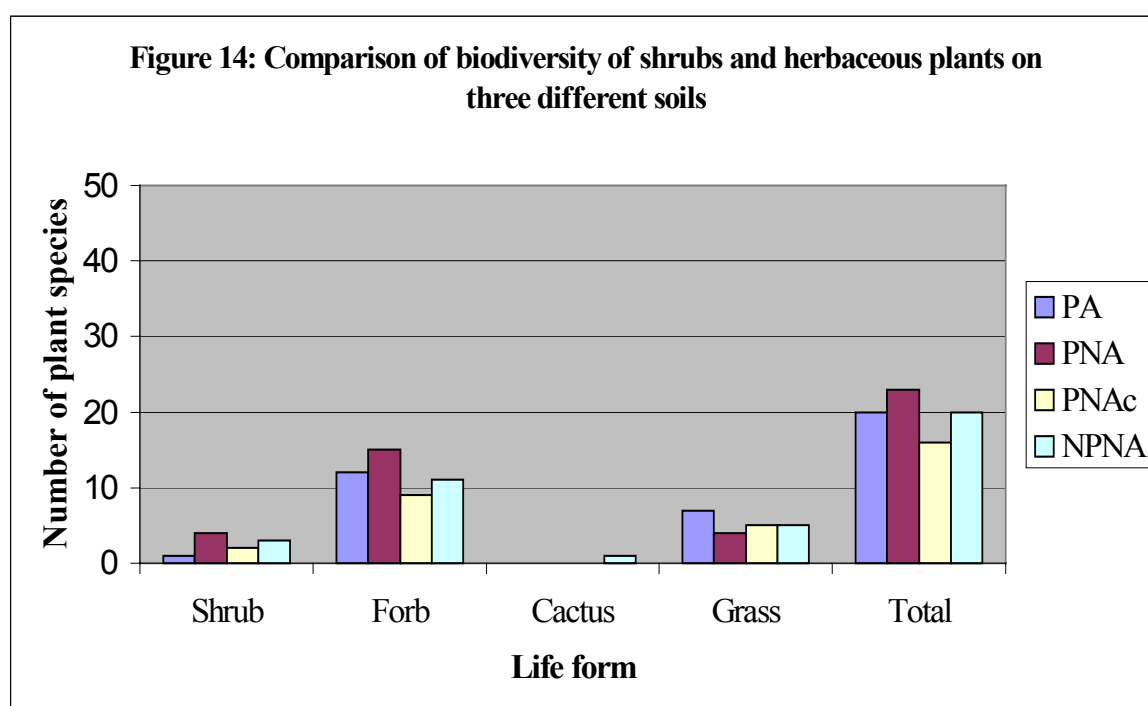
The same circumstances apply to *Opuntia species* (prickly pear). Soil group NPNA happens to be the only soil where the appearance of cacti can be assigned to continuity class V. Although estimated ground cover of Prickly pear is of small cover value, this cactus has to be considered to be one of the most prominent plant species of soil group NPNA.

Another plant with a high affinity towards soil group NPNA is *Quercus undulata* (wavyleaf oak). Being assigned to continuity class V, ground cover of this shrub is even more spacious than the coverage of prickly pear.

Both continuity and ground cover of shrubs seem to play a minor part on soil group PA and PNA.

5.3.2. Ground cover by Line-intercept method

Comparing the line-intercept method with the method of Braun-Blanquet, one difference is clearly perceptible. Number of plant species found on each soil group by using the line-intercept method is noticeably smaller than the comparable value recorded by using Braun-Blanquet.



This figure is based on data recorded by using the line-intercept method.

On soil group PA only 20 out of 31 shrubs and herbaceous plant species were found, with two shrubs and nine forbes being missed. All of these missed plant species have to be assigned to continuity class I or II and in most cases are only present with one or two individuals throughout all affiliated field units.

The impression of ground cover estimated for plants with a high cover value is mirrored accurately by using the line-intercept method. The only plant showing a strong divergence between both estimated values is Wright's deervetch (table 2). Focusing on this forb a strong response to the lack of tree competition has to be taken into consideration (personal observation).

Table 2: Comparing estimated ground cover by using two different methods on soil group PA

Life form	Genus	Species	Common name	Braun-Blanquet	Line-intercept method (%)
forb	<i>Artemisia</i>	<i>campestris</i>	Sagebrush	+ - 1	1,2
forb	<i>Artemisia</i>	<i>canadensis</i>	Wormwood	+ - 1	0,8
forb	<i>Lotus</i>	<i>wrightii</i>	Wright's deervetch	+	6,6
forb	<i>Bahia</i>	<i>dissecta</i>	Yellow ragweed	+	0,6
forb	<i>Verbascum</i>	<i>thapsus</i>	Miner's candle; Mullein	+	0,27
forb	<i>Cryptantha</i>	<i>jamesii</i>	Hiddenflower	+	0,1
grass	<i>Schizachyrium</i>	<i>scoparium</i>	Little bluestem	2	11,5
grass	<i>Bouteloua</i>	<i>gracilis</i>	Blue grama	+	0,9
grass	<i>Koeleria</i>	<i>cristata</i>	Junegrass	r - +	0,8

Results illustrated in this table represent the average value of all data estimated in the six field units of research plot PA. The median was chosen for the Braun-Blanquet data, whereas the mean was taken for the line-intercept method.

On soil group PNA the difference of the recorded number of plant species between Braun-Blanquet and the line-intercept method is even more transparent. Only 23 out of 43 shrubs and herbaceous plant species were found. However, 13 out of these 20 missing plants appear with only one or two individuals throughout all affiliated field units, and 18 of them can be assigned to continuity class I or II.

Table 3: Comparing estimated ground cover by using two different methods on soil group PNA

Life form	Genus	Species	Common name	Braun-Blanquet	Line-intercept method (%)
forb	<i>Lotus</i>	<i>wrightii</i>	Wright's deervetch	1	18,4
forb	<i>Artemisia</i>	<i>campestris</i>	Sagebrush	1	1,7
forb	<i>Bahia</i>	<i>dissecta</i>	Yellow ragweed	1	0,9
forb	<i>Senecio</i>	<i>multicapitatus</i>	Ragwort groundsel; Butterw.	+ - 1	0,9
forb	<i>Cryptantha</i>	<i>jamesii</i>	Hiddenflower	+	0,3
forb	<i>Verbascum</i>	<i>thapsus</i>	Miner's candle; Mullein	+	0,2
forb	<i>Croton</i>	<i>texensis</i>	Texas croton	+	0,1
grass	<i>Bouteloua</i>	<i>gracilis</i>	Blue grama	1	1,5
grass	<i>Sitanion</i>	<i>hystrix</i>	Bottlebrush squirreltail	r - +	0,8

Results illustrated in this table represent the average value of all data estimated in the six field units of research plot PNA. The median was chosen for the Braun-Blanquet data, whereas the mean was taken for the line-intercept method.

Again the difference of estimated ground cover value between both methods for plant species with a more spacious appearance is minor, with Wright's deervetch being the only exception (table 3).

Still it has to be mentioned that with no cactus being recorded by using the line-intercept method, a whole life form was missed.

On soil group NPNA 20 out of 28 herbaceous plants were missed by using the line-intercept method. All shrub species have been recorded.

Again, missing plant species mostly appear with a small cover value and a low continuity. Two exceptions are made by *Sitanion hystrix* and *Erigeron species* (fleabane), which both appear with a relatively high ground cover and are assigned to continuity class III and IV respectively.

Table 4: Comparing estimated ground cover by using two different methods on soil group NPNA

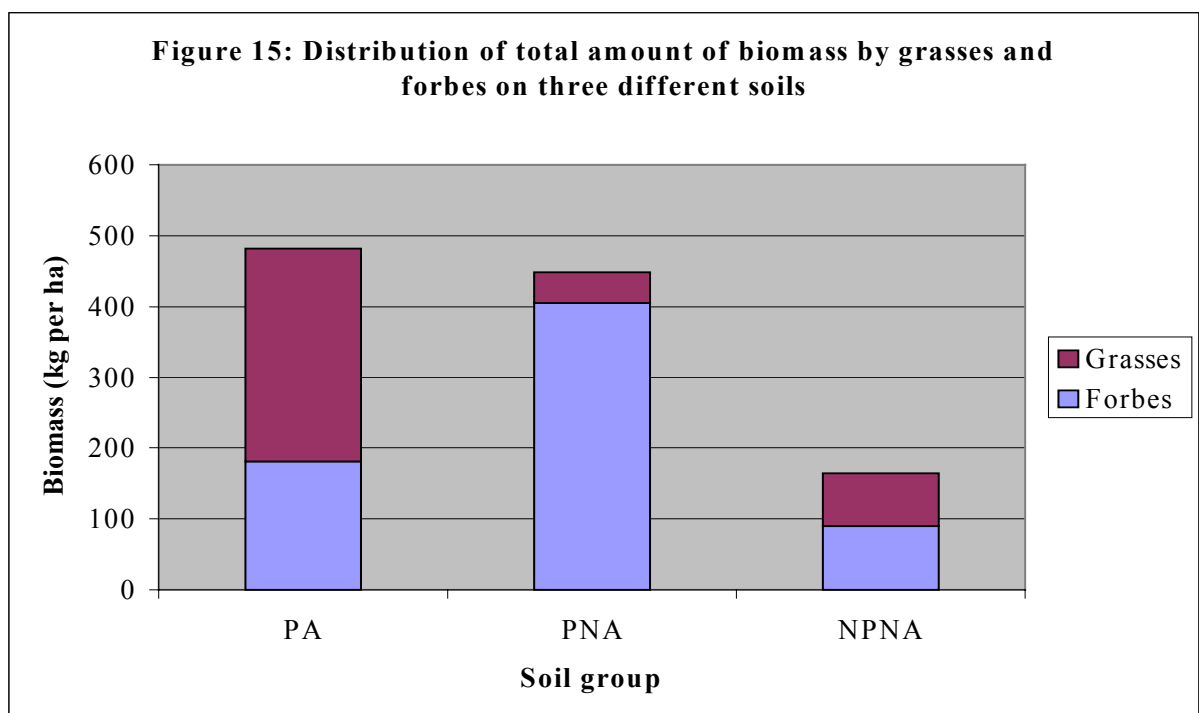
Life form	Genus	Species	Common name	Braun-Blanquet	Line-intercept method (%)
shrub	<i>Quercus</i>	<i>undulata</i>	Wavyleaf oak	+ - 1	3
forb	<i>Chrysopsis</i>	<i>villosa</i>	Golden aster	+	1,3
forb	<i>Lotus</i>	<i>wrightii</i>	Wright's deervetch	+	1,3
forb	<i>Artemisia</i>	<i>campestris</i>	Sagebrush	+	0,8
forb	<i>Bahia</i>	<i>dissecta</i>	Yellow ragweed	+	0,3
cactus	<i>Opuntia</i>	<i>species</i>	Prickly pear	+	0,1
grass	<i>Bouteloua</i>	<i>gracilis</i>	Blue grama	+	2,5
grass	<i>Schizachyrium</i>	<i>scoparium</i>	Little bluestem	+	1,2
grass	<i>Poa</i>	<i>fendleriana</i>	Muttongrass	+	0,2

