

# EVALUATING FOREST PRODUCTIVITY ON RECLAIMED MINE LAND IN THE WESTERN UNITED STATES<sup>1</sup>

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**Abstract:** Establishing forests as a post-mining land use has not been widely used in the western United States for a number of reasons. Most mine revegetation efforts in the western United States prior to the 1990's focused on establishing either herbaceous or shrub communities because most existing reclamation expertise was associated with establishing these non-forest plant communities. Hence, few existing performance standards were designed for forested plant communities. Numerous investigations in the eastern United States have examined the use of site index to evaluate post-mined land forest productivity. This study reports preliminary results comparing early (less than 20- year) estimates of site index on a high elevation mine site to the performance of artificial reforestation on adjacent forested sites with known site indices in the western United States. Using incremental height analysis, ponderosa pine seedlings planted at two locations on a high elevation mine site were tracked for up to 20 years. Similarly, seedlings planted up to 19 years before the present time were also tracked on nine "undisturbed" forested sites with a range of site indices. No difference in the growth of seedlings through nine years was found between forest sites with high and low site indices. Ponderosa pine seedlings planted on mine overburden took 2 - 4 years longer to have appreciable height growth compared with seedlings on forested sites. However, once appreciable shoot growth had begun, seedlings planted on mine overburden demonstrated growth rates comparable to those planted on less disturbed sites (through 19 years).

**Additional Key Words:** reforestation, mined land reclamation, site productivity, transplant shock

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## Introduction

The most commonly used expression of forest site quality or forest productivity in the United States is site index. Site index is based on tree growth patterns and refers to the height of dominant or co-dominant trees in even-aged stands at some index age, typically 25, 50 or 100 years. Index age is often related to an age at which the tree would be commercially viable and is most often measured at breast height (4.5 feet above the ground line). Index ages vary depending on species. The faster growing species, such as southern pines, have a younger index age. The slower growing species, such as western conifers, have an older index age. Site index information for a species is typically presented in the form of a series of age-height curves, referred to as site index curves. The curves typically become divergent over time from the age at which they begin through their respective base ages. There are numerous methods used to construct site index curves and the reader is referred to Forestry Handbook (Wenger 1984) for further information on this topic. Relative to mined land reclamation, site index and the corresponding site index curves, provide a potential mechanism for using trees to assess site quality prior to the point that trees reach commercial size which in some regions, such as the southwest, can be as long as 100 years.

Commercial forestry as an approved post-mining land use is becoming more accepted both by the regulatory authorities and the mining industry. This changing trend is true both in the eastern/Midwestern coal region and the mountainous coal and hard rock regions in the western United States. Pre-mining indigenous plant communities were often forests stocked with commercial tree species. Recent shifts in national and international policies and economics have also contributed to the increase in support for the adoption of commercial forestry as a post-mining land use. These shifts include the potential benefits of commercial forests in carbon sequestration (Karpan 1998 as cited by Boyce 1999; Amichev et al. 2004, Litynski 2004); contribution to forest products industries (Vories 2000; Boyce 1999); improvement of regional wildlife habitat (McCoy et al. 2000) and the general ecological benefits commercial forests provide (Boyce 1999).

Explanations of why commercial forestry was not more widely accepted as an approved post-mining land use prior to the mid-1990's have been reviewed elsewhere (Boyce 1999). One relevant issue of concern is the determination of performance standards that are acceptable, to the regulatory authorities, the mining industry, and other stakeholders of commercial forests. In the eastern coal mining region there has been significant progress over a relatively short period of time in the evolution of performance standards. An excellent example is the commercial forestry standard in West Virginia (Eggerud 2004). Of particular interest is the productivity standard: "*Productivity is measured by an average annual growth increment of white pine (*Pinus strobus*) indicator trees. The required productivity for final bond release for the indicator trees is an average of 1.5 feet of growth over a four-year period to be achieved by the end of the twelfth year after planting.*" (Eggerud 2004). This measurement approach for the standard appears to be based on Beck's (1971) site index standards for young stands of this species. Beck's method involves measuring the three-year or five-year height increment starting with the increment at breast height (4.5 feet above ground line) once the trees have become established and are in a free-to-grow state relative to competing vegetation (Beck 1971).

More recently in the eastern coal fields, site index measures have been used to compare forest productivity on mine sites to forest productivity on adjacent lands (Rodrigue and Burger 2001), and examine the effects of various mined land reclamation practices on forest productivity (Burger et al. 2000; Burger 2004). Further effort has begun in the eastern/Midwestern coal region to relate site features (substrate pH, geology, etc.) to tree performance as quantified by site index (Gorman et al. 2001, Jones et al. 2005). However, the use of site indices in the above discussion and associated citations are contingent upon at least one of three criteria being satisfied. Early measures of site productivity are based on a species in which: (1) the relationship of early (young) performance and long term productivity has been established (e.g. Eastern white pine; Beck 1971); (2) the base age or age at which the site productivity is determined is relatively young, (e.g. 25 years for loblolly pine; Farrar 1973); or (3) the trees measured were comparatively old (e.g. 35 to 54 years; Rodrigue and Burger 2001).

