SHORT- AND LONG-TERM TRANSPLANT PERFORMANCE ON MINE ROCK MATERIAL, QUESTA MINE, NEW MEXICO[1]

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Abstract: Past open pit mining operations at the Chevron Mining Inc. (CMI) Questa Mine in Questa, New Mexico, resulted in several large overburden rock piles. The rock piles are generally steep, angle of repose (2:1 and steeper), acidic (pH 2.5 – 7.0) and composed of a variety of igneous rock types. Pre-mining and currently undisturbed vegetation in the area of the mine site is dominated by mixed conifer forests. Forestry is the approved post-mining land use for this mine. Since the early 1990's studies have been conducted examining the potential for establishing the forest vegetation directly on the overburden rock piles. In the fall of 1996 and spring of 1997 two operational scale plantings at two locations on the mine rock piles were conducted to examine both the logistics associated with planting trees and shrubs directly on angle of repose slopes and the subsequent survival and growth performance of the transplanted vegetation. Short-term (three year) overall survival averaged 81%. There were survival differences between the two planting sites and among the three types of plants being transplanted with crop trees (conifers) averaging 87%, nurse trees (deciduous) averaging 63% and shrubs averaging 92%. Long-term (twelve year) survival averaged 43% and differed between planting sites with the lower elevation (2,500 m) planting site averaging 45% and the higher elevation (3,000 m) site averaging 41% overall survival. The resulting vegetative communities differed between the two planting sites with the higher elevation site having a higher proportion of crop trees compared to the lower site that had comparatively a higher proportion of shrub species. Implications of the results relative to future reclamation plantings are discussed.

Additional Key Words: reforestation, conifer survival, acid rock

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[1] Paper was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT, ***Revitalizing the Environment: Proven Solutions and Innovative Approaches*** May 30 – June 5, 2009. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2009 pp 1698-1710

DOI: 10.21000/JASMR09011698

http://dx.doi.org/10.21000/JASMR09011698

INTRODUCTION

The Chevron Mining Inc. (CMI) Questa Molybdenum Mine has been in operation since 1919. The mine is located in an area of steep, mountainous topography in narrow canyons adjacent to the Red River five miles east of the town of Questa, New Mexico in Taos County. Underground mining occurred from 1919 to the early 1960's when open pit development began, and the open pit mine operated from 1965 through 1983. Since 1983 to the present, mining is an underground block caving operation.

The open pit mine generated 328 million tons of overburden. Deposition of this overburden rock material occurred in the naturally steep, long slopes and narrow canyons to create the mine rock piles. Today, the rock pile surfaces are steep and long, in some cases exceeding 150 meters (500 ft) in length. Unlike many other mining operations where rock piles are situated on relatively flat ground and the height of the piles is indicative of pile depth, the depth of the rock piles at the Questa Molybdenum Mine range from 18.3 meters (60 ft) to 38 meters (125 ft) in thickness (depth) (Robertson GeoConsultants, Inc., 1999). The resulting rock pile depth was a function of several underlying topographic features including slope, slope length, and rock pile structural composition and its influence on angle of repose. The resultant surface of the rock piles has similar slope intensity to the adjacent natural topography.

The terrain surrounding the mine supports primarily coniferous ecosystems with riparian ecosystems in the bottoms of many canyons having perennial streams or rivers. The conifer dominated ecosystems range from ponderosa pine (*Pinus ponderosa*), to mixed conifer (*P. flexilis, Pseudotsuga menziesii, Abies concolor*) to spruce-fir (*Picea engelmannii* and *Abies concolor*) stands. Topographic features, specifically elevation and aspect, strongly influence species distribution (Wagner and Harrington, 1994). Also, edaphic features, which include rooting mantle thickness, water holding capacity and nutrient availability, likely influence vegetation distribution in the area. Areas in which the coniferous overstory have been disturbed, various shrub (*Quercus* spp., *Cercocarpus montanus, Ribes* spp.), aspen (*Populus tremuloides*) and narrowleaf cottonwood (*P. angustifolia*) dominated communities occur.

The other natural features, which appear to strongly influence vegetation distribution in this region, are hydrothermal scars. These naturally occurring areas have highly erodible and acidic soils (Meyer and Leonardson 1990). During the open pit-mining operations, hydrothermal scars were excavated along with intervening areas of more neutral geologic materials. Heterogeneous overburden piles resulted with a wide range of particle sizes and chemistries (specifically pH).

