COMPARISON OF FOREST REGENERATION IN A SUBSIDENCE ZONE TO A REFERENCE AREA[1]

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Abstract: Underground mining may create subsidence conditions that disturb the surface vegetation. We examined the impacts on forest regeneration in a high elevation mixed conifer forest within two subsidence zones that are classified based on surface disturbance: less than 10 feet or greater than 10 feet. When compared to a reference area, the subsidence areas have significantly more regeneration of tree species but not significantly different shrub cover. The implication of our findings is that although a different mix of species is colonizing the subsidence areas, these are still appropriate to the ecosystem of the area because they are the early natural successional species of the area. These species appear to be taking advantage of the surface disturbance and subsequent lack of competition from climax species.

Additional Key Words: revegetation, reforestation, high altitude reclamation, subsidence, reference area

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Introduction

Subsidence caused by underground mining can create surface disturbances. Comparing a reference zone with a subsided area can give a good representation of the effects of subsidence. By collecting data from both and comparing it we can get a better idea what type of vegetative standards we can meet.

The Molycorp mine is located in north central New Mexico approximately 3 miles east of Questa New Mexico. It operated as an open pit molybdenum mine until the 1980's when underground mining began. Subsidence at the study location began approximately 15 to 20 years ago. The purpose of this study was twofold: 1) to compare a current subsidence area to an undisturbed area, and 2) to evaluate the natural regeneration occurring in a subsidence area. The mine identifies two major subsidence zones: the relaxation zone (an elevation change between 1 and 10ft); and the primary subsidence zone (an elevation change more than 10ft) Tree and shrub data were collected from these two zones and compared to a nearby undisturbed area (Slickline Gulch) and evaluated for natural regeneration.

Methods

Sample Locations

The subsidence areas were divided into a grid using a series of north and east lines spaced evenly at 100 ft intervals. The intersections of these lines were assigned numeric values, and sampling locations were selected from the intersections using a random number generator. Safety concerns from prior field reconnaissance led to the exclusion of certain locations. Sampling sites were located in the relaxation zone and the primary subsidence zone, 12 and 10 locations respectively, for a total of 22 sample sites. The undisturbed area, Slickline Gulch, was similarly sampled at 47 random locations.

Tree Stocking & Basal Area

Tree stocking and basal area were measured using variable radius plots. Only trees greater than 6 feet tall with a minimum 1.1 inches stem diameter at breast height (DBH; 54 inches above the ground line) were included. Measurable trees within the variable radius plot were selected using a 10 basal area factor prism. Species name and DBH for all measurable trees were recorded at each plot in diameter classes of 2 inches intervals. The tree stocking and basal area of each sample site were calculated using the Southwestern Forest Stocking Calculator Software version 1.1 (Harrington and Loveall 2005)

Forest Regeneration

Forest regeneration was defined as trees of any species that were less than 2 m tall and had a DBH less than 2.8 cm. At each location, a permanent 100 m^2 circular plot with a radius of 5.6 m was established and divided into 4 equal subplots based on their orientation on the slope. Occurrences of overstory regeneration within each subplot were documented and summed to calculate the total for the 100 m^2 plot.

Shrub Density and Crown Cover

Shrub density was determined by counting all shrub stems penetrating the surface within the 100 m^2 plot. Shrub crown cover was estimated within the 100 m^2 circular plot by measuring the individual shrub crown length along the longest axis and width at the longest axis perpendicular to the first measurement. The average of the length and width measurements was divided in half to determine the radius. This value was inserted into the formula for the area of a circle (πr^2), which produced an estimate of the area of crown cover for that shrub. Total shrub crown cover at each sample plot was calculated by summing the crown cover for all shrubs in each subplot.

