Forty Years Later at Taylor Woods: Merging the Old and New

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Abstract—*The Taylor Woods "Levels-of-Growing-Stock" study was established in 1962 to create a replicated ponderosa pine density experiment for the Southwest, making a valuable addition to research in the Fort Valley Experimental Forest. Basal area treatments ranged from 5-20 m^2/ha (19-80 ft^2/ac) when installed, designed as growing stock levels 30/40, 60, 80, 100, 120 and 150. Residual trees averaged only 12 cm DBH despite being 42 years old. These 0.3- to 0.5-ha (0.75- to 1.24-ac) plots, with three of each growing stock level, were revisited for maintenance on a decadal basis including a recent entry in 2002/3 (the fifth). Once trees averaged 25 cm (10 in), which varied among treatments, plots were maintained at their target basal area per the intent of growing stock studies; all plots were at or above that point in 2002 with the largest trees >50 cm (20 in). Results have shown clear and predictable patterns for height and diameter growth for southwestern ponderosa pine, not different than other parts of the species' range or other species. Lower density plots have shown consistently larger diameters and faster diameter and height growth on an individual tree basis. Stand-level basal area growth is higher at higher densities based on the higher number of trees per plot (and per ha). The density at which stands can achieve maximum basal area growth has varied progressively over the four decades. But beyond such traditional interpretations of density effects on tree and stand growth, the long-term patterns shown at Taylor Woods now provides valuable insights into tree vigor and insect resistance, understory development, fire behavior, ecological restoration and potential implications of regional land management choices in light of climate change.*

Introduction

Stand density is a major regulator of tree growth and, as such, has been closely studied for many decades and for many commercial species. Systematic "level of growing stock" (LOGS) studies were initiated for ponderosa pine (*Pinus ponderosa*) as well as other species in the mid-1900s to generate consistent scientific data on this effect across regions, site qualities and stand conditions (Myers 1967, Oliver and Edminster 1988, Ronco *et al*. 1985). These LOGS studies have quantified and illuminated the subtleties of early-century observations of stocking differences and thinning responses (e.g., Gaines and Kotok 1954).

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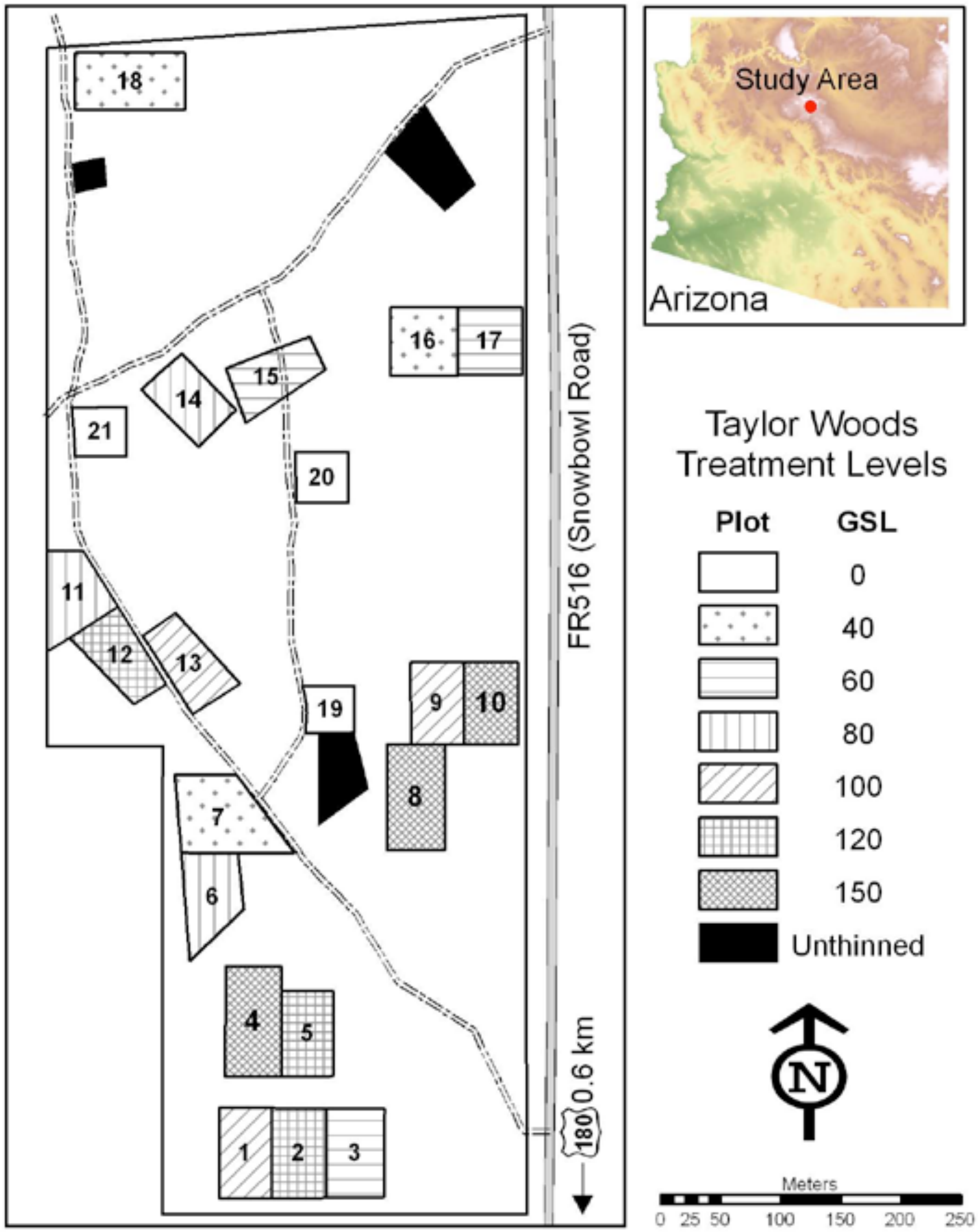