Consistent with the variability in vegetation surrounding the mine, the mine itself offers a broad range of planting sites. For example, elevation ranges from 2,500 m to 3,000 m (8,000 feet to 10,000 feet) and almost every aspect occurs. In addition to the variability in the rock pile thickness, rock pile particle size ranges from clay-sized fines to large cobble, and rock pile pH ranges from neutral (pH 7) to very acidic (pH 3). This site diversity will require a range of revegetation techniques be employed to revegetate the site.

In September 1996 and June 1997, two operational-scale plantings were conducted on the mine rock piles at the CMI Questa Mine. The primary purpose of these two plantings was to examine the feasibility and logistics of transplanting seedlings directly on the rock piles. More specifically, the objectives of these plantings were to evaluate worker safety, plant handling issues, overall logistics of the operation, costs and transplant performance. This report addresses the last objective, transplant performance. It is important to note that the design of these plantings precludes the ability to contrast/compare the two planting sites or two planting times.

MATERIALS AND METHODS

Plant Material

Seedlings used in this study were grown in the New Mexico State University – Mora Research Center Nursery. All seedlings were grown in containers ranging in size from 164 ml (10 in^3; Ray-Leach Supercell; Steuwe and Sons, Inc. Corvallis, OR) to 220 ml (13.4 in^3; 60/220 15S Copperblock; Beaver Plastics, Inc. Corvallis, OR). The plant material consisted of a wide range of plant species (Table 1). In general, the relative proportion of plant forms for both plantings consisted of 30% deciduous (nurse) trees, 55% coniferous (crop) trees, and 15% shrubs.

Planting was done by an experienced reforestation contract planting crew. The same contract crew was used for both plantings. Seedlings were planted by hand using hoedads. Targeted planting density was 9,075 seedlings/ha (3,672 seedlings/ac) achieved by a plant spacing of 1 m (3 ft) within row and 1.2 m (4 ft) between rows for both planting sites. However, immediately following planting a survey of planting density indicated that actual planting density averaged 8,490 seedlings/ha (3,435 seedlings/ac) at the Low Elevation Planting Site (LEP Site) and 8,833 seedlings /ha (3,575 seedlings/ac) at the High Elevation Planting Site (HEP Site). Areas with a thick layer of cobble sized materials contributed to the overall reduction in planting density at the LEP Site. Approximately 20,000 seedlings were planted at each site.

Table 1. Species planted in the Fall 1996 (LEP Site) and Spring 1997 (HEP Site) plantings at the Chevron Mining Inc. Questa Mine.

Plant Form	Scientific Name	Common Name	LEP Site	HEP Site
Crop Tree	*Pinus ponderosa*	Ponderosa pine	yes	yes
Crop Tree	*Pinus strobiformis*	SW white pine	yes	yes
Crop Tree	*Pinus flexilis*	Limber pine	yes	yes
Crop Tree	*Pinus aristata*	Bristlecone pine	yes	no
Crop Tree	*Pinus edulis*	Piñon pine	yes	yes
Crop Tree	*Abies concolor*	White fir	yes	yes
Crop Tree	*Pseudotsuga menziesii*	Douglas fir	no	yes
Crop Tree	*Picea pungens*	Blue spruce	no	yes
Crop Tree	*Picea engelmannii*	Engelmann spruce	yes	no
Nurse Tree	*Populus angustifolia*	Narrowleaf cottonwood	yes	yes
Nurse Tree	*Robinia neomexicana*	New Mexico locust	yes	yes
Shrub	*Salix scouleriana*	Scouler's willow	yes	yes
Shrub	*Quercus gambelii*	Gambel's oak	yes	yes
Shrub	*Prunus virginiana*	Chokecherry	no	yes
Shrub	*Artemesia frigida*	Fringed sage	yes	yes
Shrub	*Chrysothamnus nauseous*	Rubber rabbitbrush	yes	yes
Shrub	*Alnus tenuifolia*	Thinleaf alder	no	yes
Shrub	*Cercocarpus montanus*	Mt. mahogany	yes	yes
Shrub	*Chamaebatiaria millefolium*	Fernbush	yes	yes
Shrub	*Ribes cereum*	Wax currant	yes	yes
Shrub	*Jamesia americana*	Waxflower	yes	yes
Shrub	*Fallugia paradoxa*	Apache plume	yes	no
Shrub	*Juniperus scopulorum*	Rocky Mtn. juniper	yes	no
Shrub	*Atriplex canescens*	Four-wing saltbush	yes	no
Shrub	*Arctostaphylus uva-ursi*	Kinnikinnick	yes	no