Results

Tree Stocking & Basal Area

Overall the forest in the Slickline Gulch region is a mature forest composed of 6 coniferous tree species: ponderosa pine, white fir (*Abies concolor*), Douglas fir, limber pine (*P. flexilis*), piñon pine (*P. edulis*) and Rocky Mountain juniper (*Juniperus scopulorum*). Ponderosa pine, white fir, limber pine and Douglas fir are the predominant tree species. Site occupancy ranged from no trees to 130 ft^2/ac with an overall basal area of 27 ft^2/ac. Tree size was variable, with the plot mean diameter ranging from 5.7 inches to 20.5 inches (for sample sites containing trees) with an overall mean diameter of 11.0 inches. Ponderosa pine and limber pine were the two largest (in diameter) of the species. The stand structure was uneven in age. The more shade tolerant species (White and Douglas fir) dominated the smaller-diameter classes, while the remaining species were represented in the mid and upper diameter classes. The stocking rate was 41.01 trees/ac while the basal area and quadratic mean diameter were 27.02 ft^2/acre and 10.99 inches, table 1.

The zone of relaxation had a stocking rate of 86.99 trees/ac, a basal area of 52.73 ft^2/ac, and a quadratic mean diameter of 10.54 in. The primary subsidence zone had a stocking rate of 28.98 trees/ac, a basal area of 14.0 ft^2/ac, and a quadratic mean diameter of 9.41 in, Table 1.

Table 1 Tree stocking rates and basal areas for the reference and subsided areas.

	Quadratic Mean Diameter	Basal Area	Stocking Rate
Slickline Gulch	10.99	27.02	41.01
Relaxation Zone	10.54	52.73	86.99
Primary Subsidence Zone	9.41	14.00	28.98

Forest Regeneration

Regeneration of the overstory in the reference area (Slickline Gulch) was sporadic throughout the forest, averaging just fewer than 79 seedlings/saplings per acre, table 2. Only 28 of the 188 1/400th acre plots had regeneration present. Of these the majority had only 1 individual present. In terms of the larger, 100m^2 plots, slightly less than half (47%) had regeneration present. All overstory species present had some regeneration.

Forest regeneration in the relaxation zone was 4.8 trees/100m^2 (SD 3.5) or 194 trees/acre (SD 141.5), Table 2. Regeneration was recorded in 24 of the 40 subplots and all but two of the 100 m^2 sample plots had regeneration. These data were compared with those from Slickline Gulch with a one sample two-tailed t-test. The test produced a t value of 2.5768 ($p<0.030$), Table 2.

This suggests that there was significantly more regeneration in the relaxation zone than in the reference area.

Forest regeneration in the primary subsidence zone was 6.7 trees/100 m^2 (SD 5.3) or 270 trees/acre (SD 214). Regeneration was recorded in 31 of the 48 of the subplots and all of the 100m^2 plots. These data were compared with those of Slickline Gulch using a one sample, two-tailed t-test. The test produced a t value of 3.09 ($p<0.010$), Table 2. This suggests that there was significantly more regeneration in the primary subsidence zone than the reference area.

Shrub Density

Shrub density in Slickline gulch averaged 1, 409 stems/ac (SD 1286.6). This high value may have occurred because the dominant shrub component was snowberry (*Symphoricarpus oreophilus*), which can colonize sloped areas via layering. Snowberry covered the greatest amount of area, followed by Gambel oak (*Quercus gambelli*), then mountain mahogany (*Cercocarpus montanus*).

Shrub density within the relaxation zone was estimated to be 645 stems/ac (SD 499). These data were compared with that of Slickline Gulch using an unpaired, two-tailed t-test. The test produced a t value of 1.834 ($p<0.072$), Table 2. This suggests that the relaxation zone had a significantly lower shrub density than the reference area.

Shrub density within the primary subsidence zone was estimated at 1417 stems/ac (SD 2136). Similar to the relaxation zone, shrub density was variable, ranging from zero shrubs to 7,730 shrubs/acre. The most abundant shrubs within the zone of relaxation and primary subsidence zone were Gambel oak (*Q. gambelii*) and raspberry (*Rubus spp.*). Shrub density was compared between Slickline Gulch and the primary subsidence zone using an unpaired, two-tailed t-test. The test produced a t value of 0.02 ($p<0.990$), Table 2. This suggests that the sites did not have different shrub densities.