Figure 1. Taylor Woods Levels of Growing Stock (LOGS) study site, showing 3 replicate plots each of 7 stand density treatment levels, 3 unthinned areas, and their respective arrangement. Individual plots are approximately one acre. Growing Stock Level (GSL) is defined as "basal area (ft^2/ac) when the trees are, on average, 10 inches in diameter at breast height" and actual stand basal area when trees are > 10 inches, which was the case at the last measurement in 2002. Adapted from Schubert (1971).

Taylor Woods (Figure 1), located in the Fort Valley Experimental Forest, was established in 1962 as part of the ponderosa pine LOGS study site network. The original stand consisted of scattered large, sawtimber-sized trees (>50 cm DBH) with abundant slow-growing, pole-sized material in a mid-story originating from a major 1919 regeneration event (Pearson 1950). Detailed site descriptions, study implementation and early growth patterns were documented by Schubert (1971) and Ronco et al. (1985). To summarize here, three replicated plots for each of six growing stock levels were thinned heavily in 1962 to establish the range of basal area treatments, and lightly re-thinned to adjust stocking each decade thereafter. Ronco et al. (1985) reported that, except for tree height, all other size and growth metrics (i.e., stem diameter, crown length, and crown height) were negatively correlated with stand density; volume increments, including basal area growth, were positively correlated with stand density. These findings were consistent with ponderosa pine growth patterns for the region (Oliver and Edminster 1988) and LOGS studies in general (e.g., Curtis and Marshall 1986).

Measurements have continued at Taylor Woods every five years and density maintenance treatments every ten years since. This paper summarizes size and growth patterns through 2002, by which time the highest density plots had achieved a mean diameter of 25 cm (10 in) such that all growing stock designations can be converted to simple basal area. The objective of this research was to sustain this important long-term study, update the data with 20 more years of information, and extend the interpretation of these data into broader land management questions.

Methods

The Taylor Woods LOGS site is situated along Snowbowl Road in the southeastern section of the Fort Valley Experimental Forest (Figure 1). Slopes are gentle at <4%, climate is identical to the nearby Headquarters facility (Ronco *et al.* 1985), and site index for ponderosa pine is 73 (based on a base age of 100), primarily regulated by cool temperatures in this area. Soils are productive for the region, classified as a relatively deep, well-drained Typic Argiboroll over fractured bedrock. Ponderosa pine is dominant with scattered patches of New Mexico locust (*Robinia neomexicana*) in an understory dominated by Arizona fescue (*Festuca arizonica*). Initial stand conditions, plot layout, and volume removals are available in Schubert (1971) and Ronco et al. (1985) for each of the three replicates over the six treatment levels installed.