<u>Planting Sites</u>

<u>Low Elevation Planting Site.</u> The LEP Site was planted in September 1996. This planting site is situated at approximately 2,500 m (8,200 ft) elevation and has a predominately south facing aspect. The slope is at angle of repose. The rocks piles have a large portion (45 – 60%) of

coarse fragments (greater than 2 mm). The average chemical and physical properties of the fine fraction (less than 2 mm) for the LEP Site are reported in Table 2.

Table 2. Overburden soil properties at the LEP and HEP planting sites.

Parameter	LEP Site		HEP Site	
	Mean	SD	Mean	SD
pH[1]	6.77	0.72	4.98	1.32
Clay (%)[2]	19.16	2.95	21.28	1.44
Sand (%)[2]	62.27	4.71	67.65	5.87
Silt (%)[2]	18.64	2.74	11.19	4.93
Texture Classification (% of Samples)	SL (75%) SCL (25%)		SCL (80%) SL (20%)	
Calcium (meq/L)[3]	24.76	4.95	0.448	0.236
Magnesium (meq/L)[3]	2.258	1.674	0.228	0.113
Sodium (meq/L)[3]	0.267	0.119	0.138	0.069
Sodium Absorption Ratio[4]	0.067	0.028	0.250	0.160
Conductivity (mmhos/cm) @ 25°C[5]	2.173	0.359	0.160	0.042

[1] Saturated Paste, EPA Method USDA No. 60 (21A)

[2] EPA Method ASTM D 422 Hydrometer

[3] Saturated Paste, EPA Method M6010B ICP

[4] Calculated

[5] EPA Method SM2510B

High Elevation Planting Site. The HEP Site was planted in June 1997. This planting site is situated at approximately 3,000 m (9,600 ft) elevation and has a predominately south facing aspect. The slope is at angle of repose. While less than the LEP Site, the HEP Site also has a large portion (30 – 60%) of coarse fragments (greater than 2 mm). The average chemical and physical properties of the fine fraction (less than 2 mm) are reported for the HEP Site in Table 2.

Vegetation Analysis

Transplant performance was monitored twice, after three growing seasons (May 2000) and after twelve growing seasons (September 2008). Two different survey procedures were used. The survey procedure used after three growing seasons employed transects each measuring 2 m wide and 50 m long (1/100th ha/ ~1/40th acre). Six transects were placed on the LEP Site and three transects on the HEP Site. The HEP site had fewer transects due to time and financial limitations. Survey points were randomly assigned by placing a numbered grid over maps of the planting area and using a random number table to identify sample points on the grid. For ease of installation and consistency, all transects were placed perpendicular to the slope direction. After three growing seasons, evidence of all seedlings planted, living or dead, were still present. In all cases identification to plant form (crop tree, nurse tree or shrub) was possible and in most cases identification to species was also possible. Species composition (living) and frequency were recorded. Status categories included number of living seedlings, number of covered seedlings (living), and number of seedlings with broken tops (browse damaged). These status categories were used to quantify the condition of the established seedlings. Covered status indicates that there has been movement of rocks, small particles or other material over the seedling. This category includes plants that appear to be unaffected by the covering (small amount of stem covered) to those with a larger portion of the stem covered but still living. Stocking levels are determined by multiplying plant numbers in the transect by 100 for non-adjusted rates.

Due to the overall small sample sizes from the three growing season surveys, data being presented were analyzed using descriptive statistics including means, standard deviation or standard error of the mean (SAS Institute, Inc., 1996). Sums were generated from the raw data for plot by species combinations.