Results illustrated in this table represent the average value of all data estimated in the six field units of research plot NPNA. The median was chosen for the Braun-Blanquet data, whereas the mean was taken for the line-intercept method.

Data of both Braun-Blanquet and the line-intercept method again do not show much difference for plant species with a relatively high cover value (table 4).

5.3.3. Biomass

Total amount of biomass recorded on soil group PA is the highest of all soil groups with about 480 kg per ha (Fig 15). More than 62% of this quantity is produced by grass species, nearly 38% by forbes.

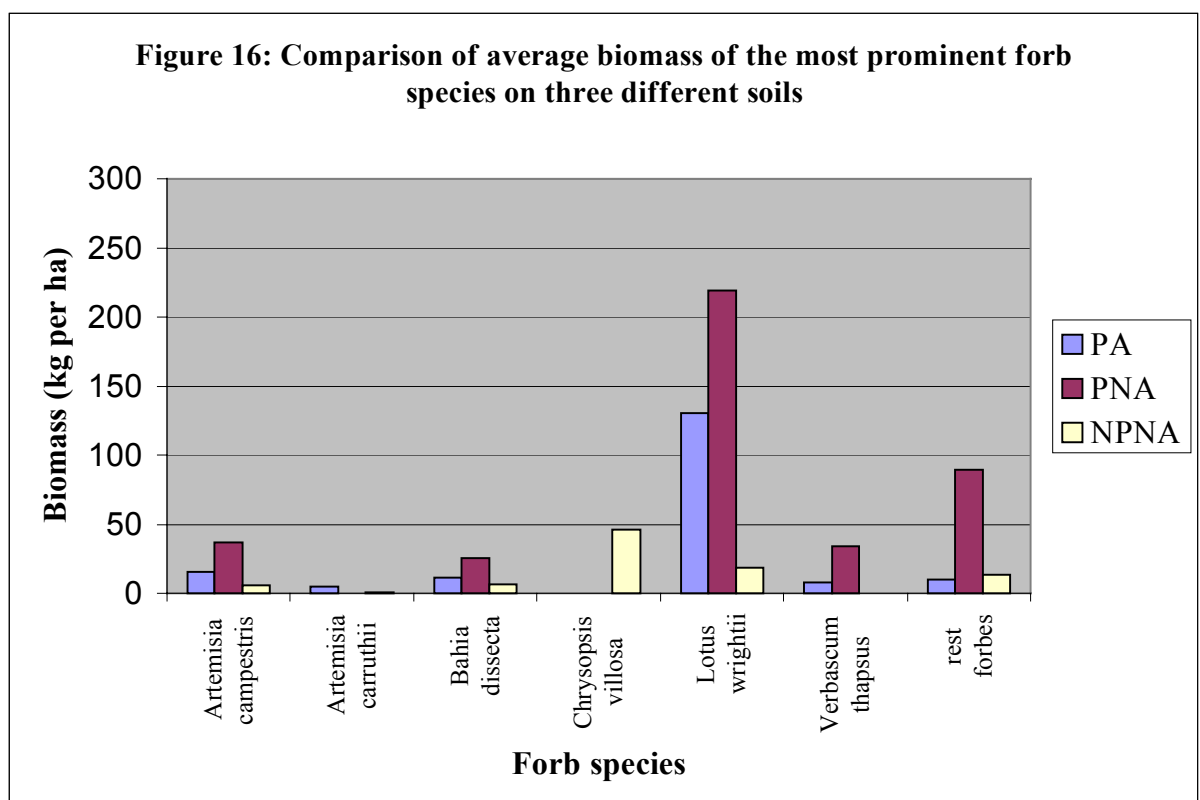


The second highest value was estimated for soil group PNA. A total amount of organic matter equating nearly 450 kg per ha was recorded. Distribution of this value by life form differs significantly. More than 90% of the total amount of biomass recorded on soil group PNA is produced by forbes, only 10% by grasses.

Smallest amount of biomass was recorded on soil group NPNA with 164 kg per ha. Production of organic matter of both grasses and forbes is similar, with a slight predominance on the part of the forb species.

Focusing on biomass production of forbes, two species attract attention. On both soil group PA and PNA *Lotus wrightii* (Wright's deervetch) causes the highest quantity of organic matter of all forbes with about 130 and 220 kg per ha respectively (Fig. 16). This leguminous forb produces nearly 50% of all biomass recorded on soil group PNA.

The second forb showing some interesting results is *Chrysopsis villosa* (golden aster). Producing nearly 30% of all biomass recorded on NPNA soils, it is one of the most prominent plant species of this soil group. On the contrary there is no evidence of any biomass found of this Asteraceae on both other soil groups.

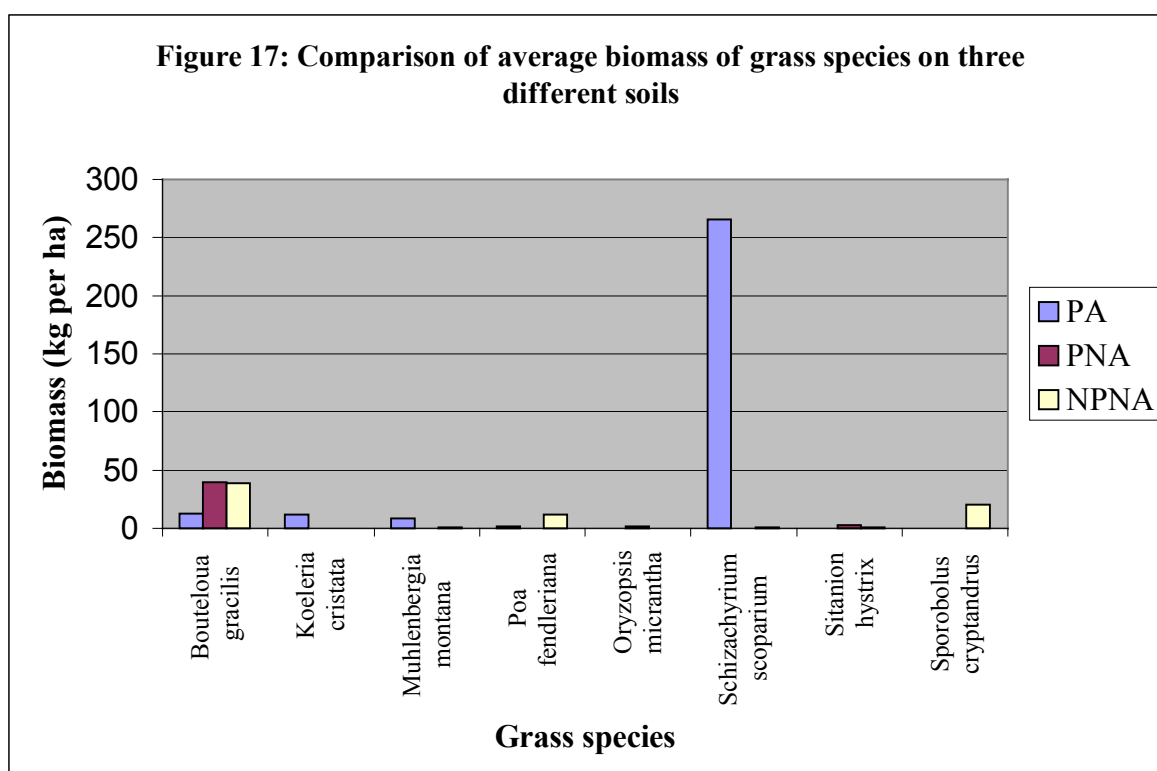


Artemisia campestris and *Bahia dissecta* show a similar pattern of biomass production on all soil groups. They play a minor part of growing biomass with less than 10% of the total amount of organic matter recorded on each soil group.

Percentage weight of “rest forbes” compared to the total amount of biomass produced by all forb species on each soil group is relatively high on soil group PNA with about 22%. On soil group NPNA this share equals about 15%, on soil group PA only 6%.

The highest amount of biomass production caused by plant species was recorded for *Schizachyrium scoparium* (little bluestem) on soil group PA with about 265 kg per ha (Fig. 17). This quantity equals a percentage weight of more than 55% of total biomass on this soil group. It is even more than 80% of biomass production caused by all grass species on PA soils.

The significance of productivity of *Schizachyrium scoparium* on this specific soil group is illustrated by another fact. The quantity of organic matter caused by this grass on soil group PA tops the total amount of biomass recorded for all plant species on soil group NPNA by 100 kg per ha.



Bouteloua gracilis (blue grama) shows the highest productivity of biomass of all grass species on soil group PNA and NPNA, with 40 and about 39 kg per ha respectively.