In the southwestern United States site index curves exist for most commercially important tree species including ponderosa pine (Minor 1964). In contrast to site index curves for the tree species in the southeastern United States or in the eastern/Midwestern coal region, where base ages are usually 25 or 50 years respectively, western species site index age is typically 100 years measured at breast height. The time interval required for ponderosa pine seedlings/saplings to attain a height of 4.5 feet above ground line is variable ranging from 6 to 29 years in northern Arizona (Minor 1964) and 8 to 25 years in northern New Mexico (Harrington unpublished data). These two features, 100 year index age, and long and variable time frame to attain an adequate size for determining site index, present challenges to using this approach for determining post mining commercial forest site productivity at most sites in the southwestern United States. Another challenge to developing an acceptable productivity standard for commercial forests on mined lands in the southwestern United States is the lack of long-term tree plantings on such sites.

The objectives of the present investigation were twofold. The first objective was to describe the early growth and development of ponderosa pine seedlings planted at the Molycorp Inc., Questa Mine site in north central New Mexico. The second objective was to contrast this growth to ponderosa pine seedlings planted on typical reforestation sites in the adjacent forest lands and to seedlings naturally regenerated within undisturbed areas of the mine site.

### **Materials and Methods**

The mine site used (Questa molybdenum mine) in this study is located in the Taos Range of the Sangre de Cristo mountains in northern New Mexico. Elevation at the site ranges from 8,000 to 10,000 feet. 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 ecosystems include ponderosa pine (*Pinus ponderosa*), mixed conifer (*P. flexilis*, *Pseudotsuga menziesii*, *Abies concolor*) to spruce-fir (*Picea engelmannii* and *A. concolor*) stands. Distribution of these species is influenced by topographic features as well as aspect. Open pit mining operations were conducted between 1965 and 1983. During this time approximately 328 million tons of waste rock were produced and placed in rock piles surrounding the open pit. In general,

mixed volcanic waste rock was excavated from a hydrothermal scar area of the pit (SRK 1995). These mixed volcanic rocks were derived from upper rhyolitic and lower andesitic series rocks of Tertiary age. The mixed volcanics are highly fractured and weathered, and typically exhibit a paste pH in the range of 2.3 to greater than 6.0, the majority less than 3.5. Paste extractions of these rocks typically indicate a high TDS content. The remainder of the waste rock was derived from propylitic black andesite, aplite and granite. Black andesite, aplite and granitic intrusives (mine aplite) typically exhibit neutral paste pH and low paste TDS content.

### Study Sites

Two planting sites on the Molycorp Inc., Questa Mine site and nine planting sites on the Carson National Forest were used in this investigation. In addition, naturally regenerated ponderosa pine from two site classes on undisturbed forests within the Molycorp Inc., Questa Mine property were evaluated for early growth. All of the planting sites were less than 25 years old at the time the investigation was conducted (Table 1). The naturally regenerated seedlings were all less than 30 years of age at the time of the investigation. The two planting sites at the Molycorp Inc., site consisted of a 1978 planting done on a safety berm at the toe of a series of overburden piles. The berm is approximately 12 meters in height and constructed of local colluvium.

Scrapers were used to construct the berm in a series of lifts (layers) which were compacted with dozers. No written records exist on the site preparation or stock types used in the 1978 planting. Based on interviews with mine employees present at the time, the seedlings were small container grown ponderosa pine seedlings and were hand planted. At the time of planting a "fertilizer pellet" was dropped into the planting hole along with the seedlings. No information exists on the chemical composition of the fertilizer used. Throughout the first growing season until the late summer rains came, seedlings were irrigated by hand once every three to four weeks (Lacome, personal comm.). The second planting at the Molycorp Mine site was done in the fall of 1992. This planting consisted of a series of bench plantings on the overburden piles and directly into the overburden material. The bench planting sites were former haul roads used to construct the overburden piles. The benches (haul roads) and overburden piles were constructed over 25 years prior to the planting. In the intervening years the benches had not been used as haul roads. The planting sites were ripped to mitigate any compaction problems associated with the previous uses of the benches. A sixteen inch ripping depth was targeted. However, the wide range of particle sizes from clay sized fines to large rocks in excess of 60 cm diameter resulted in variable ripping depths ranging from ten inches to twenty inches. Geologic material in these portions of the overburden piles consisted of a mix of black andesite and aplite. These materials were relatively neutral with a paste pH of 7.1 and low salt levels (TDS of 30) (SRK 1995). The planting stock used in the 1992 planting was eight month old ponderosa pine seedlings produced in a 164 cm<sup>3</sup> container. Seedlings were planted by hand using a dibble bar and the planting was performed in late summer to correspond with the rainy season. No subsequent cultural treatments were provided to the seedlings following planting.

Table 1. Location and planting attributes for the nine Carson National Forest and two Molycorp Inc., Questa Mine plantings used in this study.

