FINAL REPORT

Repeated Prescribed Fires and Mechanical Fuel Treatments May Promote Multiple Management Objectives in the Southern Appalachian Mountains

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ABSTRACT

Fire managers of the southern Appalachian Mountains have many questions of how to use prescribed fire and mechanical treatments to meet numerous objectives. Common objectives include restoration to an open woodland, oak regeneration, and fuel reduction. The southern Appalachian site of the National Fire and Fire Surrogate study has been burned 3 times and a mechanical treatment has been conducted twice since 2002. This paper provides information about reaching each of these management objectives by using prescribed burning (B), mechanical fuel reduction (M), and a combination of both fire and mechanical treatment (MB). Stand structure was changed by each active treatment but restoration goals were not achieved by any. MB treatment units had the desired structure but heavy sprouting of woody species prevented the establishment of a diverse herbaceous forest floor. Oak reproduction was increased in number by all active treatments, largely by sprouting of top-killed stems. Fuel reduction differed by treatment. All reduced the shrub layer, thus reducing the vertical fuel component. B and MB treatments reduced most fuels and likely reduced the severity of a subsequent wildfire. Additional burning is required to meet each management objective. Fires should be conducted more frequently, in a different season, and/or in combination with other treatments.

BACKGROUND AND PURPOSE

Forests of the southern Appalachian Mountains are among the most biologically significant and complex in the United States, making them among the most difficult to manage. The Appalachian Plateau, Ridge and Valley Province, and the Blue Ridge Mountains cover over 32 million hectares, including portions of NC, SC, TN, GA, AL, VA, and KY. The region has high ecosystem diversity because of its wide variety of land types, soils, precipitation levels, and disturbance histories. Some areas have the fastest growing wildland-urban interfaces in the country. Forest ecosystems are changing and losing key ecological functions because of fire exclusion. Appalachian hardwood ecosystems were developed by a broad array of natural disturbances, but the role played by natural and anthropogenic fire has not been appreciated until recent years (Brose et al. 2001, Waldrop et al. 2007). In some areas, prescribed burning is not possible, such as along the wildland/urban interface. Mechanical treatments may prove to be an acceptable surrogate for fire, but little information is available.

Managers of the southern Appalachian Mountain region have only recently begun to establish guidelines for prescribed burning and mechanical fuel reduction. Much remains to be learned about treatment impacts across a landscape that is so complex as to have extremely dry sites and extremely wet sites at the same time. A survey of managers in 2014-2015 indicated that priority knowledge gaps included the number of treatments needed to reach restoration goals, impacts on threatened, endangered, and sensitive wildlife, impacts on oak reproduction, impacts of burning at different seasons, and how well treatments reduce fuels (S. Rodriguez , Clemson University, Clemson, SC, USA, unpublished report). Although these are fundamental questions, they remain unanswered for the southern Appalachians because of the relatively new use of prescribed fire and mechanical fuel reduction in the region (Van Lear and Waldrop 1989).

Topography and associated moisture regimes are the primary factors in predicting treatment impacts in the Appalachian Mountains. Reilly et al. (2006) found that one wildfire increased herbaceous species richness at intermediate scales (>100m^2), but increases in tree species richness were limited to small scales (<10m^2) due to lack of immigration. This finding held true after a second fire in a study of prescribed burning (Waldrop et al. 2007b). Vegetation changes after prescribed burning can be minor and short lived (Arthur et al. 1998, Elliott et al. 1999, Kuddes-Fisher and Arthur 2002). The major changes deal with the loss of overstory trees and changes in ecosystem structure. Tree mortality may take as many as 5 years to observe and it can range from a few trees to all depending on initial tree condition (Yaussy and Waldrop 2010). Where most trees die, plant species richness and diversity do not change in the long term as most woody species sprout and eventually dominate the overstory. Most long-term ecosystem changes are those associated with bird habitat, insect abundance, and predicted wildfire intensity (Waldrop et al. 2014).