Focusing on soil group PNA, blue grama is the most prominent grass species, but plays a minor part compared to the total amount of biomass on this soil group.

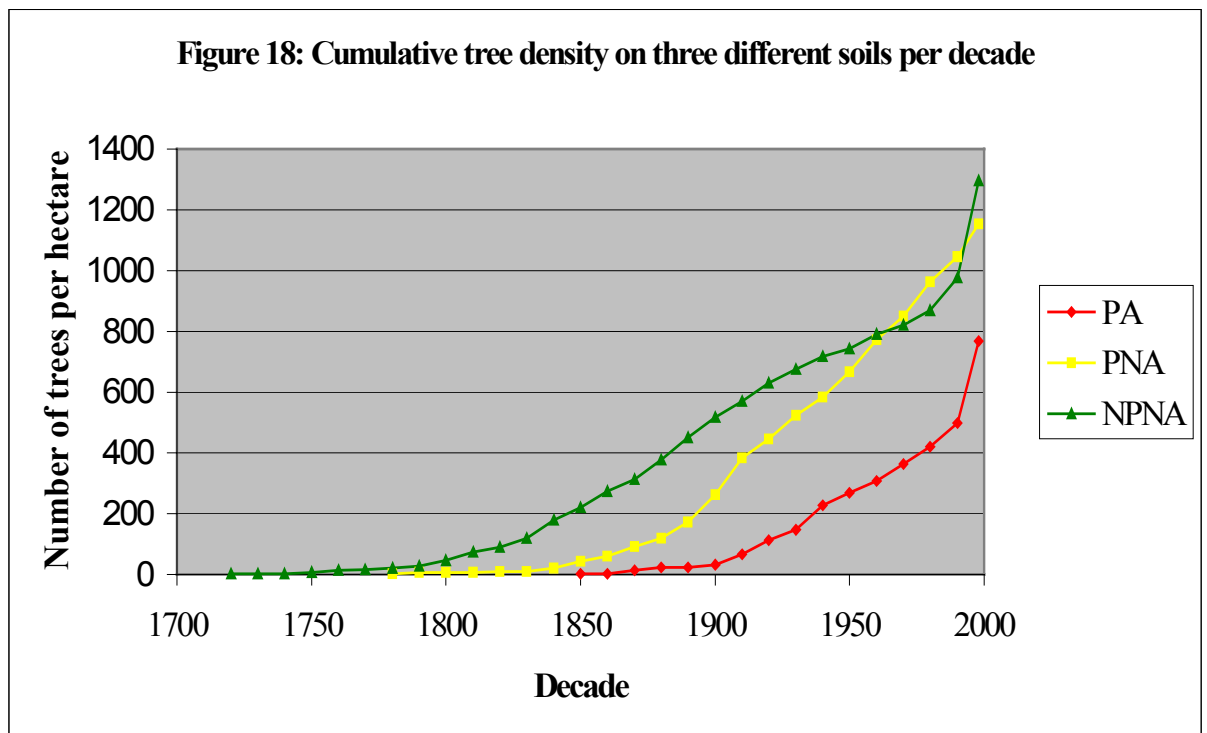
Bouteloua gracilis produces more than 23% of the total amount of biomass on soil group NPNA.

6. Comparison of soil groups

In order to find out whether there are some differences between vegetation structure of soil group PA, PNA, and NPNA, the most striking results will be compared in this chapter. In the first part results of tree studies will be illustrated, whereas the second part deals with the results of shrubs, forbes, cacti, and grasses.

6.1. Trees

Focusing on tree studies, some conspicuous differences between all soil groups can be observed. Both density and ground cover of trees on soil group PA are significantly below the comparable values of soil group PNA and NPNA. Additionally the youngest age class structure has been recorded on PA soils.



Comparing tree density on soil group PA and NPNA through time, the idea of a different vegetation structure suggests itself. It is appropriate to assume that at least fragments of piñon-juniper woodlands have already been existent on shallow, rocky soils in the 18th century.

First indication of *Juniperus monosperma* (one-seed juniper) and *Pinus edulis* (Colorado piñon pine) on PA soils is perceptible at the end of the 19th century. It is very likely to believe

that the establishment of these tree species is connected to a growing human influence, including intensified grazing and the suppression of natural fire (see chapter 4). Hence, the transition from a grassland with no evidence of Colorado piñon pine or one-seed juniper to a piñon-juniper woodland can be supposed on soil group PA.

Still the invasion of one-seed juniper and Colorado piñon pine in the existing grassland of PA soils needs to be scrutinized more precisely. During the turning of the century the most prominent tree species coexisting in the grassland of soil group PA is supposed to be *Pinus ponderosa* (ponderosa pine). Almost the whole population of this tree species has been killed during the 1950s drought. Today, only dead logs refer to the former presence of this tall pine tree.



Logs of dead ponderosa pine at plot unit PA2. The picture exposes a concentration of one-seed juniper and Colorado piñon pine around the former root system of the dead trees.

Taking a closer look at the location of one-seed juniper and Colorado piñon pine on soil group PA, a concentration of these trees at the former root system of *Pinus ponderosa* can be detected (Fig. 19).

Due to this observation, ponderosa pine can be considered as some kind of stepping stone for the invasion of other piñon and juniper trees in the grassland of soil group PA.

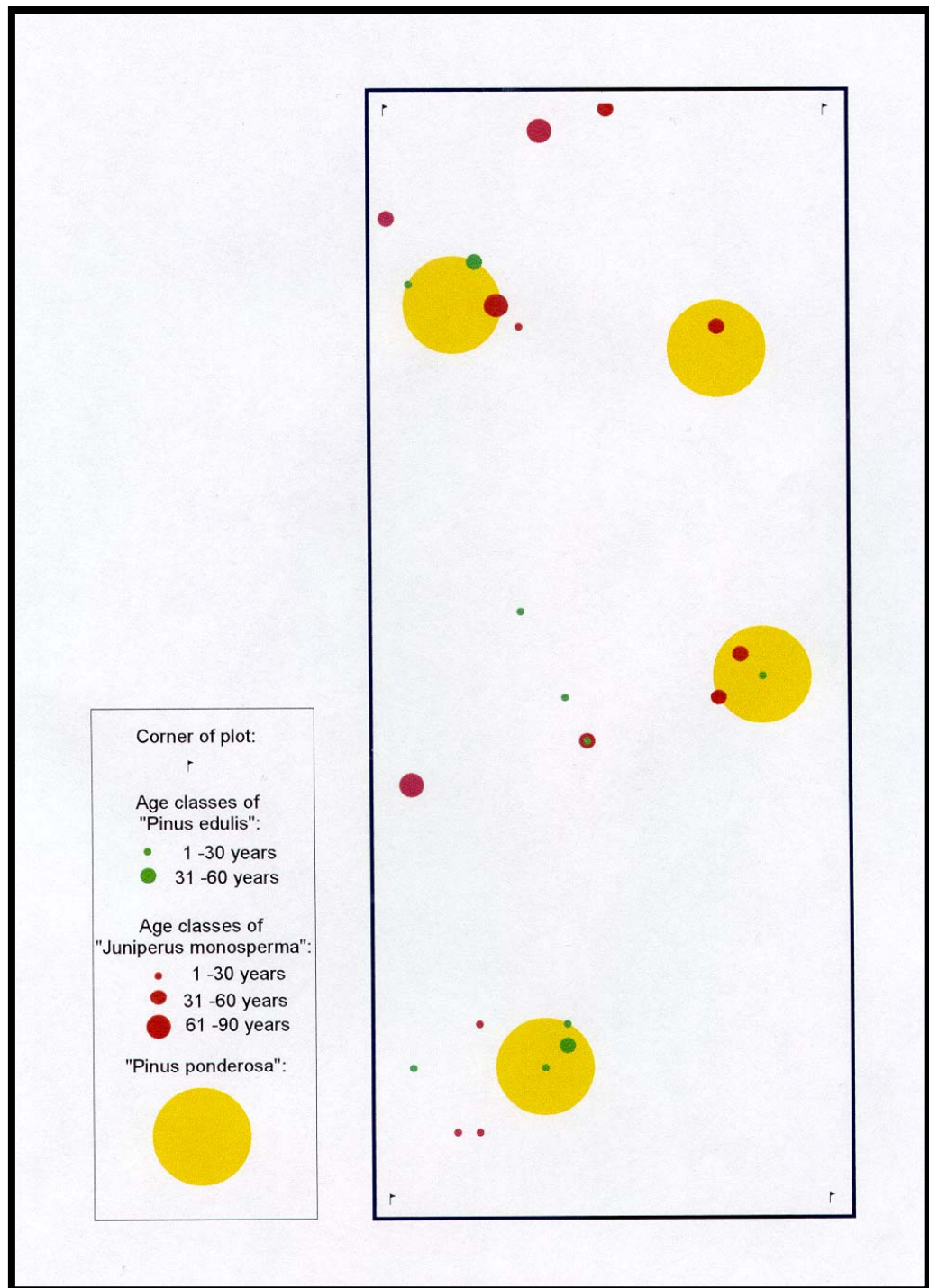


Figure 19: Tree map of plot PA2 reconstructed for 1958

GOTTFRIED et al.(1995) mention that birds are considered to be the most important dispersal agent for piñon seeds. In addition piñon and juniper seedlings are often found in the

shade of mature trees (GOTTFRIED et al. 1995). Hence, dropped piñon seeds and juniper berries might have taken the advantage of the canopy cover of *Pinus ponderosa* to germinate.