Name	Latitude (D M.M)	Longitude (D M.M)	Elevation (feet)	Aspect (Degree)	Planting Year	Site Index	Stock Type <sup>1</sup>
Safety Berm	N36° 41.820	W105° 29.162	8200	140	1978	na	C- ?
Overburden	N36° 41.845	W105° 29.256	8650 - 9000	Bench	1992	na	C – 10 in <sup>3</sup>
Carson NF							
Ticolote 1	N36° 20.763	W105° 23.209	9300	20	1991	60.0	C – 9 in <sup>3</sup>
Ticolote 2	N36° 20.467	W105° 23.108	9470	60	1991	54.5	C – 9 in <sup>3</sup>
Ticolote 3	N36° 19.961	W105° 22.838	9640	165	1991	51.9	C – 9 in <sup>3</sup>
Mondragon 1	N36° 22.054	W105° 23.748	8700	310	1985	59.8	BR – 2-0
Mondragon 2	N36° 21.672	W105° 23.760	8840	20	1985	67.1	BR – 2-0
Upper Ranchos	N36° 23.684	W105° 28.194	9240	140	1983	57.9	C - ?
Vallecitos	N36° 12.967	W105° 36.093	8720	120	1982	80.3	C - ?
Seally	N36° 44.971	W105° 05.989	8070	330	1983	68.7	C - ?
Fuente	N36° 14.303	W105° 35.691	8200	250	1987	67.4	BR – 2-0

<sup>1</sup> - Stock type abbreviations: C = container, BR = Bareroot

The nine plantings sites in the Carson National Forest ranged in age from 9 to 19 years at the time of measurement, approximately the same span of time as the two mine planting sites (Table 1). Commercial timber harvesting had occurred on eight of these sites. The ninth site, Mondragon 1, was replanted after a wildfire. Both bare root and container produced stock types were used in the Carson National Forest plantings. Based on field notes and the original prescription, hand scalping was the only site preparation method used. Based on the spatial arrangement of the trees, it was obvious that the seedlings had been hand planted.

Ponderosa pine seedlings/saplings naturally regenerating in undisturbed forest sites at the MolyCorp Inc., Questa Mine property were also sampled. Samples were taken in two different soil types on the mine. Natural geologic features referred to as alteration scars or hydrothermal scars occurred within the Red River Canyon near and on the mine property. In general these scar materials have low pH (pH = 3.2; SRK 1995), and high soluble salts (TDS > 2000; SRK 1995) and were highly erodible (Meyer and Leonardson 1990). Therefore, the naturally regenerated population of seedling/saplings was stratified with one sample growing on an alteration scar and/or the debris fan immediately beneath the scar. The second naturally regenerated population sampled was growing in a forested area with no apparent influence from an alteration scar. No soils information was recorded for the sites where the non-scar seedlings/saplings were measured.

#### Plant Measurements

Annual height increment in ponderosa pine is monocyclic (fixed growth, Resinosa pattern) with a spring shoot developing from a winter bud (Lanner 1976). This growth pattern results in a whorl of branches originating at the base of the terminal bud each year thus providing a mechanism to track a tree's height through time by measuring the height of each whorl (Fig. 1). The height of each whorl was measured back from the year of measurement for each tree until a discernible branch whorl could not be identified. For seedlings/saplings at the 11 planting sites tree age was known based on date of planting. Determining age of the naturally regenerated seedlings/saplings was accomplished by cutting the tree at the ground line and counting the number of tree rings. From this information we were able to determine annual height increment. The number of replications varied depending on the age by site combination with a minimum of five replications and a maximum of 176 replications for any given year X site combination.

### **Results & Discussion**

Successful transplant establishment depends on the ability of the planting stock to overcome the stresses associated with the transplant process and establishment at the site. Some degree of stress associated with transplanting is unavoidable regardless of planting conditions. The degree and duration of this stress is a function of the interaction of the planting stock and site conditions. This transplant stress can be expressed as both a condition and a process (Rietveld 1989). The stress condition is the impact of the transplant on the planting stock physiological processes and physical being. The process is associated with the mechanisms employed by the planting stock to acclimate to site conditions (establishment).

There were no difference in height growth of the two groups of seedlings for the three ages in which the data for the 1978 colluvium (undisturbed mine site) and the 1992 overburden plantings overlapped, years seven to nine, (Fig. 2). Contrasting the 1978/1992 plantings to the average height growth for the nine Carson National Forest plantings, there appears to be an extended establishment interval of roughly four years (Fig. 2). The seedlings planted on the national forest sites became established by the end of the third growing season after which these seedlings began growing at an increasing rate. In contrast seedlings growing on the berm and overburden sites only showed increasing growth beginning at the end of the seventh growing season. This extended establishment interval appeared to last throughout the measurement period. By the end of the measurement period, 19 years for the Carson National Forest plantings and 23 years for the berm plantings, the two groups were growing at the same rate; 21.3 cm/yr for the ponderosa pine growing on the Carson National Forest and 22.4 cm/yr for the ponderosa pine growing on the berm.



Figure 1. Photograph of ponderosa pine branch whorls from tree growing at the Molycorp Inc., Questa Mine.

One establishment mechanism is the process of developing new root tissues, thus allowing the planting stock to integrate into the site (South and Zwolinski 1997). Excavations of other ponderosa pine plantings on the overburden piles at the Molycorp Inc., Questa Mine revealed an extensive, both in lateral and depth, root system being developed prior to the period of rapid shoot elongation (Harrington unpublished data; Fig. 3). This would indicate that the seedlings were preferentially allocating resources to root system development rather than shoot development.

The naturally regenerated seedlings growing in the undisturbed forests adjacent to the mine areas took longer than the planted seedlings on the Carson National Forest to become established (Fig. 4). Once established these seedlings had the fastest growth rates measured in this study.