In 2000, a team of Federal, State, university, and private scientists and land managers designed the Fire and Fire Surrogate (FFS) study, an integrated national network to address the need for many types of information. The national network included 12 sites on Federal and State lands extending from Washington to Florida. At each site, impacts of fuel reduction treatments were studied on a broad array of variables, including flora, fauna, fuels, soils, forest health, and economics (see Youngblood et al. 2005 for a description of the national study). Treatments were designed to restore ecosystems by re-establishing an ecosystem process (fire), stand structure (mechanical fuel reduction), or both. Changes in stand structure can alter ecosystem components such as vegetative diversity (Hutchinson 2006), fire behavior and return interval (Phillips et al. 2006, Waldrop et al. 2010), and soil processes (Boerner et al. 2008). McIver et al. (2012a, 2012b) summarized the national study by stating that treatments significantly modified stand structure and fuels making post-treatment stands much more resistant to moderate wildfire. However, for the great majority of ecosystem components, short-term response to treatments were subtle and over time, ecosystem effects dampened and fire risk increased.

Most FFS sites were abandoned after reporting impacts that occurred within 1 year after treatment. However, managers at the FFS site in the southern Appalachian Mountains have been able to continue the prescribed burning and mechanical treatments for over 13 years. The primary management objective is to reduce wildfire severity by reducing live and dead fuels. Secondary objectives are to increase oak reproduction and to improve wildlife habitat by increasing cover of grasses and forbs. It may be possible to obtain each of these goals by restoring this community to the open woodland habitat once common in these regions (described in syntheses by Stanturf et al. 2002 and Van Lear and Waldrop 1989).

The numerous variables measured in the first years of the Appalachian FFS study strongly indicated that repeated entries of fire and/or mechanical treatments were necessary to reach management objectives. This paper examines each fuel-reduction treatment for three of the top knowledge gaps identified by managers (S. Rodriguez, unpublished report): restoration to an open woodland community, oak regeneration, and fuel reduction. Changes to vegetation, stand structure, and fuels over time were examined for each active treatment as they occurred over three prescribed burns and two mechanical fuel-reduction treatments.

STUDY DESCRIPTION AND LOCATION

The Southern Appalachian Mountains site of the FFS study is located in Polk County, North Carolina, on the Green River Game Land, which is managed for wildlife habitat, timber, and other resources by the North Carolina Wildlife Resources Commission. Elevations range from 366 to 793 m. Forests of the study area are 80 to 120 years old, and show no indication of past agriculture or recent fire. Forest composition is mixed-oak with pitch pine and Table Mountain pine on xeric ridges and eastern white pine in moist coves. A dense layer of ericaceous shrubs—mountain laurel, rhododendron, flame azalea, and blueberry—is found throughout. Soils are primarily Evard series (file loamy, oxidic, mesic Typic Hapludults). These are moderately deep, well-drained, mountain upland soils (Keenan 1998).

The experiment was designed as a randomized complete block with three replicate blocks composed of four factorial treatment units. Individual treatment units were 10 to 12 ha in size. All treatment units were surrounded by buffer zones of approximately 4 to 10 ha; both the treatment unit and its corresponding buffer received the experimental treatment. Treatment units were designed to include all prevailing combinations of elevation, aspect, and slope. However, these conditions varied within experimental units (treatment units) and could not be separated for analysis. A 50 by 50-m grid was established in each treatment unit to measure fuels. Grid points were permanently marked and geo-referenced. Ten sample plots of 0.10 ha were established at randomly selected grid points within each treatment unit to measure vegetation.

Treatments were selected to alter stand structure in a manner to reduce fuels, improve density of oak reproduction, and improve habitat for some wildlife species by producing open woodlands. Our definition of woodlands was given by Kabrick et al. (2014) who described them as "natural communities characterized by open to nearly closed canopies of overstory trees, relatively sparse midstory and understory, and dense, species-rich ground flora. In contrast to forests, many of the dominant and codominant trees in the canopy of woodlands have large, spreading crowns (Nelson 2005, Nuzzo 1986, Taft 2009). Shrubs, saplings, and small trees may be present but generally are much less abundant than in a mature forest (Nelson 2005). The relatively open canopy and midstory of woodlands allows sunlight to reach the ground to support a species-rich layer of light-demanding plants dominated by forbs, sedges, and grasses that may be present but seldom are abundant in closed-canopy forests (Kinkead et al. 2013)."