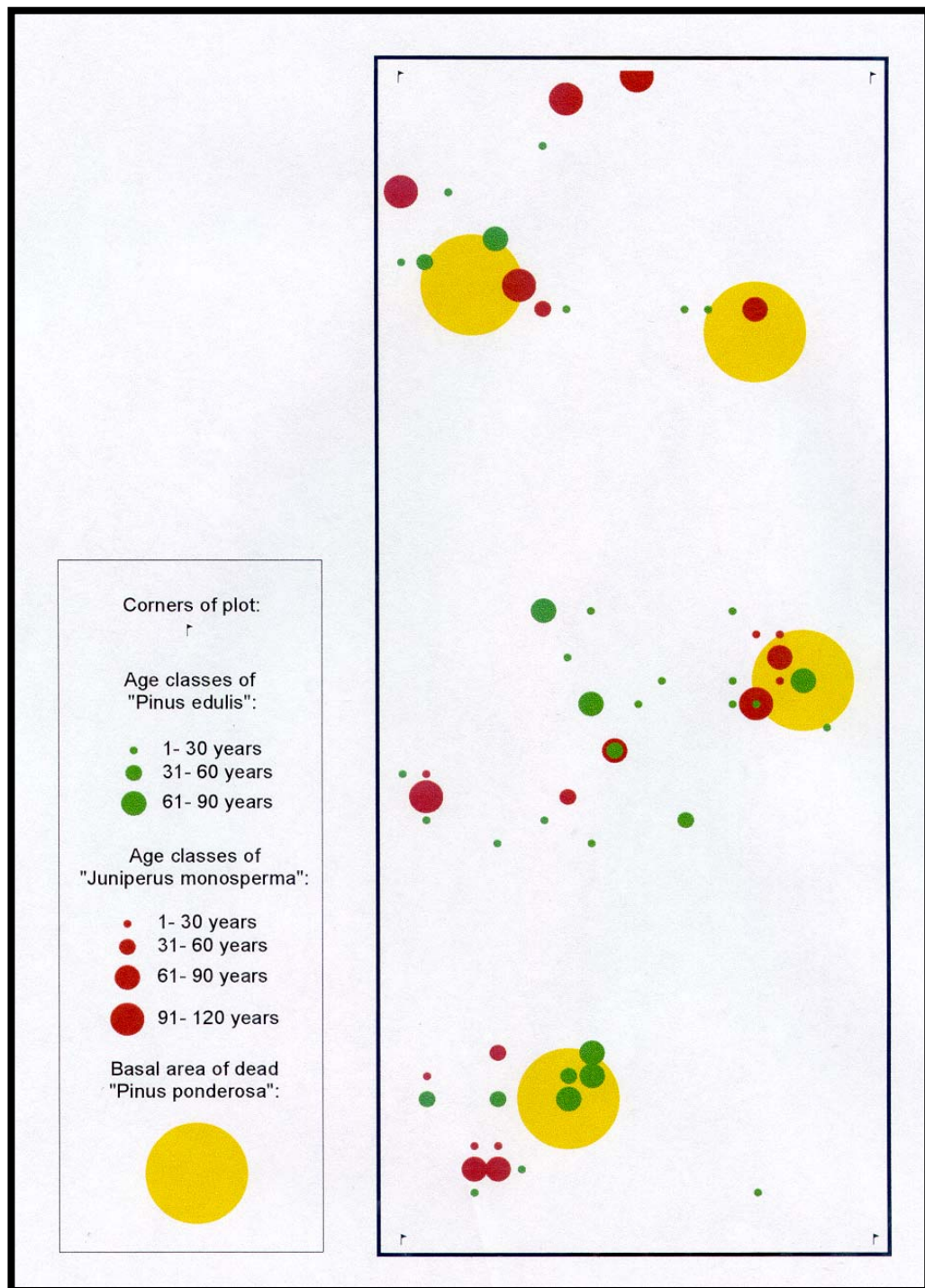


Figure 20: Tree map of plot PA2 in 1998

With a relatively dense cover of forbes and grasses in the intercanopy spaces and the population of ponderosa pine still living the vast majority of germinating piñon and juniper

seedlings have not been able to get established on soil group PA until the turning of the century. Growing human influence with its familiar consequences combined with the 1950s drought and the perishing of ponderosa pine changed this ecological balance.

Due to this assumption one-seed juniper and Colorado piñon pine invaded the existing grassland on soil group PA starting at the former canopy spaces of ponderosa pine (Fig. 20).

Vegetation structure on soil group PNA can only be conjectured for the time before the turning of the century. Tree population is low but obvious during the 19th century. Tree establishment of one-seed juniper and Colorado piñon pine in particular is clearly responding to the effects of an intensified human influence. Still the collected data do not give an unambiguous idea about vegetation structure on soil group PNA before the turning of the century.

Present vegetation structure on PNA soils is dominated by one-seed juniper and Colorado piñon pine in particular. Ground cover of tree on soil group PNA is showing the highest values compared to both other soil groups.

In addition the amount of biomass and ground cover of forbes is highest on this soil group, which might be effected by the lack of tree competition in the affiliated plot units since 1997.

6.2. Shrubs, forbes, cacti, and grasses

Results of ground cover and biomass of shrubs, forbes, cacti, and grasses support the idea that soil group PA formed the basis of a grassland, now heavily invaded by piñon and juniper trees.

Both ground cover and biomass on soil group NPNA are relatively low compared to soil group PA and PNA. Whereas PNA soils favor the production of forbes (see part 5.3.3.), the opposite is perceptible on soil group PA.

Again the important position of *Schyzachyrium scoparium* (little bluestem) needs to be mentioned. This perennial grass both produces the highest amount of biomass and causes the highest ground cover value of all shrubs and herbaceous plants recorded on soil group PA by far.

Compared to the data recorded for all shrubs, forbes, cacti, and grasses on all soil groups, the productivity of organic matter of little bluestem on PA soils is unequalled.

Comparing ground cover by Braun-Blanquet little bluestem is the only plant on all soil groups that has been assigned to ground cover class “2”.

The highest ground cover according to the line-intercept method is recorded for *Lotus wrightii* on soil group PNA with an average of 18,4% cover. Little bluestem comes second with an average ground cover of about 11,5% on soil group PA.



Picture of *Schizachyrium scoparium* (center) and *Lotus wrightii* (bottom; with red and yellow flowers).

Finally the assumption that vegetation structure on soil group PA differs from soil group PNA and NPNA respectively can be confirmed for the present situation. Vegetation is dominated by one-seed juniper and Colorado piñon pine on PNA and NPNA soils, whereas relics of grassland is perceptible on soil group PA.

A protected F-test at a probability level of 0,05 was realized to assure this assumption statistically. Two null hypotheses were tested:

- a) $H_0 =$ Productivity of biomass caused by both forbes and grasses is the same on all soil groups.
 $H_1 =$ Productivity of biomass caused by both forbes and grasses on soil group PA is higher than on soil group PNA and NPNA respectively.
- b) $H_0 =$ Productivity of biomass caused by all grass species is the same on all soil groups.

$H_1 =$ Productivity of biomass caused by all grass species on soil group PA is higher than on soil group PNA and NPNA respectively.

Answer a)

Comparing soil group PA and PNA the null hypothesis is confirmed.

Comparing soil group PA and NPNA the null hypothesis has to be rejected in account of H_1 . Productivity of biomass caused by both forbes and grasses on soil group PA is significantly higher than on soil group NPNA.

Answer b)

In both cases the null hypothesis has to be rejected in account to H_1 . Productivity of biomass caused by all grass species on soil group PA is significantly higher than on soil group PNA and NPNA respectively.

Before the turning of the century the difference of vegetation structure is even more obvious for soil group PA and NPNA. NPNA soils formed the base of piñon-juniper woodlands since the 18th century, whereas occurrence of one-seed juniper and Colorado piñon pine is evident on soil group PA since the late 19th century.

An unambiguous statement about vegetation structure on soil group PNA before the turning of the century is not feasible.

7. Discussion

This work supports the hypothesis that vegetation structure differs between specific soil groups on South Mesa at Bandelier National Monument. Due to a higher amount of soil water available for forbes and grasses the presence of both a pumiceous surface layer and an argillic horizon in a soil depth of up to 120 cm (48 inches) is supposed to favor the development of a grassland structure. The lack of trees older than 120 years and a relatively high amount of biomass and ground cover of herbaceous plants on soil group PA support this assumption.

In contrast it is hypothesized that the development of piñon-juniper woodlands is supported by the existence of a shallow, rocky soil. Again collected data correspond with this hypothesis (see chapter 5.). Development of vegetation structure on deep soils with a pumiceous surface layer is uncertain.