Standard mensurational techniques were used to measure diameter at breast height (by diameter tape to the nearest 0.25 cm) for all trees in each plot since last published for 1982. Heights (hand-held clinometers to the nearest 0.3 m) were measured on a subsample of trees identified for the 1998 re-measurement, comprised of ten trees in each 2.5-cm diameter class (<10% of trees in high density plots, but >60% of the trees in lower density plots). Individual trees were identified by permanent metal tags; all plots also had marked corners. Percent understory vegetative cover was estimated visually to within 10% using a 0.5x2m sampling frame as a guide to broadly classify the range of surface vegetation abundance.

The strength of this study is certainly in the long-term nature of the data and the contribution of recent re-measurements, but that value was enhanced with ANOVA analysis of 2002 conditions using a mixed model for year and treatment effect (SAS). Several regressions on growth trends are also presented within this paper. A complete presentation of this extensive data set, including crown characteristics and volume growth trends, is available from the Rocky Mountain Research Station and in an upcoming Research Paper.

Results and Discussion

Mean height growth (m/decade) varied among GSLs (*p<0.001*), and did not vary among measurement cycles from 1962 to 2002 (Figure 2); dominant tree height and height growth, however, did not vary among GSLs. This first trend for mean height is consistent with higher density plots of ponderosa pine containing some smaller trees and, thus, lowering mean height and mean height growth (Myers 1958). The lack of trend with dominant tree height reflects a relatively uniform site quality at Taylor Woods, measured as height growth over time, with a greater effect of small microsite conditions on height growth than a large range of density treatments. Both patterns are consistent with basic silvicultural texts (e.g., Tappeiner *et al*. 2007) and with Ronco et al. (1985) for this site.

Diameter/radial growth showed a steeper slope across GSLs (Figure 3; *p<0.001*), also a standard pattern for density studies (Oliver and Edminster 1988) and recorded immediately at Taylor Woods by Schubert (1971). Diameter growth varied significantly, however, among decades (*p<0.001*) as well, and showed an interaction between GSLs and years (*p<0.001*). This effect is attributable to a general slowing of diameter growth in lower density plots in the last decade, shown consistently in all replicates relative to the decade ending in 1992. Some decrease in radial/diameter