Height growth of naturally regenerated ponderosa pine was strongly influenced by substrate (soil). The productivity of naturally regenerated forests on material in or immediately below alteration scars was less than those growing in adjacent forests on different soil and this difference became more pronounced over time (Fig. 5).

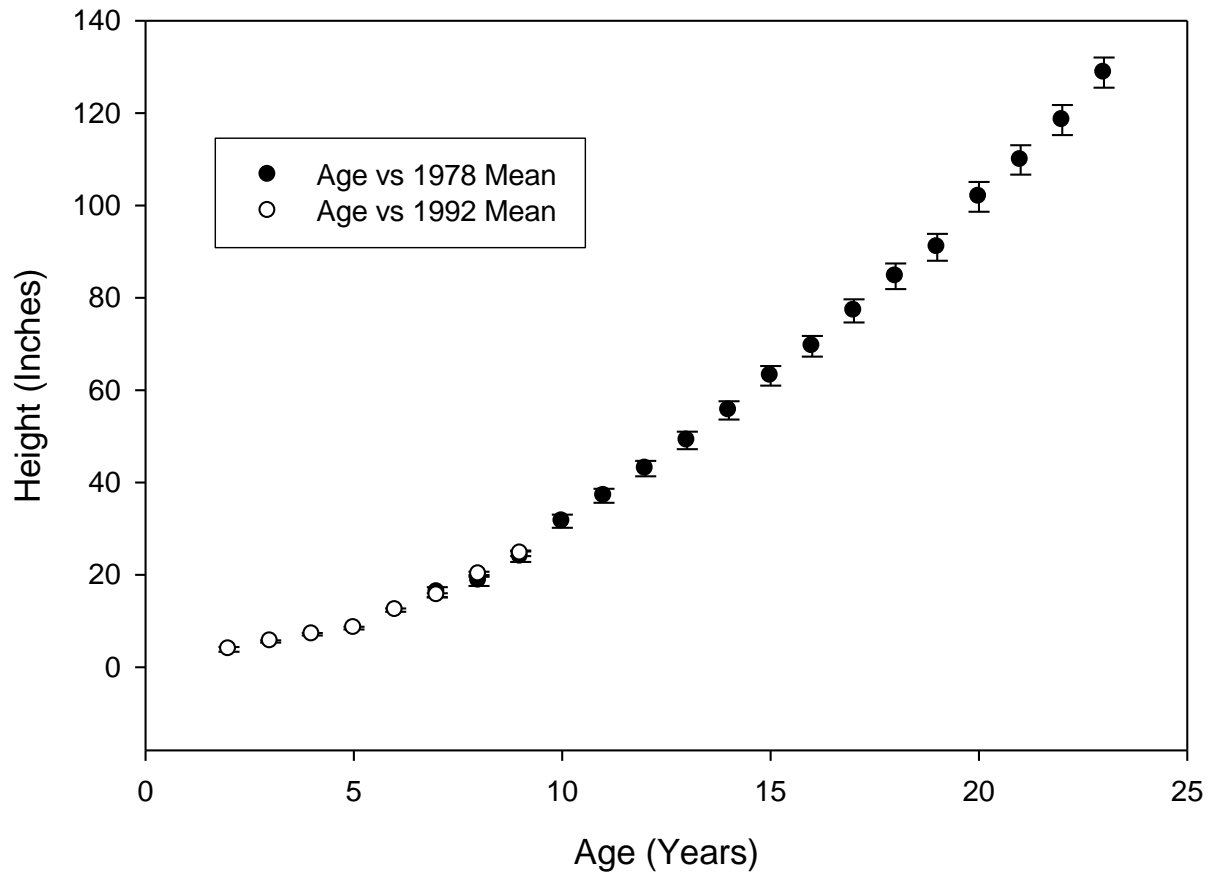


Figure 2. Plot of average annual height of ponderosa pine planted in 1978 and 1992 at the Molycorp Inc., Questa Mine and the average annual height of seedlings planted in the Carson National Forest from nine plantings planted from 1983 through 1992. Bars indicate +/- one standard error of the mean.





Figure 3. Photograph of excavated ponderosa pine seedling planted into overburden at the Molycorp Inc., Questa Mine after six growing seasons.