The survey procedure used during the twelfth growing season inventory used 1/100th ha (1/40th acre) circular plots. Increase in plant size and inability to identify covered or dead transplants were the basis for changing sampling procedures. Plant species, life form, height, crown width and whether the plant was planted or naturally occurring were recorded. Life form classification was categorized as crop tree (coniferous tree), nurse tree (deciduous tree) or shrub (deciduous or coniferous). Plant height was measured using a tape measure and recorded to the nearest centimeter. Crown width was measured twice, once along the widest portion of the crown and then perpendicular to the first measurement. Crown width was measured using a tape measure and recorded to the nearest centimeter. Using the two crown width measurements canopy area was calculated using the formula for an ellipse.

RESULTS

Stocking rates at the LEP and HEP Sites after three growing seasons were 7,288 and 8,833 seedlings/ha, respectively (Table 3). There was considerable variability in stocking rates within sites as illustrated by the high coefficients of variation for these estimates: 10.3% and 26.2% for the LEP and HEP Sites, respectively. The relatively few sample points taken after three growing seasons (six at the LEP Site and three at the HEP Site) may be contributing to the overall high levels of observed variability. However, the larger sample size (ten plots per site) used during the survey conducted after twelve growing seasons still resulted in relatively high levels of variability in stocking rates within each planting site, 31.4% and 25.6% for the LEP and HEP Sites, respectively.

Table 3. Stocking rates for the LEP and HEP sites after three and twelve growing seasons.

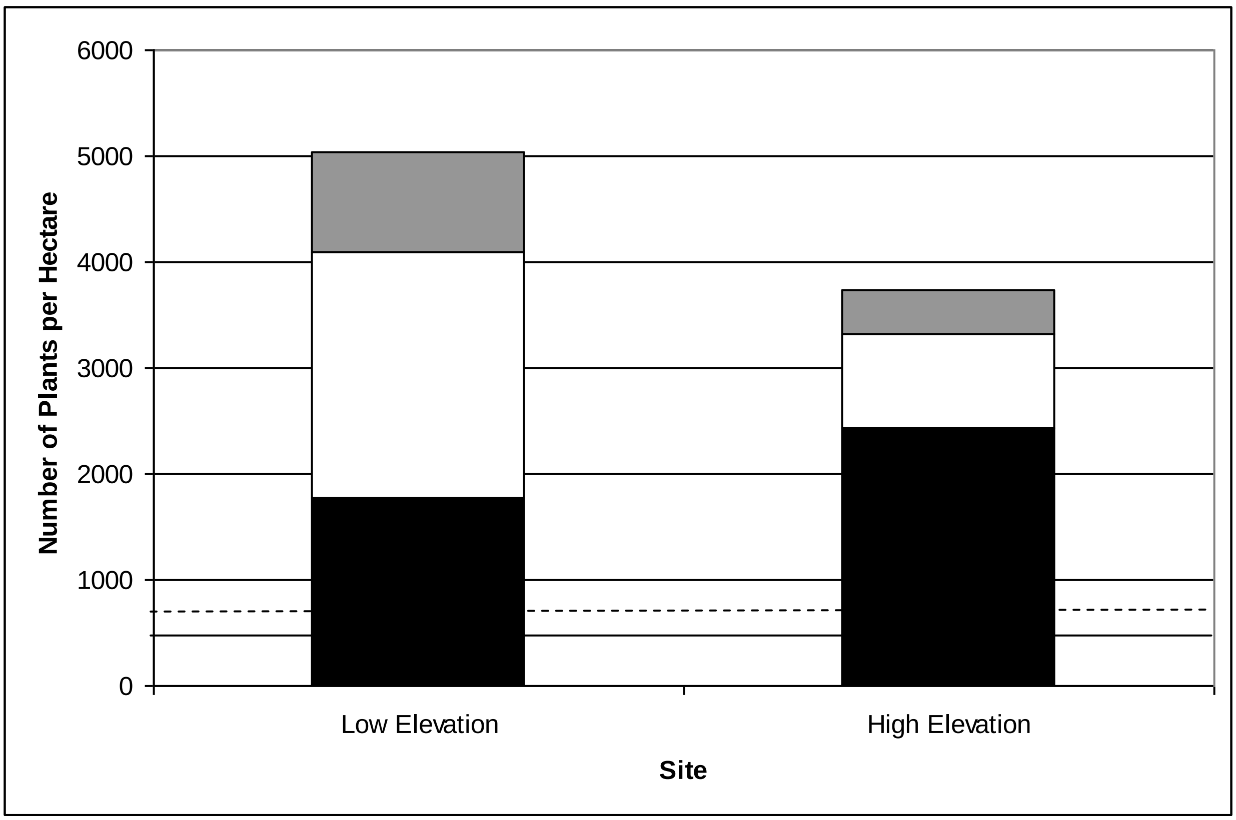
Planting Site	Plant Category	Year 3 Stocking (plants/ha) Mean	Year 3 Stocking (plants/ha) SD	Year 12 Stocking (plants/ha) Planted Mean	Year 12 Stocking (plants/ha) Planted SD	Year 12 Stocking (plants/ha) All plants Mean	Year 12 Stocking (plants/ha) All plants SD
LEP Site	Crop Tree	3778	918	1769	963	1769	963
	Nurse Tree	2226	449	1433	641	2323	1367
	Shrub	1284	777	919	484	949	471
	Total	7288	752	4122	1290	5041	1582
HEP Site	Crop Tree	5167	1595	2432	1016	2432	1016
	Nurse Tree	1800	755	850	792	880	804
	Shrub	1867	351	415	241	415	241
	Total	8833	2312	3697	977	3726	953