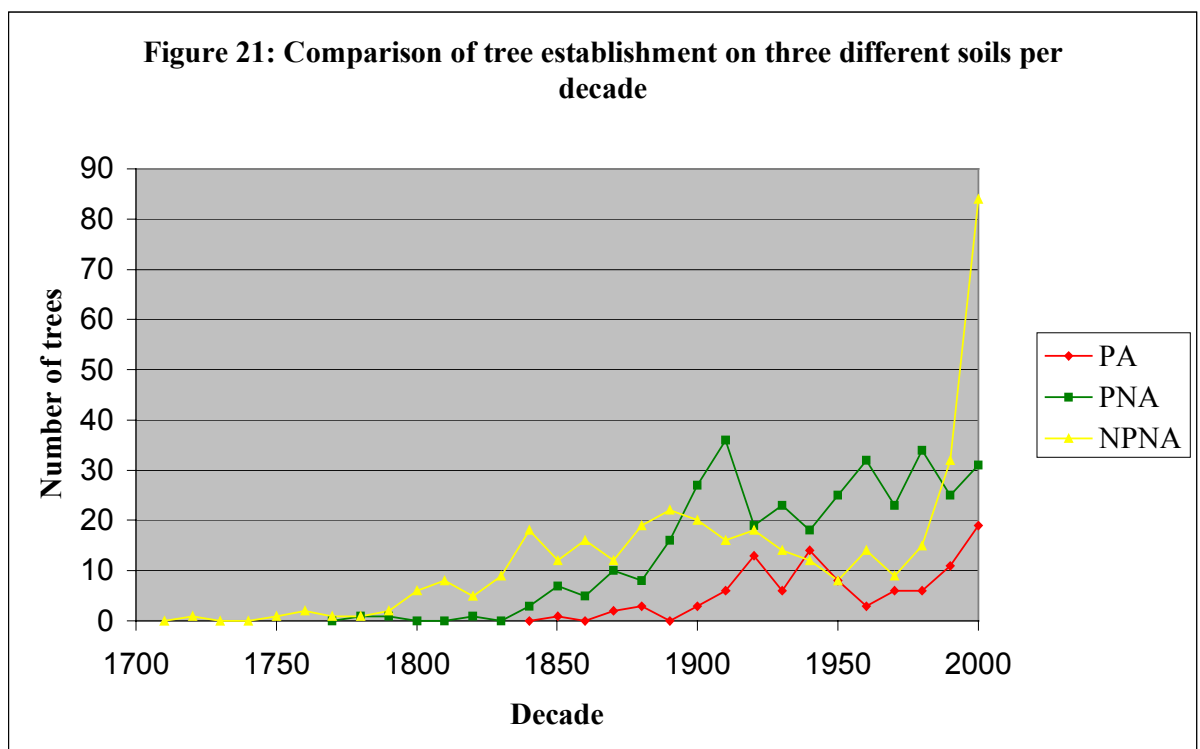
The most prominent herbaceous plant of the vegetation recorded on soil group PA is *Schyzachyrium scoparium* (little bluestem). Both productivity of biomass and ground cover outgo comparable data of shrubs and other herbaceous plants by far. WEAVER (1919) gives a precise description of the root system of little bluestem on two different soils. He mentions that “roots are so abundant as to form a dense sod, completely filling the soil to a depth of from 12 inches (28 cm) in gravelly soil and to as much as 30 inches (75 cm) in clay loam.” In addition, he describes the deeper soil layer from 30 to 60 inches (75 to 150 cm) as being fairly well occupied. WEAVER (1920) sees one basic reason for the wide distribution of little bluestem in the great plasticity of its root system. Due to this observation *Schyzachyrium scoparium* benefits directly from the higher amount of soil water available in soil group PA.

Until the end of the 19th century, occurrence of one-seed juniper and Colorado piñon pine on soil group PA is low to nonexistent (Fig. 21). This phenomenon might be caused by the high competitiveness of a well developed, dense grassland maintaining outbreaks of natural fire. JOHNSON (1962) illustrates the competitiveness of *Bouteloua gracilis* (blue grama) against seedlings of *Juniperus monosperma* (one-seed juniper) on grasslands of Northern Arizona. He demonstrated that after three years only the largest juniper juveniles survived grass competition. Additionally JOHNSON (1962) mentions that growth of juniper seedlings was 52% better with no competition than with it. JAMESON (1962) tested the effectiveness of

grass fires in killing one-seed juniper trees. He recorded that kill of trees less than 4 feet (about 120 cm) high ranged from 70 to 100% on all burns.

Competition for water, light, and nutrients is one of the main factors for the development of plant societies (WALTER 1964). According to WALTER (1964), combination and intensity of locational factors favor growth of one or the other plant species. The changing of locational factors leads to an indirect loss of plant species by reducing their competitiveness against other plants (WALTER 1964).

Comparing tree establishment on all soil groups per decade, some characteristics attract attention (Fig. 21).



First, during the turning of the century tree establishment peaked on all soil groups. In addition, occurrence of trees on soil group PA became prominent since this period of time. It is very likely that increasing appearance of one-seed juniper and Colorado piñon pine is connected to a growing human influence in this area. GOTTFRIED et al. (1995) mention that ecological changes in woodlands of the Pajarito Plateau have been triggered by high intensity grazing. In addition, ALLEN (1989) points out that the often intertwined effects of grazing histories and fire suppression resulted in major changes of most vegetation types throughout the Bandelier area in the past century.

Second, a decline of tree establishment in the middle of the 20th century can be observed. BETANCOURT et al. (1993) indicate that a massive die-off of piñons and junipers has been caused by the 1950s drought throughout the Middle Rio Grande Basin. JOHNSEN (1962) additionally points out that damage of junipers caused by droughts depends on age and size of the tree. Droughts may severely damage small juniper trees, whereas larger trees may not be affected. JOHNSEN (1962) mentions that grasses evade droughts by becoming dormant. Still the drought resistance of larger juniper trees is likely to result in a reduction of grass competition (JOHNSEN 1962).

Intensified human influence during the turning of the century combined with the 1950s drought lead to a replacement of grassland structure by piñon-juniper woodlands on soil group PA. On soil groups PNA and NPNA locational factors, in particular with regard to the amount of soil water, differ from soil group PA.

Density, ground cover, and age class structure of trees as well as production of biomass and ground cover of shrubs and herbaceous plants on soil group NPNA form a sharp contrast to the comparable data of soil group PA. Number of tree establishment per decade indicates that piñon and juniper trees have been existent on soil group NPNA a long time before intensified grazing of livestock or suppression of natural fire by humans took effect.

JOHNSEN (1962) emphasizes the fact that rock outcrops have favorable temperatures and moisture conditions for tree establishment. Mature one-seed juniper usually develop both tap and lateral root system, the latter occupying much of the soil in the inter-tree spaces (JOHNSEN 1962). In addition, BRESHEARS et al. (1997) mention that both one-seed juniper and Colorado piñon pine can use shallow water in intercanopy spaces. One-seed juniper in particular shows a high efficiency of using shallow soil water in intercanopy spaces under dry conditions (BRESHEARS 1997).

This observation corresponds with the higher density of one-seed juniper in contrast to Colorado piñon pine on soil group NPNA. The high competitiveness of Colorado piñon pine and one-seed juniper is likely to be one of the main reasons explaining the low occurrence of biomass and ground cover of herbaceous plants on soil group NPNA. Still the passing of soil erosion thresholds on this already degraded soil has to be taken into account (DAVENPORT et al. 1998).

8. Summary

The current study examines differences of vegetation structure on three soils at Bandelier National Monument, New Mexico, U.S.A. Experiments were carried out in nine research plots on South Mesa, which is a part of the Pajarito Plateau at the southeastern flank of the Jemez Mountains.

1. The general part of this study gives a brief description of geography, geology, soil, climate, and vegetation of New Mexico and Bandelier National Monument in particular.
2. Starting with the first indication of people 9,000 to 10,000 years ago, the historical background of the Bandelier landscape is reviewed. Impact of a growing human influence on the vegetation structure beginning at the end of the 18th century is described.
3. Experimental revegetation work at Bandelier National Monument has been initiated in 1992 in order to stop accelerated soil erosion, which causes major natural and cultural problems. The current study is directly linked to the Watershed Restoration Project, which intends to test former developed restoration methodology at a functional ecosystem scale.
4. Existing soil units on South Mesa were divided into four soil groups by using the criteria
 - absence or presence of pumice and
 - absence or presence of an argillic horizonwithin the soil profile.
5. On three out of four soil groups vegetation structure was analyzed. Density, age class structure, and ground cover of *Pinus edulis* (Colorado piñon pine) and *Juniperus monosperma* (one-seed juniper) as well as ground cover and biomass of shrubs, forbes, cacti, and grasses was estimated.

The decade of tree establishment was measured by counting tree rings. An aerial picture helped to estimate ground cover of trees per soil group and tree density was ascertained by determining the number of trees per soil group.

Both the line-intercept method and the method invented by Braun-Blanquet were used to examine ground cover of shrubs and herbaceous plants. Biomass production was measured by clipping and weighing the dried organic matter of forbes and grasses.

6. Results confirmed the assumption that the presence of both a pumiceous surface layer and an argillic horizon in a depth of up to 120 cm (48 inches) within the soil profile favor the establishment and growth of forbes and grasses. On this soil group (called PA), density and ground cover of trees were lowest, and the youngest age class structure was analyzed. First indication of one-seed juniper and Colorado piñon pine correspond to a growing human influence beginning at the turning of the century. In addition, the highest production of biomass and ground cover of shrubs, forbes, cacti, and grasses was estimated, with *Schizachyrium scoparium* (little bluestem) being the most prominent herbaceous species.

Hence, the transition of vegetation structure from a grassland with no evidence of Colorado piñon pine or one-seed juniper to a piñon-juniper woodland can be assumed on soil group PA.

Results of deep, pumiceous soils without an argillic horizon in a soil depth of up to 120 cm (called PNA) are halfway between the comparable values of both other soil groups. A predominance of Colorado piñon pine compared to one-seed juniper, and of forb species compared to grass species can be observed.

On shallow, rocky soils with no evidence of pumice or an argillic horizon (soil group NPNA) density of juniper and piñon trees is highest, whereas biomass and ground cover of shrubs and herbaceous plants present the lowest values of all soil groups. With one-seed juniper and Colorado piñon pine being existent for more than 250 years, at least fragments of piñon-juniper woodland have always been prominent on NPNA soils.

7. In the present environment differences of vegetation structure on soil group PA compared to both other soil groups are still perceptible. One-seed juniper and Colorado piñon pine dominate the vegetation on PNA and NPNA soils, whereas relics of grassland are still discernable on soil group PA.

Acknowledgements

I would like to express my sincere appreciation to Richard G. Gatewood who taught me a lot about scientific research, provided a great deal of support and helped me to complete this project.

I also would like to thank Brian Jacobs and Dr. Craig D. Allen for guidance and explanation about the ecology and the flora of New Mexico.

Kay Beeley helped a lot with the construction of computer maps. Suggestions and helpful advice for the measurement of tree age and the realization of tree coring was given by James Riser.

I further would like to express my appreciation to professor Dr. Wolfgang Schumacher who provided constructive criticism and guidance.

Kristina Strauß and Susanne Sollmann helped a lot by doing the proofreading of this paper.

Finally I would like to thank all SCA- volunteers for the assistance with the data collection.