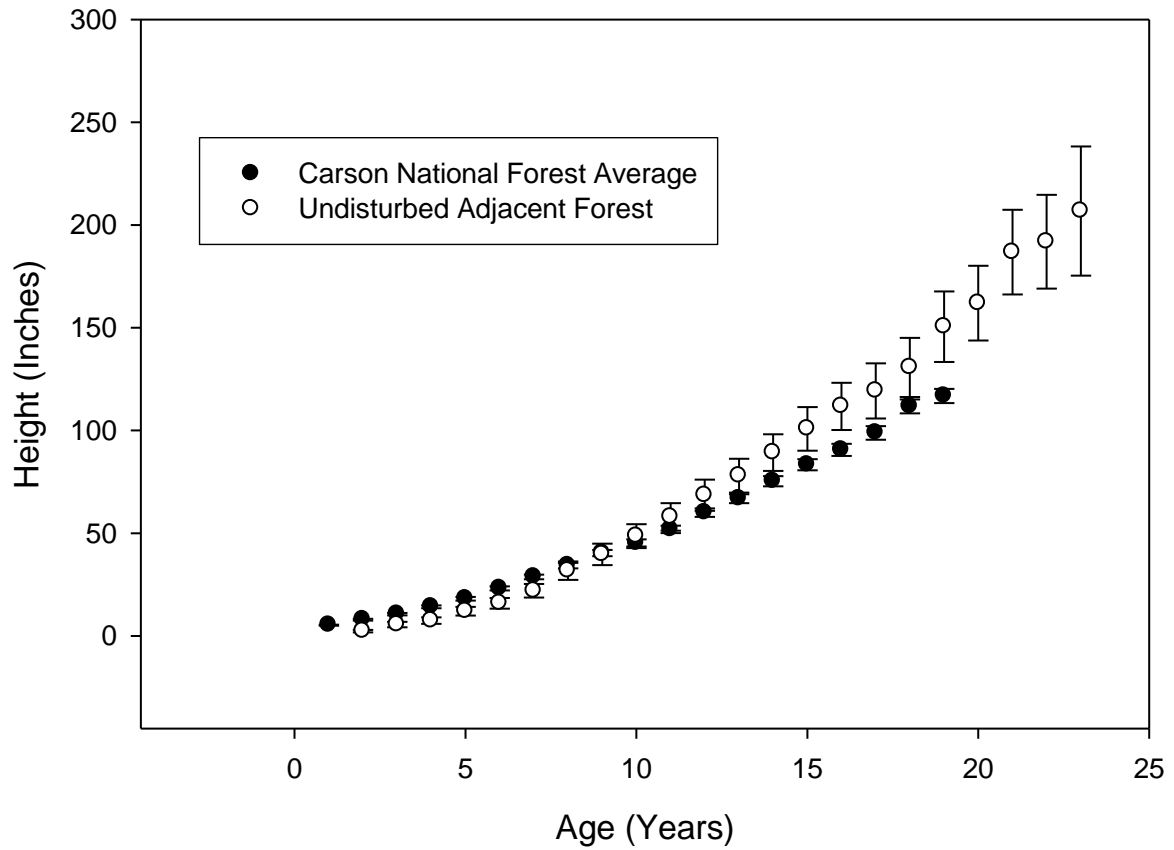


Figure 4. Plot of average annual height of naturally regenerated ponderosa pine growing in undisturbed forests adjacent to the MolyCorp Inc., Questa Mine and the average annual height of seedlings planted in the Carson National Forest from nine plantings planted from 1983 through 1992. Bars indicate +/- one standard error of the mean.

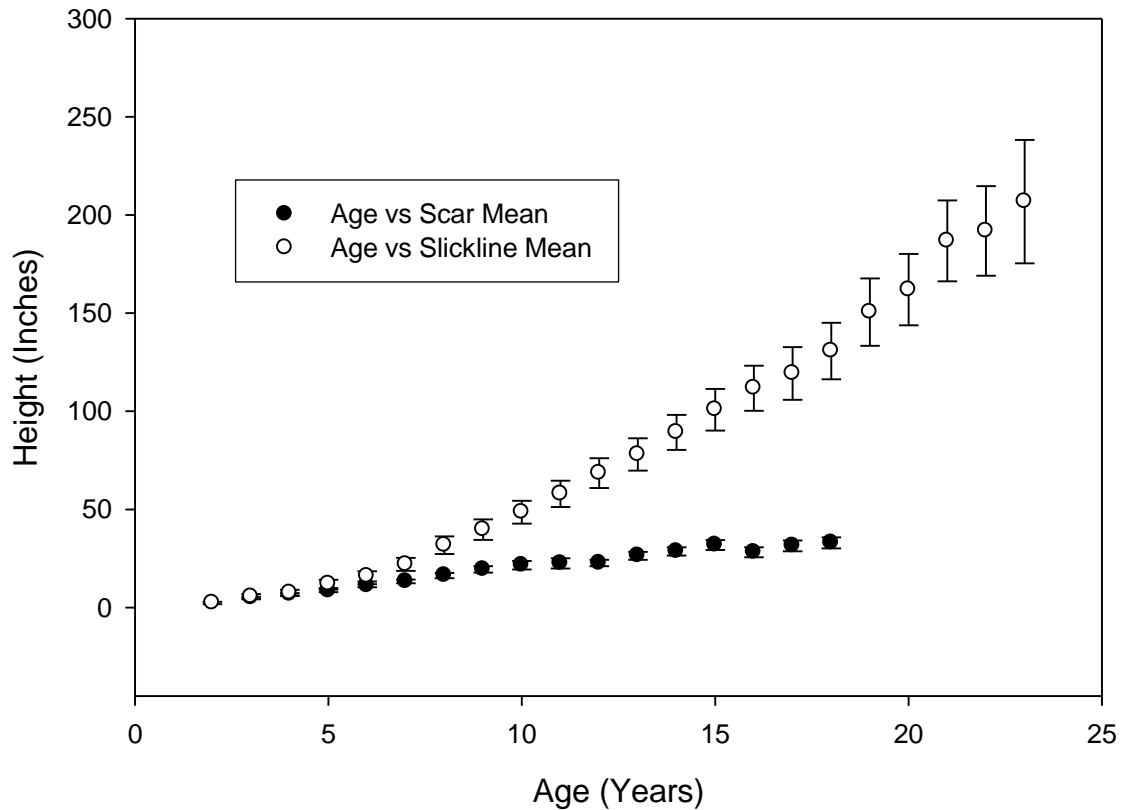


Figure 5. Plot of average annual height of naturally regenerated ponderosa pine growing in undisturbed forests and on alteration scars adjacent to the Molycorp Inc., Questa Mine. Bars indicate +/- one standard error of the mean.