After three growing seasons, seedlings at the HEP Site had greater levels of herbivory damage than those growing at the LEP Site. Just over 19% of the seedlings at the HEP Site had signs of being browsed compared to less than 3% at the LEP Site. The greater browsing damage at the HEP site is likely due to this site being adjacent to an undisturbed forest and an appreciable distance from any public roads. In contrast, the LEP Site was approximately a ½ km from undisturbed forest and in comparatively close proximity to a public highway. Seedlings growing at the HEP Site also had greater levels of covering, 36.6%, when contrasted with the level of covering at the LEP Site, which had just over 10% of the seedlings having material burying part of their stem. This increase in covering may have been due to the increase in wildlife activity on the HEP Site dislodging materials on the angle of repose slopes or the increase may have been due to differences in the rock materials between the two sites, or a combination of both of these factors.

Overall, stocking rates fell between the third and twelfth growing season measurement periods. Based on stocking rates after three growing seasons, stocking rates dropped 43% to 4,122 seedlings/ha at the LEP Site (Table 3). If naturally established (root sprouts/natural seeding) plant material is included the drop in stocking levels is only 31%, or a resulting stocking rate of 5,041 seedlings/ha. Much of the overall loss in stocking rates was due to a 56% loss in the stocking rate of crop trees from an average of 3,778 seedlings/ha after three growing seasons to 1,769 seedlings/ha after twelve growing seasons (Table 3). This stocking rate still greatly exceeds the lower limit of the crop tree stocking rate of 432 crop trees/ha specified in the mine's 1994 closeout plan (Figure 1). In contrast, the loss in stocking rates of nurse tree species, primarily narrowleaf cottonwood, and shrubs were 36% and 28% respectively. There were no signs of dead trees or stems at any of the measurement sites, indicating that the mortality contributing to the loss of stocking rates probably occurred shortly after the three-year measurements. It is also interesting to note that if root sprouts and naturally seeded individuals are including in the stocking tallies, the nurse tree category appears to have an increase in stocking levels from 2,226 seedlings/ha to 2,323 seedlings/ha (Table 3). This apparent increase is largely due to the root sprouting nature of narrowleaf cottonwood growing on this site.

The resulting composition of plants on the LEP Site after twelve growing seasons is 43% crop trees, 35% nurse trees and 22% shrubs (Table 4). This ratio of plant forms deviates slightly from the original planting composition of 55% crop trees, 30% nurse trees and 15% shrubs. The crop trees and shrubs both averaged 3.6 different species per plot while the nurse tree category averaged 1.7 different species per plot (Table 4). The lower species diversity value for nurse trees would be expected as only two different nurse tree species were planted (Table 1). The number of species by plant form found after twelve growing seasons illustrates that the tree planting crew was effective in reducing large block plantings of single species.