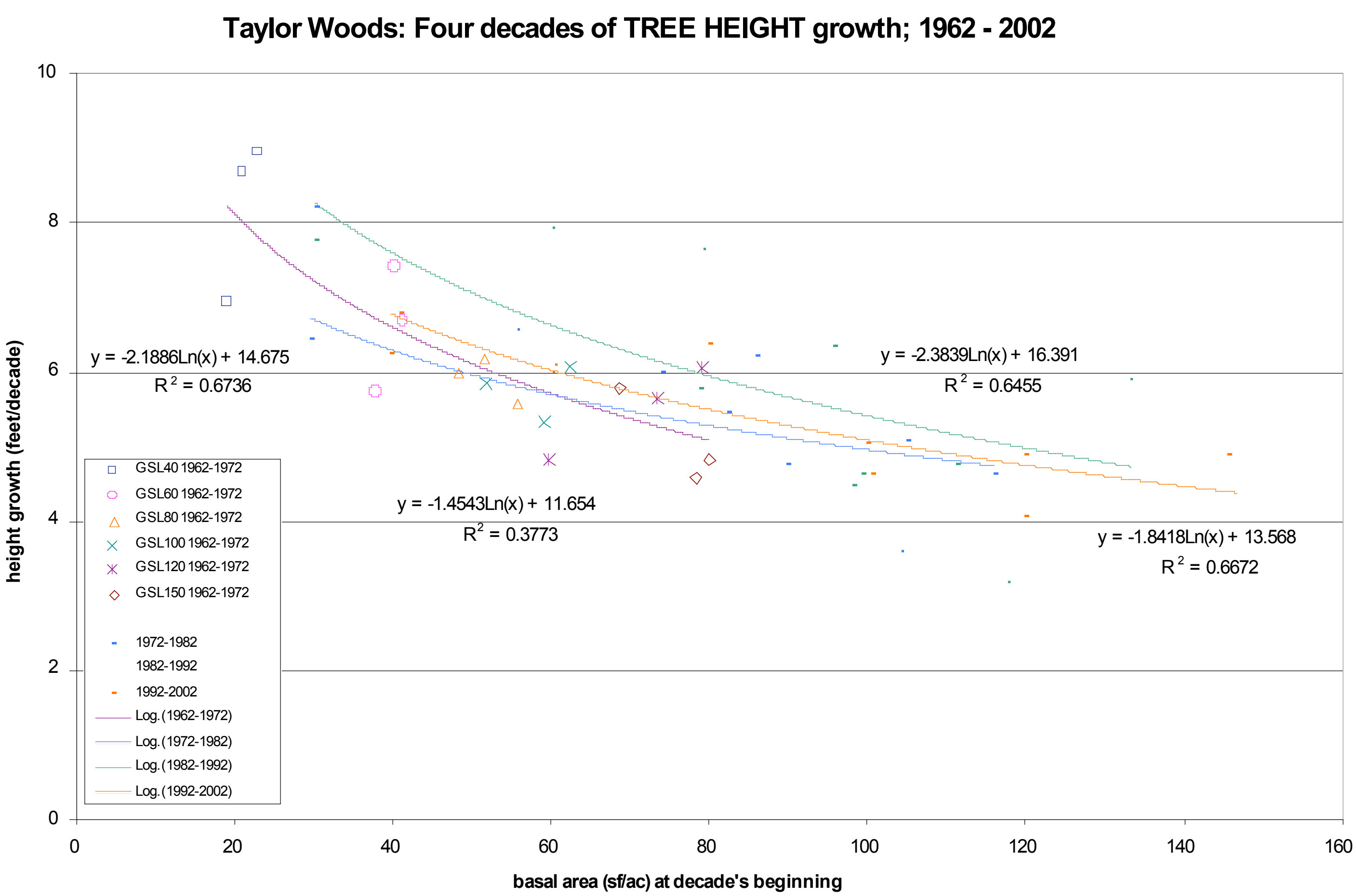

Figure 2. Mean height growth of ponderosa pine trees at Taylor Woods, northern Arizona, across six basal area treatments and four measurement decades: 1962-72, 1972-82, 1982-92, and 1992-2002, shown as separate regression lines.