The forests on undisturbed areas at the Molycorp Inc., Questa Mine have overall low productivity with an average site index for ponderosa pine of 33.5 feet at a base age of 100 years (Buchanan Consultants unpublished data). When plotted, the growth rates were variable (Fig. 6) for the 25 sample trees used to determine the average site index along with the younger, naturally regenerated trees growing on non-alteration scar material. It appeared the early growth of the young ponderosa pine was much faster than calculated by the  $SI = 33.5$  curve calculated using Minors formula (1964). However, when plotted using the ponderosa pine growing on the highest measured site index site of the nine Carson National Forest plantings, the Vallecitos planting ( $SI=80.3$ ) and the naturally regenerated ponderosa pine growing in the undisturbed forests adjacent to the mine had comparable growth rates (Fig. 7). Using only the ponderosa pine in the 20-29 year age category on undisturbed forests adjacent to the mine and Minor's site index formula, the average site index was 78.3 feet. This large difference in site productivity estimations illustrates the challenge of using relatively young (less than 30 year) trees to

determine site index with an index age of 100. The lack of fit of the calculated site index curve and the observed growth of ponderosa pine at this site is particularly evident at younger ages (Fig. 6). The data for the younger trees was more variable (Fig. 6) and the younger material grew at a rate analogous to the most productive planting measured on the Carson National Forest as part of this study (Fig. 7). However, it must be noted that in Minor's development of site index curves for ponderosa pine, the lowest site index determined was  $SI = 40$ . Observed data from the forest on the undisturbed mine property was less productive than  $SI = 40$  (Fig. 6).

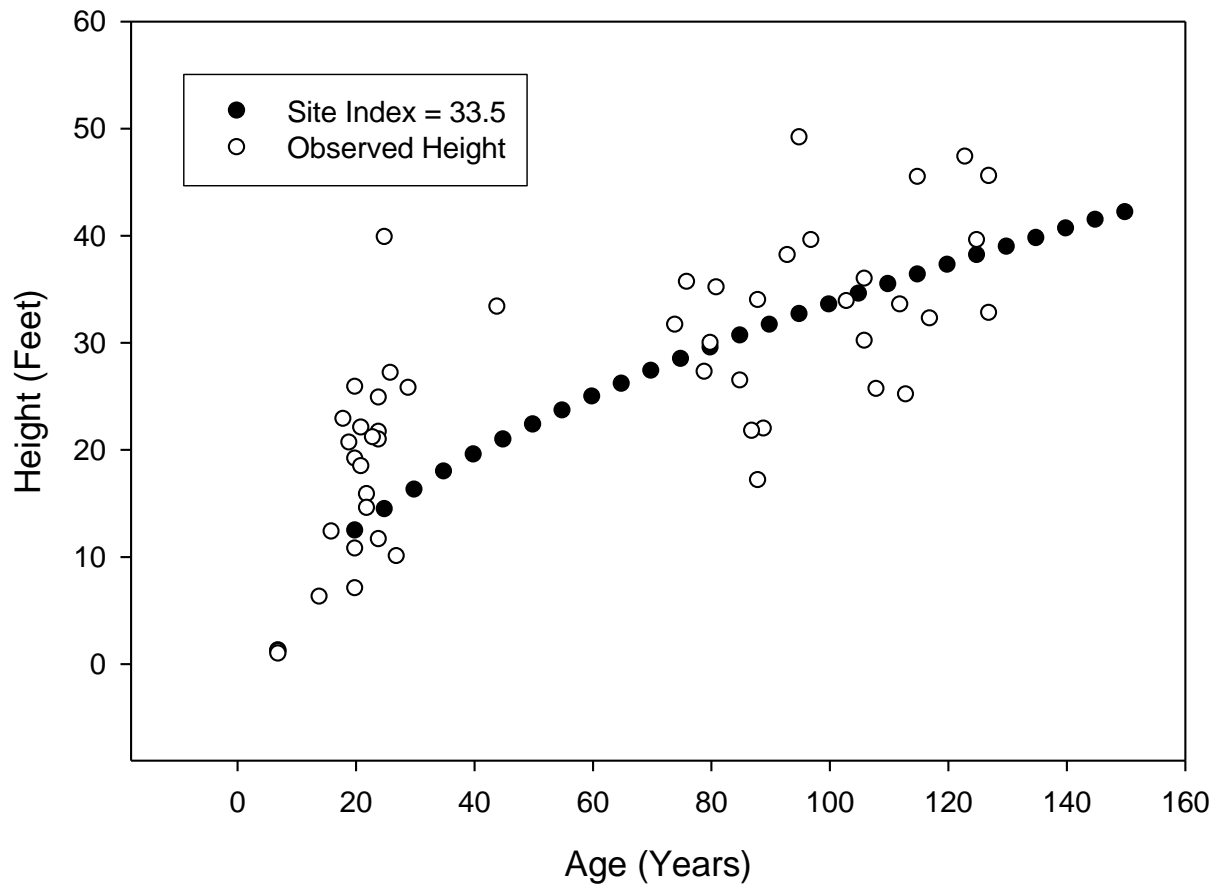


Figure 6. Height by age plot of ponderosa pine growing in an undisturbed forest adjacent to the MolyCorp Inc., Questa Mine. Plotted line illustrates the site index curve generated using Minor's formula for ponderosa pine site index (Site Index = 33.5 feet).