List of figures:

Figure 1:	Location of study area	p. 1
Figure 2:	Topographic map of New Mexico	p. 2
Figure 3:	Different map units at the Watershed Restoration Project on South Mesa	p. 7
Figure 4:	Aerial photo of Bandelier National Monument Headquarters and South Mesa including the borders of the Watershed Restoration Project prior to treatment.	p. 18
Figure 5:	Four different soil groups on South Mesa including location of research plots and soil profiles	p. 21
Figure 6:	Location of research plot NPNA 1 shown on an aerial photo and zoomed in to full extent.	p. 27
Figure 7:	Arrangement of field units, vegetation transects, and biomass frames within a research plot.	p. 29
Figure 8:	Comparison of tree density on three different soils	p. 39
Figure 9:	Number of tree establishment on soil group PA per decade	p. 40
Figure 10:	Number of tree establishment on soil group PNA per decade	p. 41
Figure 11:	Number of tree establishment on soil group NPNA per decade	p. 42
Figure 12:	Comparison of percentage tree density cover above ground on three different soils	p. 43
Figure 13:	Comparison of biodiversity of shrubs and herbaceous plants on three different soils (Braun-Blanquet)	p. 44
Figure 14:	Comparison of biodiversity of shrubs and herbaceous plants on three different soils (line-intercept method)	p.46
Figure 15:	Distribution of total amount of biomass by grasses and forbes on three different soils	p. 49
Figure 16:	Comparison of average biomass of the most prominent forb species on three soils	p. 50
Figure 17:	Comparison of average biomass of grass species on three different soils	p. 51

Figure 18:	Cumulative tree density on three different soils per decade	p. 52
Figure 19:	Tree map of plot PA2 reconstructed for 1958	p. 54
Figure 20:	Tree map of plot PA2 in 1998	p. 55
Figure 21:	Comparison of tree establishment on three different soils per decade	p. 60

List of tables:

Table 1:	Number of trees per research plot	p. 39
Table 2:	Comparing estimated ground cover by using two different methods on soil group PA	p. 47
Table 3:	Comparing estimated ground cover by using two different methods on soil group PNA	p. 47
Table 4:	Comparing estimated ground cover by using two different methods on soil group NPNA	p. 48

Bibliography

- Allen, C.D. Ecological patterns and environmental change in the Bandelier landscape.
Unpublished manuscript (28 June, 1997).
- Allen, C.D. 1989. Changes in the landscape of the Jemez Mountains, New Mexico. Ph. D.
Dissertation, University of California, Berkeley, CA.
- Betancourt, J.L., E.A. Pierson, K.A. Rylander, J.A. Fairchild-Parks, and J.S. Dean. 1993.
Influence of History and Climate on New Mexico Piñon-Juniper Woodlands.
pp. 42-62 In: Aldon, E.A., and D.W. Shaw (tech. coord.), Managing Piñon-Juniper
Ecosystems for Sustainability and Social Needs. USDA For. Serv. Gen. Tech. Rep.
RM-236. Fort Collins, CO. 169.
- Bracker, S.B. 1996. How many people lived at Bandelier? Unpublished report on file at
Bandelier National Monument, NM. 77 pp. 13 maps.
- Braun-Blanquet, J. 1964. Pflanzensoziologie- Grundzüge der Vegetationskunde. 3. Auflage.
Springer Verlag. Wien/ New York.
- Breshears, D.D., O. B. Myers, S.R. Johnson, C.W. Meyer, and S.N. Martens. 1997.
Differential use of spatially heterogeneous soil moisture by two semiarid woody
species: *Pinus edulis* and *Juniperus monosperma*. Journal of Ecology, 85, pp. 289-
299.
- Buol, S.W., F.D. Hole, and R.J. McCracken. 1980. Soil Genesis and Classification. Second
Edition. The Iowa State University Press, Ames.
- Carlson, S.R. 1969. New Mexico's sheep industry, 1850- 1900. New Mexico Historical Rev.
44 (1).
- Castetter, E.F. 1956. The Vegetation of New Mexico. Third annual research lecture,
University of New Mexico.
- Chong, G. 1993. Revegetation of piñon-juniper woodlands with native grasses. In: Aldon,
E.F.; Shaw, D.W. tech coords. Managing piñon-juniper ecosystems for sustainability
and social needs. 1993 April 26-30. Santa Fe, N.M. Gen. Tech. Rep. RM-236. Fort

- Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 28p.
- Davenport, D.W. 1997. Soil Survey of Three Watersheds on South Mesa, Bandelier National Monument. Los Alamos, New Mexico.
- Davenport, D.W., D.D. Breashers, B.P. Wilcox, and C.D. Allen. 1998. Viewpoint: Sustainability of piñon-juniper ecosystems-a unifying perspective of soil erosion thresholds. *J. Range Management* 51. pp. 231-240.
- Dethier, D.P. 1996. Geologic Map of the White Rock Quadrangle. New Mexico Bureau of Mines and Mineral Resources.
- Dierschke, H. 1994. Pflanzensoziologie: Grundlagen und Methoden. UTB für Wissenschaft. Ulmer, Stuttgart.
- Gottfried, G.J., T.W. Swetman, C.D. Allen, J.L. Betancourt, and A. Chung-MacCoutbrey. 1995. Piñon-Juniper Woodlands of the Middle Rio Grande Basin, New Mexico. pp. 95-132 In: D.M. Finch and J.A. Tainter (tech. eds.). *Ecology, Diversity, and Sustainability of the Middle Rio Grande Basin*. USDA For. Serv. Gen. Tech. Rep. RM-268, Fort Collins, Colorado. 186 p.
- Izett, G.A., and J.D. Obradovich. 1994. Ar (40)/ Ar (39) age constraints for the Jaramillo Normal Subchron Matuyama-Brunshes geomagnetic boundary. *Journal of Geophysical Research*. 99 (B2): 2925-2934.
- Jacobs, B.F. 1989. A Flora of Bandelier National Monument. Unpublished report on file at Bandelier National monument, New Mexico. 104 p.
- Jameson, D.A. 1962. Effects of Burning on a Galleta-Black Grama Range Invaded by Juniper. *Ecology*, Vol. 43, No. 4, pp. 760-763.
- Johnsen, T.N. Jr. 1962. One-seed Juniper Invasion of Northern Arizona Grasslands. Crops Research Division, Agricultural Research Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona. *Ecological Monographs*. Vol. 32. No. 3.

- Knapp, R. 1971. Einführung in die Pflanzensoziologie. 3. Auflage. Verlag Eugen Ulmer
Stuttgart
- Martin, W.C., and C.R. Hutchins. 1980. A Flora of New Mexico. Volume 1. J. Cramer. In der
A.R. Gantner Kommanditgesellschaft. FL-9490 VADUZ.
- Martin, W.C., and C.R. Hutchins. 1981. A Flora of New Mexico. Volume 2. J. Cramer. In der
A.R. Gantner Kommanditgesellschaft. FL-9490 VADUZ.
- Phipps, R.L. 1985. Collecting, Preparing, Crossdating, and Measuring Tree Increment Cores.
U.S. Geological Survey. Water-Resources Investigations Report 85-4148.
- Reneau, S.L., D.P. Dethier, and J.S. Carney. 1995. Landslides and Other Mass Movements
Near Technical Area 33, Los Alamos National Laboratory, Los Alamos, NM 48 p., 1
plate.
- Reneau, S.L., and D.P. Dethier. 1996-a. Pliocene and Quarternary history of the Rio Grande,
White Rock Canyon and vicinity, New Mexico. pp. 317-324 In: F. Goff, B.S. Kues
M.A. Rogers, L.D. McFadden, and J.N. Gardner (eds.) New Mexico Geological
Society Guidebook, 47th Field Conference, Jemez Mountains Region. 484 pp.
- Reneau, S.L., and D.P. Dethier. 1996-b. Late Pleistocene landslide-dammed lakes along the
Rio Grande, White Rock Canyon, New Mexico. Geologic Soc. Amer. Bull.
108(11) : 1492-1507.
- Scheffer, F. and P. Schachtschabel. 1998. Lehrbuch der Bodenkunde. 14. Auflage von P.
Schachtschabel (†), H.-P. Blume, G. Brümmer, K.H. Hartge, U. Schwertmann.
Fredinand Enke Verlag, Stuttgart.
- Self, S., D.E. Kircher, and J.A. Wolff. 1988. The El Cajete Series, Valles Caldera, New
Mexico. Journal of Geophysical Research. 93 (B6): 6113- 6127.
- Sterner, Ray. 1995. Color landform atlas of the United States. John Hopkins University
Physics Laboratory.
- Swetnam, T.W., and C.H. Baisan. 1996. Historical Fire Regime Patterns in the Southwestern

- United States Since AD 1700. Pp. 11- 32 In: Allen, C.D., (technical editor).
 Proceedings of the 1994 Symposium on the La Mesa Fire. USDA Forest Service
 General Technical Report RM-286, Fort Collins, CO. 216 p.
- Touchan, R., C.D. Allen, and T.W. Swetnam. 1996. Fire History and Climatic Patterns in
 Ponderosa Pine and Mixed-Conifer Forests of the Jemez Mountains, Northern New
 Mexico. pp.33- 46 In: Allen C.D., (technical editor). Proceedings of the 1994
 Symposium on the La Mesa Fire. USDA Forest Service General Technical Report
 RM-286, Fort Collins, CO. 216 pp.
- Trails illustrated. 1994. Topographic map of Bandelier National Monument, New Mexico.
 Ponderosa Publishing Company. CO.
- U.S. Department of Agriculture. 1975. Soil Taxonomy. A Basic System of Soil Classification
 for Making and Interpreting Soil Surveys. Agriculture Handbook No. 436.
- Walter, H. 1964. Die Vegetation der Erde in öko- physiologischer Betrachtung. Band I: Die
 tropischen und subtropischen Zonen. 2. Auflage. VEB Gustav Fischer Verlag Jena.
- Walter, H. 1968. Die Vegetation der Erde in öko- physiologischer Betrachtung. Band II: Die
 Gemäßigten und arktischen Zonen. Gustav Fischer Verlag Stuttgart.
- Weaver, J.E. 1919. The Ecological Relation of Roots. Carnegie Institution of Washington.
 Publication No. 286.
- Weaver, J.E. 1920. Root Development in the Grassland Formation. A Correlation of the Root
 System of Native Vegetation and Crop Plants. Carnegie Institution of Washington.
 Publication No. 292.
- Wilcox, B.P., J. Pitlick, C.D. Allen, and D. Davenport. 1996. Runoff and Erosion from a
 Rapidly Eroding Piñon-Juniper Hillslope. pp. 61-77 In: M.G. Anderson and S.M.
 Brooks (eds.), Advances in Hillslope Processes. Volume 1. John Wiley and Sons Ltd,
 New York.