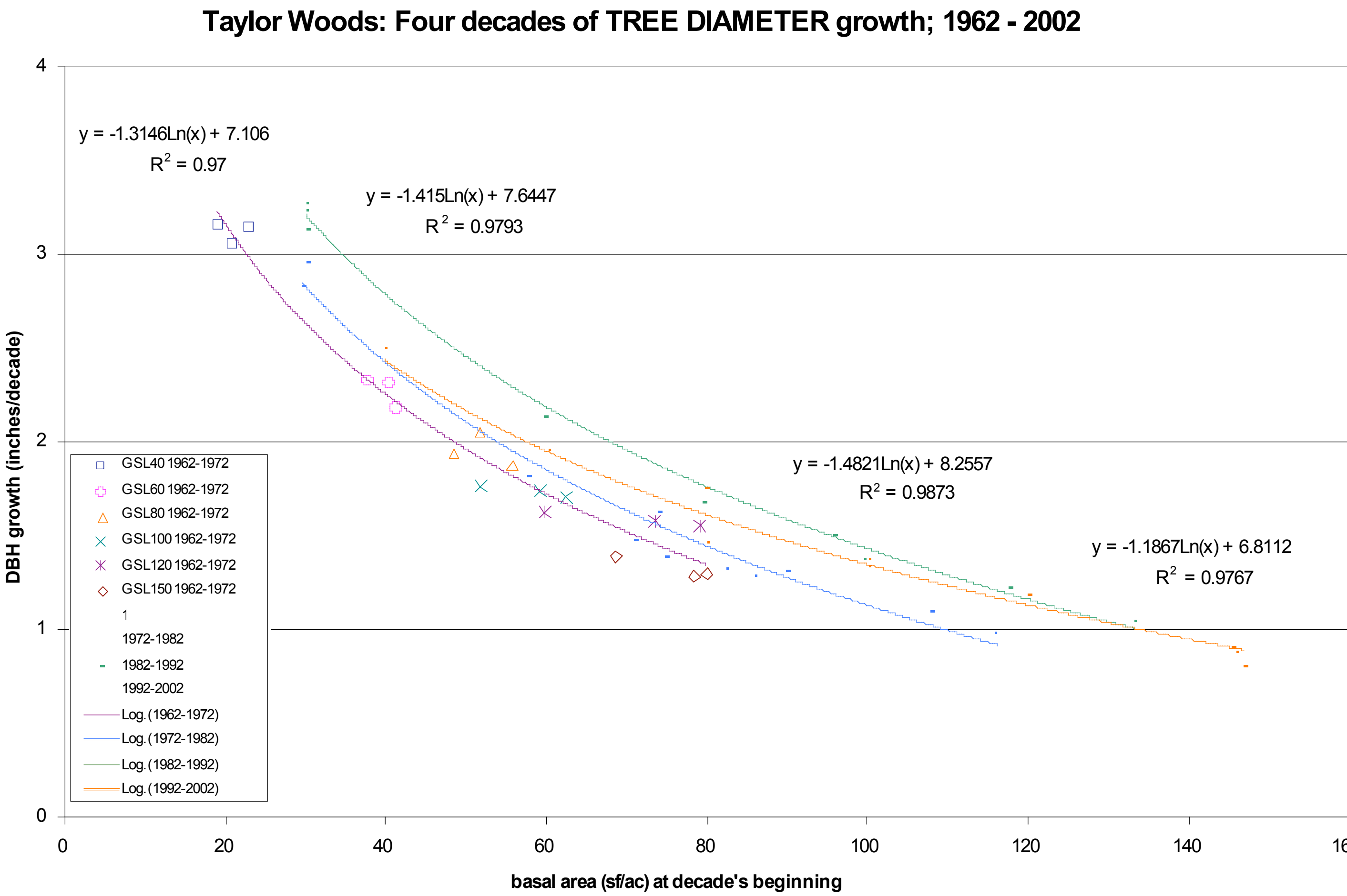

Figure 3. Mean diameter (breast height) growth of ponderosa pine trees at Taylor Woods, northern Arizona, across six basal area treatments and four measurement decades: 1962-72, 1972-82, 1982-92, and 1992-2002, shown as separate regression lines.

growth with increasing size is a normal growth pattern for ponderosa pine across the west (Alexander and Edminster 1980), and trees in the lowest basal area treatment are nearly twice the diameter of those in the highest basal area treatment. Basal area growth per tree was different among GSLs ($p<0.001$) and a consistent shape (slope and intercept not different) among the four decades. This was consistent with a progressive drop in diameter growth (Figure 3) and may reflect the unusually dry climatic conditions beginning in 1996.

Stand-level basal area growth (m^2/ha/decade) varied significantly among GSLs ($p<0.001$), but the shape of that relationship (slopes and intercepts of decadal lines) were not different (Figure 4), indicating no change in this relationship over time. Within the lower range of basal area (10-20 m^2/ha), however, decade is a significant effect ($p<0.001$) except within 1972-1992. The visual progression of curves in Figure 4 demonstrates the natural progression of basal area growth with increasing tree size. The consistency of its shape is remarkable and indicative for the close regulation of spacing in this study (Ronco et al. 1985). This basal area growth trend is standard among density studies and first recorded for Taylor Woods by Schubert (1971). The larger gap between the decades ending 1992 and 2002 may further indicate the dry climatic cycle noted above for diameter growth rates, but such a trend is speculative until the next measurement cycle.