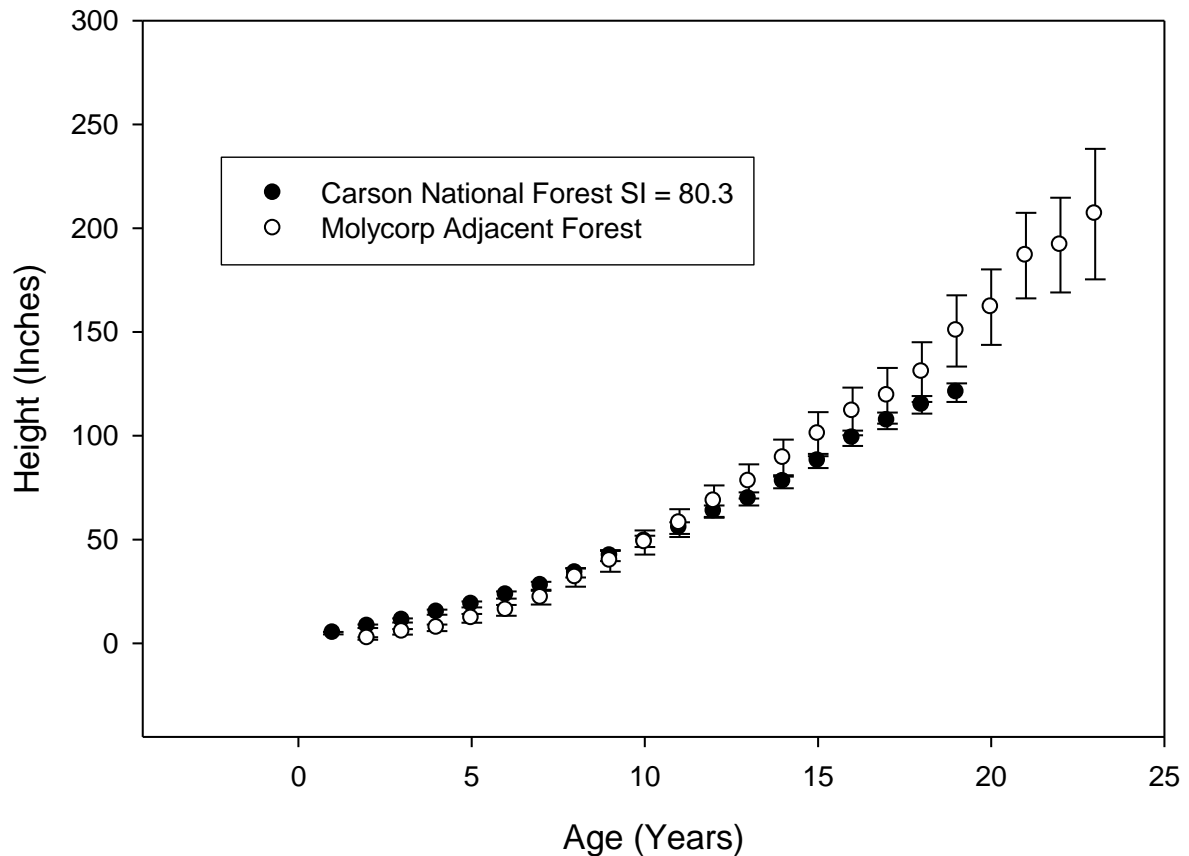


Figure 7. Plot of average annual height of naturally regenerated ponderosa pine growing in undisturbed forests adjacent to the Molycorp Inc., Questa Mine and the average annual height of seedlings planted in 1982 at the Vallecitos planting site (Site Index = 80.3 feet) in the Carson National Forest. Bars indicate +/- one standard error of the mean.

The poor relationship of early observed height growth and overall site productivity as measured by site index of trees closer to the index age was also evident in the nine Carson National Forest plantings. Through year three, height growth was not distinguishable among the nine plantings (Fig. 8). By the end of the fourth growing season height growth among the sites began to segregate. However, the best performing trees, as measured by cumulative height, from years four through nine, were growing on a site with the second lowest measured site productivity, Tecolote 2 (SI = 54.5; Fig. 8). As plant age approached 19 years, segregation of planted ponderosa pine height growth appeared more indicative of measured site productivity, with ponderosa pine growing on sites with higher site indices attaining greater height (Fig. 8).