Family	Genus	Species	Common name
Anacardiaceae	<i>Rhus</i>	<i>trilobata</i>	Skunkbush
Asteraceae	<i>Achillea</i>	<i>lanulosa</i>	Western Yarrow
Asteraceae	<i>Artemisia</i>	<i>campestris</i>	Sagebrush
Asteraceae	<i>Artemisia</i>	<i>carruthii</i>	Wormwood
Asteraceae	<i>Artemisia</i>	<i>ludoviciana</i>	Louisiana wormwood
Asteraceae	<i>Bahia</i>	<i>dissecta</i>	Yellow ragweed
Asteraceae	<i>Brickellia</i>	<i>brachyphylla</i>	Plumed brickelbush
Asteraceae	<i>Chrysopsis</i>	<i>villosa</i>	Golden aster
Asteraceae	<i>Conyza</i>	<i>canadensis</i>	Horseweed
Asteraceae	<i>Crysothamnus</i>	<i>nauseosus</i>	Rabbit brush
Asteraceae	<i>Erigeron</i>	<i>flagellaris</i>	Trailing fleabane
Asteraceae	<i>Erigeron</i>	<i>speciosus</i>	Oregon fleabane
Asteraceae	<i>Erigeron</i>	<i>species</i>	Fleabane
Asteraceae	<i>Gutierrezia</i>	<i>sarothrae</i>	Snakeweed
Asteraceae	<i>Helianthus</i>	<i>petiolaris</i>	Prairie sunflower
Asteraceae	<i>Hymenopappus</i>	<i>filifolius</i>	Ragweed
Asteraceae	<i>Lactuca</i>	<i>serriola</i>	Prickly lettuce
Asteraceae	<i>Senecio</i>	<i>multicapitatus</i>	Ragwort groundsel
Asteraceae	<i>Stephanomeria</i>	<i>pauciflora</i>	Skeletonweed
Boraginaceae	<i>Cryptantha</i>	<i>jamesii</i>	Hiddenflower
Boraginaceae	<i>Lithospermum</i>	<i>species</i>	Gromwell; Puccoon
Brassicaceae	<i>Erysimum</i>	<i>capitatum</i>	Western wallflower
Brassicaceae	<i>Sisymbrium</i>	<i>linearifolium</i>	Purple wallflower
Cactaceae	<i>Echinocereus</i>	<i>species</i>	Hedgehog cactus
Cactaceae	<i>Opuntia</i>	<i>species</i>	Prickly pear
Chenopodiaceae	<i>Chenopodium</i>	<i>album</i>	Lamb's quarters
Cupressaceae	<i>Juniperus</i>	<i>monosperma</i>	One-seed juniper
Euphorbiaceae	<i>Croton</i>	<i>texensis</i>	Texas croton
Euphorbiaceae	<i>Euphorbia</i>	<i>fendleri</i>	Fendler spurge
Fabaceae	<i>Lotus</i>	<i>wrightii</i>	Wright's deervetch
Fabaceae	<i>Lupinus</i>	<i>kingii</i>	King's lupine
Fagaceae	<i>Quercus</i>	<i>undulata</i>	Wavyleaf oak
Liliaceae	<i>Yucca</i>	<i>baccata</i>	Banana yucca
Loasaceae	<i>Mentzelia</i>	<i>pumila</i>	Golden blazing star
Nyctaginaceae	<i>Mirabilis</i>	<i>oxybaphoides</i>	Trailing Four-o'clock
Onagraceae	<i>Oenothera</i>	<i>caespitosa</i>	Evening-primrose
Pinaceae	<i>Pinus</i>	<i>edulis</i>	Colorado pinyon pine
Pinaceae	<i>Pinus</i>	<i>ponderosa</i>	Ponderosa pine
Poaceae	<i>Aristida</i>	<i>purpurea</i>	Three awn; Poverty grass
Poaceae	<i>Bouteloua</i>	<i>gracilis</i>	Blue grama
Poaceae	<i>Koeleria</i>	<i>cristata</i>	Junegrass
Poaceae	<i>Muhlenbergia</i>	<i>montana</i>	Mountain muhly
Poaceae	<i>Oryzopsis</i>	<i>micrantha</i>	Littleseed ricegrass
Poaceae	<i>Poa</i>	<i>fendleriana</i>	Muttongrass
Poaceae	<i>Schizachyrium</i>	<i>scoparium</i>	Little bluestem

Plant list

Poaceae	<i>Sitanion</i>	<i>hystrix</i>	Bottlebrush squirreltail
Poaceae	<i>Sporobolus</i>	<i>cryptandrus</i>	Sand dropseed
Poaceae	<i>Stipa</i>	<i>comota</i>	Needle-and-thread
Polemoniaceae	<i>Ipomopsis</i>	<i>aggregata</i>	Skyrocket
Polygonaceae	<i>Eriogonum</i>	<i>jamesii</i>	Antelope-sage
Rosaceae	<i>Cercocarpus</i>	<i>montanus</i>	Mountain-mahogany
Rosaceae	<i>Fallugia</i>	<i>paradoxa</i>	Apache plume
Scrophulariaceae	<i>Penstemon</i>	<i>secundiflorus</i>	Spring penstemon
Scrophulariaceae	<i>Penstemon</i>	<i>species</i>	Beardtongue
Scrophulariaceae	<i>Verbascum</i>	<i>thapsus</i>	Miner's candle; Mullein
Solanaceae	<i>Physalis</i>	<i>hederaefolia</i>	Groundcherry

Eidesstattliche Erklärung

Ich versichere eidesstattlich, daß ich die vorstehende Arbeit selbständig und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Alle Stellen, die wörtlich oder sinngemäß aus der Veröffentlichung entnommen sind, wurden als solche kenntlich gemacht. Die Arbeit hat in gleicher Weise oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegen.

Bonn, den 27.04.1999

Christian Julius
13.Semester
Agrarwissenschaften
Naturschutz und Landschaftsökologie

**Eine vergleichende Studie über die Vegetationsstruktur
auf drei verschiedenen Böden in Bandelier National
Monument, New Mexico, U.S.A.**

Deutsche Zusammenfassung der Diplomarbeit

**“A comparison of vegetation structure on three different soils in Bandelier
National Monument, New Mexico, U.S.A.”**

Einleitung:

Ein bezeichnendes Charakteristikum der Vegetation im Südwesten der Vereinigten Staaten von Amerika ist die Bestandszunahme von Kiefer und Wacholder in der bereits vorhandenen Graslandschaft. Der Grund für diesen vegetativen Umbruch wird hauptsächlich in der Beweidung sowie der Unterdrückung des natürlichen Feuerzyklusses durch den Menschen vermutet. Dieser anthropogene Eingriff, der seit dem Ende des neunzehnten Jahrhunderts deutlich an Intensität zugenommen hat, läßt den vorhandenen Gräsern und Kräutern wenig Spielraum sich gegen die eindringenden Baumarten durchzusetzen. Es entstanden sogenannte Kiefer-Wacholder-Wälder, die sich in einem breiten Band durch einen Großteil des Südwestens der Vereinigten Staaten von Amerika etablieren konnten.

Dieser Vegetationswechsel ist auch deutlich in Bandelier National Monument, einem Nationalmonument im zentralen Norden New Mexico, erkennbar.

Die ansteigende Dominanz von Colorado piñon pine (*Pinus edulis*) und oneseed juniper (*Juniperus monosperma*) und der abnehmende Deckungsgrad der ursprünglich vorhandenen Gräser und Kräuter führen hierbei zu einer zunehmenden Erosion des Bodens. Das Ausmaß dieser Bodenerosion, welches durch wolkenbruchartige Niederschläge in den Sommermonaten verursacht wird, wird auf zwei bis fünf Zentimeter pro Dekade geschätzt (WILCOX et al. 1994).

Neben dem bedenklich hohen Verlust an Bodenmaterial sind tausende archäologischer Funde beschädigt worden oder laufen Gefahr beschädigt zu werden.

1992 wurden erstmals Revegetationsmaßnahmen in Bandelier National Monument durchgeführt. Ziel dieser Maßnahmen war es, einen bestmöglichen Weg zu finden um den ursprünglich vorhandenen Deckungsgrad einheimischer Gräser und Kräuter wieder herzustellen und somit die Bodenerosion einzudämmen. Das Abtreiben des vorhandenen Baumbestandes sowie das Liegenlassen des dadurch entstandenen Mulches zeigten bisher die meist versprechenden Ergebnisse.

1996 wurden diese Revegetationsmaßnahmen von GATEWOOD, JACOBS und ALLEN durch das „Watershed Restoration Project“ ergänzend weitergeführt. Das Projekt findet auf dem „South Mesa“, einem Plateau südwestlich der Hauptzentrale von Bandelier National Monument statt. Es umfaßt eine Fläche von etwa 80 Hektar. Durch diese Fläche verlaufen

zwei natürliche Abflüsse in nord-südlicher Richtung, die das gesamte Gebiet in zwei Wasserscheiden unterteilen. Der Verlauf dieser Abflüsse endet im „Loomis Canyon“.