The average reduction in stocking rate from the third to the twelfth growing season at the HEP Site was 58%, going from an average of 8,833 seedlings/ha to 3,697 seedlings/ha (Table 3). Much of this loss in stocking was driven by the 78% reduction in shrubs, in contrast to the average 53% reduction in both nurse and crop tree species. Again the resultant crop tree stocking rate of 2,432 tree/ha is over five-fold greater than the lower limit of crop tree stocking rate in the mine's 1994 closeout plan (Fig. 1). In contrast to the LEP Site, there were comparatively fewer, 29 seedlings/ha versus 919 seedlings/ha, root sprouts or naturally established seedlings at the HEP Site. The greater loss of shrubs from the third to the twelfth growing season at the HEP Site resulted in a lower average number of shrub species per plot (1.6 species/plot). In contrast, there was a greater diversity in crop trees at the HEP Site (Table 4). The resulting plant community composition after twelve growing seasons at the HEP Site was 66% crop trees, 23% nurse trees, and 11% shrubs (Table 4).



Crop Tree
Nurse Tree
Shrub
Upper Limit of Successful Establishment (680 Crop Trees / ha)
Lower Limit of Successful Establishment (432 Crop Trees / ha)

Figure 1. Stocking rates of crop trees, nurse trees and shrubs planted at the LEP and HEP sites at the Chevron Mining Inc. Questa Mine twelve years after planting.

Table 4. Species diversity measures for the LEP and HEP sites after twelve growing seasons.

	Percent of Stocking		Mean Number of Species ± Standard Deviation	
	LEP	HEP	LEP	HEP
Crop	43	66	3.6 ± 0.8	4.9 ± 0.6
Nurse	35	23	1.7 ± 0.5	1.2 ± 0.9
Shrub	22	11	3.6 ± 1.2	1.6 ± 1.2

Overall plant canopy cover was greater at the HEP Site with an average of over 12% canopy cover in contrast to just over 10% cover at the LEP Site (Table 5). In the case of the LEP Site, most of the canopy cover (66%) was made up of the canopies of nurse trees. At the HEP Site, the majority (70%) of the canopy area was made up of crop trees. While there was little difference between the height of nurse trees and shrubs between the two sites, the height of crop trees growing at the HEP site was over two-fold greater than those growing at the LEP Site (Fig. 2).

Table 5. Canopy coverage by plant form as a percentage of total area for the LEP and HEP sites after twelve growing seasons.

Planting Site	Plant Form	Percent of Total Area	Percent of Plant Cover
LEP Site	Crop	1.6	15.6
	Nurse	6.8	66.2
	Shrub	1.9	18.2
	Total	10.3	na
HEP Site	Crop	8.9	70.5
	Nurse	3.4	27.0
	Shrub	0.3	2.5
	Total	12.6	na