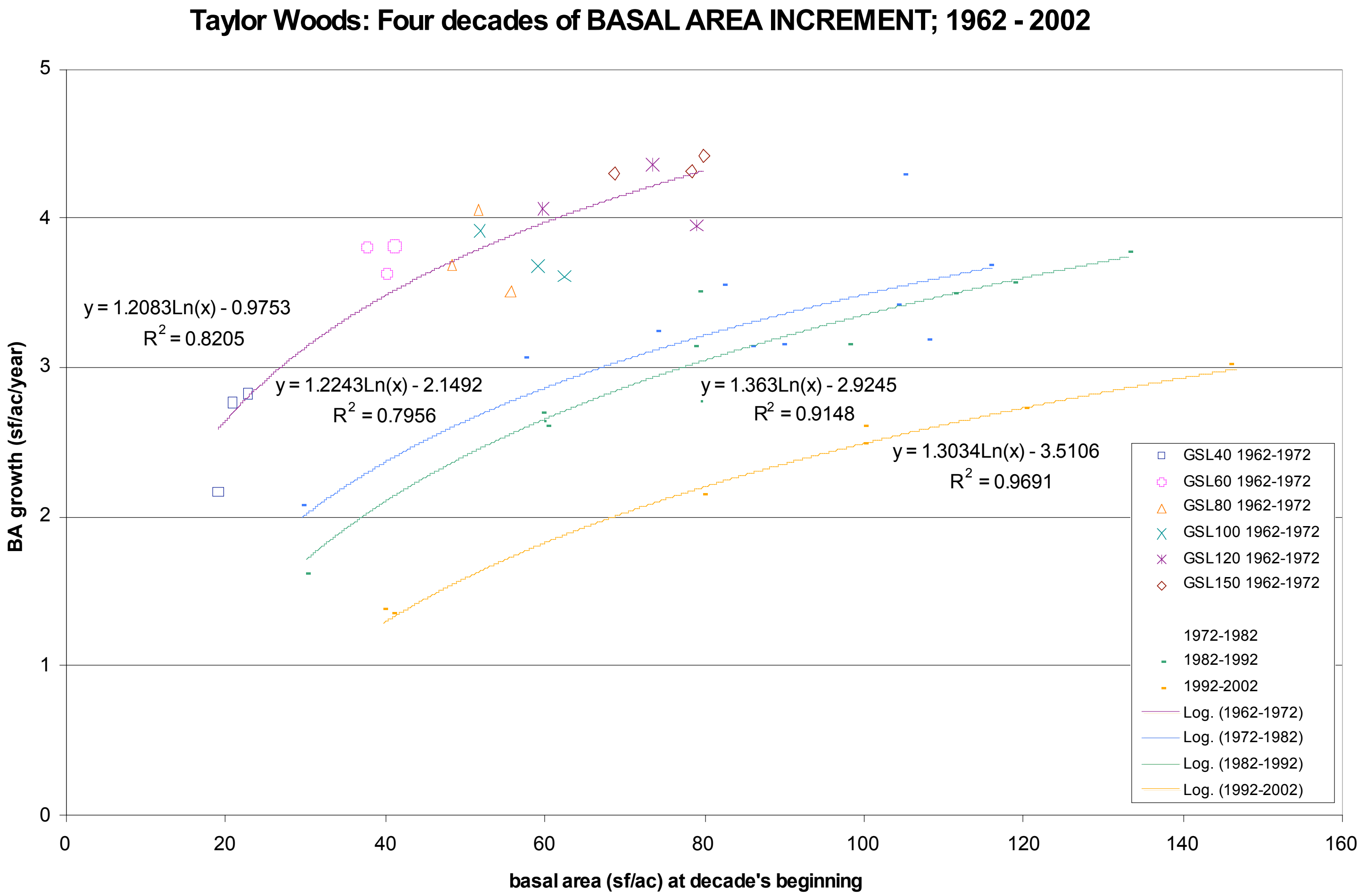

Figure 4. Mean basal area growth per unit land area of ponderosa pine trees at Taylor Woods, northern Arizona, across six basal area treatments and four measurement decades: 1962-72, 1972-82, 1982-92, and 1992-2002, shown as separate regression lines.

The Future

The value of this long-term study, with continued and careful maintenance of density treatments, re-measurement, and replicated plots (though <0.5 ha), has gone well beyond the height and diameter growth trends presented here or the detailed volume projections in Ronco et al. (1985) and a pending updated Research Paper for which it was originally designed. Tree and stand responses seen at Taylor Woods relate to stand responses following low-density harvest treatments intended to restore presettlement structure in southwestern ponderosa pine (Moore et al. 2004). The two lowest density treatments represent mid- and upper-range presettlement density, so individual tree growth and architecture patterns can be analyzed and compared to older presettlement trees still surviving in the landscape. Similarly, understory plant community responses can be compared and projected from the five-fold increase (5 to 25% cover) in mean understory cover from the highest to lowest basal area treatments. Living understory plant cover is negligible (<10%) with any more than 10 m^2/ha of evenly-distributed ponderosa pine overstory. Clumping residual trees and basal area, as with restoration treatments and group selection silviculture, may raise this threshold and, at a minimum, promote spatially diverse understory conditions where that is a land management objective. And this understory development, combined with overstory inputs, allows fuel accumulation dynamics to be constructed for comparison.

Taylor Woods has also become a template for several basic studies of ponderosa pine ecology and physiology (e.g., Kolb et al. 1998, McDowell et al. 2006) related to water use efficiency, drought tolerance and insect resistance in southwestern ponderosa pine. Continued interest in the effects of climatic fluctuations and long-term drift can be further explored across these treatments. Having an experimental framework to examine the role of density is fundamental to advance the science in all these areas. As a long-term and uninterrupted data set, Taylor Woods will provide further insight in understory development, fuels accumulation, fire behavior, and stand structure responses to climatic variability. In fact, few sites will be able to provide such insights as we move into the next century.

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