Der westliche dieser beiden Abflüsse dient als Kontroll-Wasserscheide, während der östliche als Versuchs-Wasserscheide fungiert. Die Fläche von Kontroll- und Versuchs-Wasserscheide sind in etwa gleich groß.

In der Versuchs-Wasserscheide wurden sämtliche oneseed juniper und Colorado piñon pine, deren Umfang in Brusthöhe geringer als 18 cm war, abgetrieben und verbleibender Mulch wurde auf der gesamten Fläche verteilt. Um einen Vergleichswert zu erhalten, blieb die Kontroll-Wasserscheide unbehandelt. Sowohl in der Versuchs- als auch in der Kontroll-Wasserscheide wurden zwanzig Vegetationstransecte angelegt und einmal jährlich werden auf ihnen nach dem „Line Intercept“-Verfahren Daten gesammelt.

Ziel:

Das Ziel dieser Arbeit ist es, charakteristische Merkmale der vorhandenen Baum- und Krautschicht auf drei dominanten Böden der Versuchs-Wasserscheide zu untersuchen und gegebenenfalls Unterschiede herauszustellen.

Die Erkenntnis, ob bestimmte Eigenschaften der Bodenstruktur die Entwicklung der Krautschicht signifikant begünstigen kann für zukünftige Revegetationsmaßnahmen in Bandelier National Monument von großem Nutzen sein.

Meine Arbeit basiert auf der Annahme, daß die Existenz einer Pumice-Auflage die Infiltration von Regenwasser in das Bodenprofil erhöht und somit den Oberflächenabfluß des Niederschlags verringert. Das zusätzliche Vorhandensein eines Tonhorizontes in einer Bodentiefe von bis zu 120 cm wiederum führt zu einer Aufstauung des Bodenwassers. Aufgrund dieser Tatsachen ist ein mehr an Bodenwasser in einer Bodentiefe vorhanden, welche vornehmlich von „flachwurzelnenden Pflanzen“ (= Gräser und Kräuter) genutzt werden kann. Bei ihrem Wettbewerb um Aufnahme des vorhandenen Bodenwassers führen diese Umstände zu einem Vorteil der Kräuter und Gräser gegenüber den Bäumen. Ein geschlossener Kraut- und Grasbestand wiederum verringert, beziehungsweise verhindert eine Etablierung von Baumsämlingen.

Methoden:

Das von mir untersuchte Gebiet befindet sich im Bereich der Versuchs-Wasserscheide des „Watershed Restoration Project“.

1997 wurden die verschiedenen Bodentypen dieses Gebietes durch den Bodenkundler Dr. David W. Davenport identifiziert und näher beschrieben. Herr Davenport teilte aufgrund seiner Untersuchungen die Böden des Projektgebietes in neun verschiedene Einheiten (=“*map units*“) auf. Jede dieser Einheiten bezeichnet einen bestimmten Bodentyp.

Da zwei der neun beschriebenen Bodentypen anstehendes Felsgestein bezeichnen, sind sie für meine weiteren Untersuchungen ohne Interesse und konnten insofern vernachlässigt werden.

Die verbleibenden sieben Bodentypen habe ich nach den Kriterien

Existenz oder Abwesenheit einer Pumice-Auflage und

Existenz oder Abwesenheit eines Tonhorizontes in einer Bodentiefe von bis zu 120 cm

in vier Gruppen unterteilt.

Diese vier Gruppen lauten wie folgt:

- Gruppe A (PA): Existenz sowohl einer Pumice-Auflage als auch eines Tonhorizontes in einer Tiefe von bis zu 120 cm im Bodenprofil
- Gruppe B (PNA): Existenz einer Pumice-Auflage;
Tonhorizont liegt deutlich unterhalb 120 cm oder fehlt gänzlich im Bodenprofil
- Gruppe C (NPNA): Sowohl Pumice-Auflage als auch Tonhorizont sind im Bodenprofil nicht existent
- Gruppe D (NPA): Existenz eines Tonhorizontes, aber Fehlen einer Pumice-Auflage im Bodenprofil

Die Böden der Gruppe D wurden bei meinen Untersuchungen vernachlässigt, da das Flächenausmaß der in dieser Gruppe beinhalteten Bodentypen im Verhältnis zu dem Flächenausmaß der Bodentypen der drei anderen Gruppen jeweils relativ gering ist.

In dem Gebiet der drei verbleibenden Gruppen A, B und C wurden von mir jeweils drei Untersuchungsflächen erstellt. Ich habe dabei sichergestellt, daß sich jede dieser

Untersuchungsflächen in einer homogenen Einheit („map unit“) befindet. Die Auswahl der jeweiligen Einheit geschah nach Häufigkeit und Flächengröße. Die Lage der jeweiligen Untersuchungsfläche innerhalb der Einheit wurde anhand des Zufallsprinzips durchgeführt. Jede Untersuchungsfläche ist 20 mal 50 m groß, ost- oder westexponiert und in einer Nord-Süd-Achse ausgerichtet.

In jeder dieser neun Untersuchungsflächen habe ich folgende Studien durchgeführt:

Untersuchungen des Baumbestandes

a) Dichte des Baumbestandes:

Die Anzahl der Bäume pro Untersuchungsfläche wurde bestimmt. Die Baumdichte wurde in Anzahl der Bäume pro Hektar dargestellt.

b) Altersstruktur des Baumbestandes:

Die Altersstruktur sämtlicher Colorado piñon pine und oneseed juniper wurde durch das Zählen von Baumringen geschätzt. Das Alter eines Baumes wurde hierbei auf das Jahrzehnt genau bestimmt.

c) Deckungsgrad anhand einer Luftbilddaufnahme:

Der Deckungsgrad sämtlicher Colorado piñon pine und oneseed juniper wurde in den jeweiligen Untersuchungsflächen untersucht. Da zum Zeitpunkt meiner Untersuchungen bereits ein Großteil der Bäume abgetrieben worden war, wurde eine Luftbilddaufnahme bei der Schätzung zur Hilfe genommen.

Untersuchungen des Gras- und Krautbestandes

a) Deckungsgrad:

Der Deckungsgrad sämtlicher Gras- und Krautarten wurde in jeder Untersuchungsfläche ermittelt. Ich habe bei meiner Schätzung sowohl die Methode nach „*Braun-Blanquet*“ als auch die „*Line-Intercept*“ Methode angewandt.

b) Biomasse:

Das durchschnittliche Gewicht sämtlicher Grasarten und der häufigsten Krautarten wurde nach einer einheitlichen Trocknung ermittelt.

Zusätzlich

a) Karte:

Die Koordinaten jedes einzelnen Baumes in den verschiedenen Untersuchungsflächen wurden von mir ermittelt. Anhand dieser Daten sowie der ermittelten Altersstruktur wurde für die Untersuchungsflächen der Gruppe A eine Übersichtskarte des Baumbestandes für die Jahre 1958 und 1998 erstellt.

Die in den jeweiligen Untersuchungsflächen gesammelten Daten wurden zu Durchschnittswerten der einzelnen Gruppen zusammengefaßt. Die so erlangten Gruppenwerte wurden mit den Durchschnittswerten der anderen Gruppen verglichen.

Ergebnisse:

Die Ergebnisse der Untersuchungen bestätigen die Vermutung, daß die Anwesenheit sowohl einer Pumice-Auflage als auch eines Tonhorizontes in einer Tiefe von bis zu 120 cm innerhalb des Bodenprofils das Vorkommen und Wachstum von Kräutern und Gräsern begünstigen. Auf dieser oben beschriebenen Bodengruppe (PA) konnte der geringste Deckungsgrad, die niedrigste Baumdichte sowie die jüngste Altersstruktur des vorhandenen Baumbestandes festgestellt werden. Das erstmalige Auftreten von oneseed juniper und Colorado piñon pine stimmt zeitlich mit dem wachsenden anthropogenen Einfluß Ende des letzten Jahrhunderts überein.

Darüber hinaus konnte der höchste Anteil an Biomass sowie der größte Deckungsgrad aller Sträucher, Kräuter, Kakteen und Gräser auf dieser Bodengruppe festgestellt werden, wobei das Gras *Schizachyrium scoparium* (little bluestem) eine besondere Stellung einnimmt.

Anhand dieser Ergebnisse ist die Annahme, daß im Laufe der letzten 120 Jahre auf Bodengruppe PA ein Wechsel der Vegetationsstruktur von einer Graslandschaft ohne jeglichen Hinweis auf die Baumarten Colorado piñon pine und oneseed juniper hin zu einem Kiefer-Wacholder Wald stattgefunden hat durchaus zu vertreten.

Die Ergebnisse der Bodengruppe PNA deuten eine Vormachtstellung von Colorado piñon pine gegenüber oneseed juniper sowie eine Dominanz von Kräutern gegenüber Gräsern an.

Auf flachen, felsigen Böden ohne Pumice-Auflage und Tonhorizont (Bodengruppe NPNA) wurde die größte Baumdichte festgestellt. Außerdem ist die Produktion von Biomasse sowie der Deckungsgrad vorhandener Sträucher, Kräuter, Kakteen und Gräser am geringsten.

Darüber hinaus konnte festgestellt werden, daß Colorado piñon pine und oneseed juniper seit mehr als 250 Jahren auf dieser Bodengruppe existent sind. Es ist insofern davon auszugehen, daß sich zumindest Fragmente von Kiefer-Wacholder Wäldern bereits im 18ten Jahrhundert auf NPNA Böden befunden haben.

Zum gegenwärtigen Zeitpunkt sind Unterschiede in der Vegetationsstruktur der Bodengruppe PA im Vergleich zu beiden anderen untersuchten Bodengruppen leicht erkennbar. Oneseed juniper und Colorado piñon pine sind auf Bodengruppe PNA und NPNA dominant, während Relikte einer Graslandschaft auf Bodengruppe PA nach wie vor feststellbar sind.