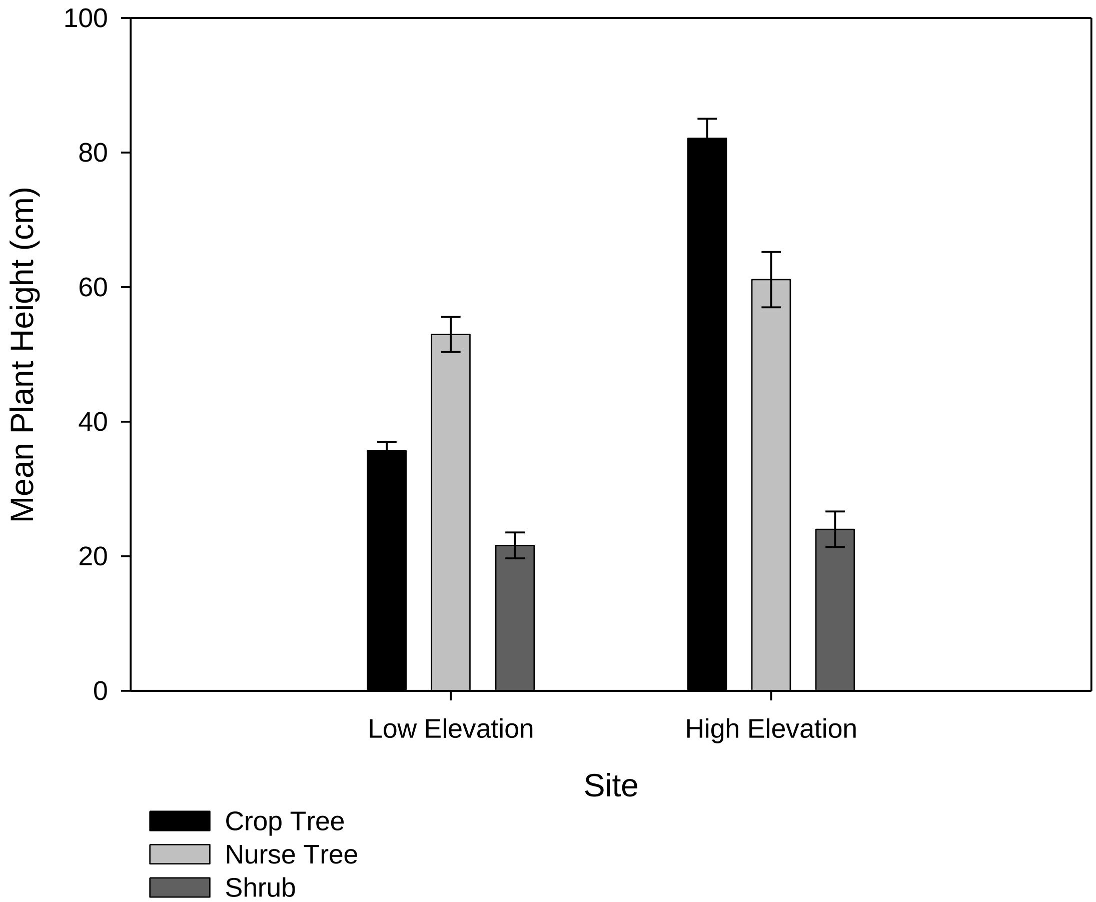


Figure 2. Mean height of crop trees, nurse trees and shrubs planted at the LEP and HEP sites at the Chevron Mining Inc. Questa Mine twelve years after planting. Bars indicate +/- one standard error of the mean.

DISCUSSION

These results, specifically the stocking rates and species composition data, demonstrate the planting approach used in the trial operational plantings allows for successful establishment of forest seedlings and results in a heterogeneous plant community. Despite having an estimated survival rate below 50%, the lack of observed recent (within the past several years) mortality indicates that the majority of transplant mortality occurred within the first 5 to 8 years after planting. Secondly, the level of variability in species composition observed at both the early and late intervals indicate that the approach used resulted in a diverse planting community. The preliminary data generated by this study should help refine planting numbers to ensure specific plant distributions in the resulting plant community.

Protection from herbivory during the years following planting may be helpful in reducing plant and growth losses due to browsing and/or covering that was observed primarily at the HEP Site. The costs associated with any herbivory protection system would need to be compared to the cost of over-planting in anticipation of herbivory damage.

In a previous study at the Questa Mine, growth of ponderosa pine planted on overburden was compared to growth of ponderosa pine planted on nearby sites within the Carson National Forest (Harrington and Loveall 2006). There appears to be a four to seven year establishment period before trees planted on overburden exhibit appreciable height growth. In that study, ponderosa pine growing on the mine site averaged 115 cm in height after twelve growing seasons. In contrast, the average height of crop trees found at the LEP and HEP sites in this study were 36 and 82 cm, respectively. Inclusion of slower growing crop tree species may be contributing to the apparent slower growth observed in this study.

In the current study, annual shoot growth has not yet been measured or used as an indicator of success. The results of the aforementioned comparison study and others indicate that seedlings (both transplanted and natural regeneration) appear to concentrate substantial energy into root development and little into shoot growth for the first four to six years after establishment (Harrington 2000, unpublished data). Following this period, shoot growth becomes evident on an annual basis. It is anticipated that within the next two years, shoot growth will be measured to assist in determination of successful establishment at these sites.

The successful establishment of seedlings at the site has been attributed to three factors. As noted above, whenever possible, site adapted (genetic) plant material is used in the planting program. For some species, this appears to be a critical component of successful establishment (Harrington et al., 2000). The second factor is using pre-conditioned, container-grown stock. The higher than expected mortality of the narrowleaf cottonwood in the 1996 fall planting was in part because the plants were not conditioned properly and were susceptible to an early frost kill. Lastly, proper planting techniques, as is seen in any forestry planting, are critical to successful establishment of the seedlings. The 80% survival and the subsequent stocking levels three years after transplanting are evidence that the seedlings were planted properly.

This reclamation program is in the early stages of implementation. The program anticipates continued development and research of plant material, planting techniques and post-planting maintenance. The reclamation program has a long-term objective of establishing a self-sustaining forest ecosystem at the site that is appropriate to the area.

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