Shrub Crown Cover

Shrub crown cover was variable throughout the all sampling plots in all of the areas sampled. In the Slickline Gulch area, it was estimated to be 6.62% (SD 6.75), while in the zone of relaxation it was estimated to be 11.1% (SD 13.4). Three of the ten 100 m^2 plots in the zone of relaxation did not have any shrub crown cover, while the remaining seven had crown cover values ranging from 1.8% to 35.9%. The data from Slickline Gulch and the Relaxation Zone were compared using an unpaired two-tailed t-test. The test produced a t value of 1.57 ($p<0.123$), Table 2. The test suggests that there was no statistically significant difference between the shrub crown cover of the two sites.

Shrub crown cover was estimated to be 10% (SD 14.9) in the primary subsidence zone. As with the shrub density estimates, shrub crown cover was variable throughout this area. Four of the twelve 100 m^2 plots did not have any shrubs, while in the remaining plots, the shrub crown cover ranged from 1.0% to 50%. As stated above, the Slickline Gulch region had an estimated shrub crown cover of 6.62% (SD 6.75). The data from the primary subsidence zone and Slickline Gulch were compared using an unpaired, two-tailed t-test. The test produced a t value of 1.17 ($p<0.246$), Table 2. Again, this test showed that there was no statistically significant difference in shrub crown cover between the primary subsidence zone and the Slickline Gulch reference area.

Table 2 T-test results and means for the Slickline Gulch, Primary Subsidence Zone, and Relaxation Zone

	Mean	St. Dev.	N	t-value	P<
One sample t-test					
Regeneration, seedings/ac					
Slickline Gulch	78.7		47		
Relaxation Zone	194.00	141.50	10	2.58	0.030
Primary Subsidence Zone	270.00	214.400	12	3.09	0.010
Two tailed unpaired t-test					
Shrub Density, stems/ac					
Slickline Gulch	1408.5	1286.6	47		
Relaxation Zone	645.0	499.0	10	1.84	0.072
Primary Subsidence Zone	1417.0	2136.0	12	0.02	0.990
Shrub Crown Cover, %					
Slickline Gulch	6.62	6.75	47		
Relaxation Zone	11.10	13.40	10	1.57	0.123
Primary Subsidence Zone	10.00	14.90	12	1.17	0.246

Discussion

These results demonstrate that Slickline Gulch, the undisturbed area was significantly different in both cover and composition from the two subsidence zones in Goathill Gulch. Forest regeneration was significantly higher for both subsidence zones compared to the Slickline Gulch area. Subsidence does affect landscape configuration and the available seed stock produces higher regeneration than the reference area due to reduced competition from affected species.

The shrub density results were somewhat ambiguous. Although the reference area had a statistically higher shrub density than the zone of relaxation, there was no significant difference between the reference area and the primary zone. Shrub crown cover also provided little insight into the differences between the subsidence areas and the reference area. No statistical differences were found between the subsidence areas and the reference area. This may be explained by the frequent occurrence of certain smaller, more rhizomatous species such as raspberry (*Rubus spp.*) in the subsidence zones. In contrast, the reference area was dominated by species that occur less frequently but cover larger areas in terms of crown cover, for example Gamble oak (*Quercus gambelii*).

Conclusion

The comparison between the subsidence areas and the undisturbed Slickline Gulch area provides evidence that these areas are at different stages in terms regeneration. The Slickline Gulch area was a relatively undisturbed, mature, mixed conifer forest and the subsidence areas have undergone a significant compositional change. Forest regeneration was significantly higher in the subsidence zones probably due to the fact that the forest is in the process of regeneration rather than maintenance. Shrub density and crown cover provided little insight into the differences between the areas.