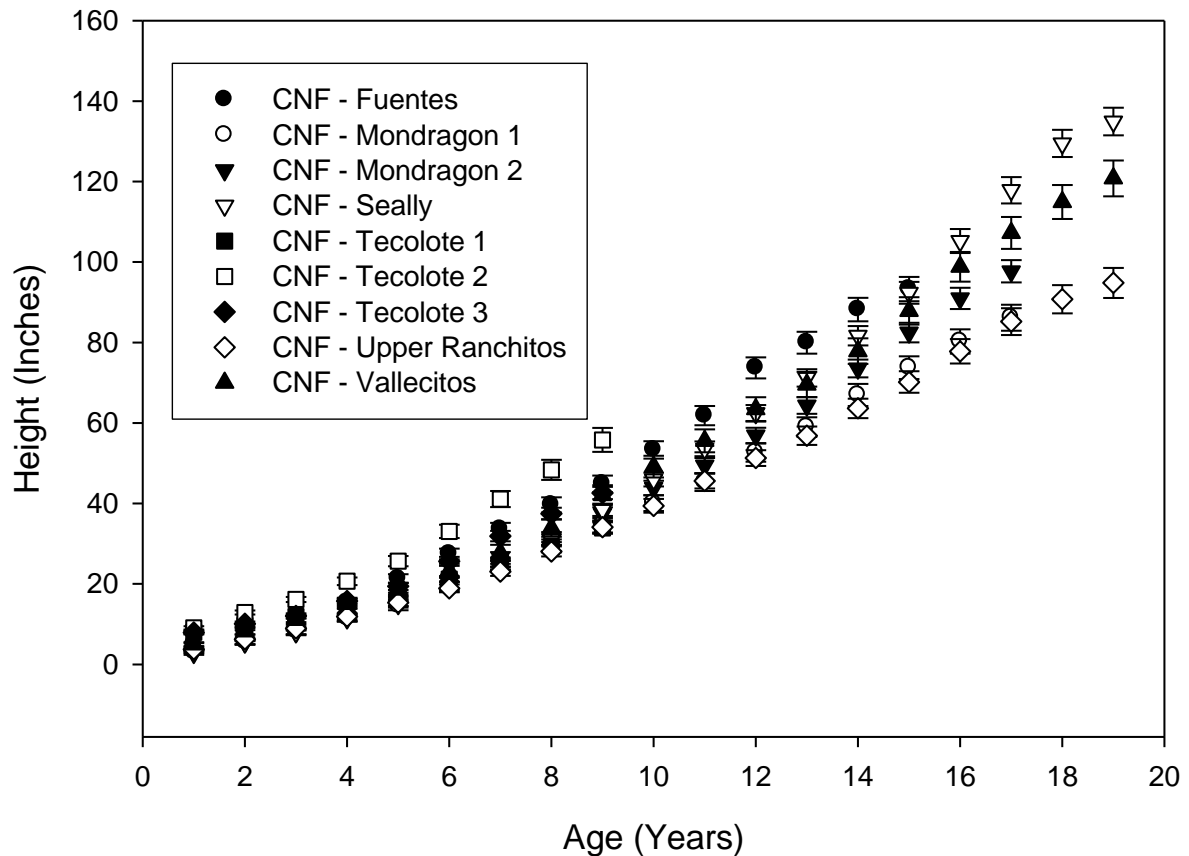


Figure 8. Plot of the average annual height of ponderosa pine seedlings planted at nine planting sites throughout the Carson National Forest from 1982 through 1992. Bars indicate +/- one standard error of the mean.

The data from the undisturbed forest growing on the mine property and from the nine plantings on the Carson National Forest illustrate the limitations of using young trees, less than one-third of the index age, in conjunction with traditionally developed site index formula such as Minor's site index formula for ponderosa pine. In terms of developing a commercial forestry productivity standard in mined land reclamation, use of site index measure with long, 100 year, index ages appears to be of limited value. A growth intercept method for determining site productivity such as the one published by Beck (1971) for eastern white pine may also be of limited application in the southwest as evidenced by the poor relationship of early growth of transplanted seedlings and site productivity as measured by site index. As trees became older the height increments did begin to sort themselves out closer to measured site index, but still overestimated site productivity when compared to site index determinations using trees closer to the index age. The improved accuracy of the intercept method in determining site productivity

when using older, closer to index age, material has been documented elsewhere (Alban 1972).

A further limitation to the intercept method in the southwest is the method's sensitivity to climatic fluctuations (Daniel et al 1979). Precipitation amount and annual distribution can have a large impact on forest growth and development in the southwest. Precipitation in the southwest can fluctuate considerably both annually and at multi-year intervals (Scurlock 1998). Therefore, depending on when the growth intercept method is applied there is the potential for the interval to be taken during a prolonged "wet period" (for example the period from the later 1970's through the early 1990's) or possibly during a prolonged "dry period" (for example the mid-1990's through the turn of the century). Shorter precipitation extremes (for examples the severe drought of 1956-57) can influence up to three years of height increment on fixed growth species such as ponderosa pine depending upon the timing of the drought relative to bud set and bud elongation periods.

A possible alternative to either traditional site index measures or the conventional application of the growth intercept method may reside in the use of comparison or check plantings. Such plantings would require the use of the same stock types planted in roughly the same geographic (climatic) region as the test plantings. The test and comparison plantings would not necessarily need to be the same age. Rather, the comparison would need to be performed when the two stands are at similar stages of development. This still may require a prolonged period of time depending on the duration of the establishment period.

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