Factorial treatments were randomly allocated among treatment units within a site, and all treatment units were sampled through the pretreatment year (2001). Treatments consisted of prescribed burning (B), mechanical fuel reduction (M), a combination of mechanical treatment and prescribed burning (MB), and an untreated control (C). M involved creating a vertical fuel break by chainsaw-felling all tree stems >6 feet tall and <4 inches diameter at breast height (dbh) and all shrubs, regardless of size. This treatment was accomplished between December 2001 and February 2002. Prescribed fires were applied in B and MB units during March 2003 and again in March 2006. B and MB units were burned for the third time in March 2012. A second chainsaw felling of small trees and shrubs was completed in early 2012 (January to February) in M units only. A second mechanical treatment was not required in MB treatment units. The objectives of prescribed burning were to remove vertical fuels and create a few snags. All fires were burned

with a spot-fire technique; the first was done by helicopter ignition and the others were done by hand ignition.

Vegetation and fuels data were collected before treatment (2001) and at various years after treatment, depending on the date the treatment was completed. B plots were measured in 2003 (1 year after burning), 2005 (3 years after burning), 2006 (1 year after the second burn), 2011 (1 year before the third burn) and 2012, 2013, and 2014 (1, 2, and 3 years after the third burn). M plots were measured in 2002 (1 year after felling), 2004 (3 years after felling), 2006 (5 years after felling), 2011 (1 year before the second felling), and 2012, 2013, and 2014 (1, 2, and 3 years after the second felling). MB plots were measured in 2002 (1 year after felling), 2003 (1 year after burning), 2005 (3 years after burning), 2006 (1 year after the second burn), 2011 (1 year before the third burn), and 2012 2013, and 2014, (1, 2, and 3 years after the third burn). C plots were measured every year from 2001 through 2006 and annually from 2011 through 2014.

Vegetation data were collected on the 0.1 ha sample plots. Each plot was 50 m by 20 m in size and divided into 10 subplots, each 10 m by 10 m. All trees 10 cm dbh or larger were measured in five subplots at each sample date. For each tree, the tree number, species, dbh, and status (i.e., standing live or dead) were recorded. Shrubs >1 m tall were measured on five 10 m by 10 m subplots using ocular estimates of the percentage of area covered by the crowns of each shrub. Herbaceous cover was estimated for each species in 20 subplots, 1 m by 1 m in size, within each 0.1 ha plot.

Down dead-woody fuels were measured before and after treatment using the planar intercept method described by Brown (1974). Three 15.2-m transects were established approximately 2 m from each grid point in a randomly selected direction. This method produced a total of over 21,000 m of fuel transects. Litter depth and duff depth were measured at three locations along each fuel transect at 3.0 m, 7.6 m, and 12.2 m from the start.

Soils were collected and analyzed for several of the same variables as have been previously reported for this site. We collected pre-fire samples for analysis of soil organic matter, and for soil nitrogen (N) mineralization. Five samples were collected from each treatment unit in proximity to vegetation measurement plots, and these were averaged for a single datum per plot for statistical analysis for each soil variable. Nitrogen mineralization assays employed the closed-top core method of Knoepp and Swank (1998) prior to the fires in Winter 2011. Subsequent mineralization assays were performed on a quarterly basis for the first year following fires, and for the third year following fires (2012, and 2013). Ammonium and Nitrate concentrations were determined on 1.0 M KCl extractions of all incubated and initial soils on a Lachat continuous-flow autoanalyzer. Soil organic matter was determined using a micro-Dumas combustion technique (Perkin Elmer 2400 Series II CHN/SO analyzer). Soil pH was measured on a 1:1 soil:water slurry using a Fisher Scientific dual channel pH/ion/conductivity meter (McLean 1982).

One of the most dynamic pools of soil carbon is that contained in fine roots. Fine root biomass is known to be responsive to fire treatments in many ecosystems (e.g. in grasslands [Kitchen et al. 2009]), but to our knowledge, has not been evaluated for southern Appalachian ecosystems. Given the previously measured changes in vegetation on the southern Appalachian FFS site, we

hypothesized that changes in grass cover are likely to result in changes in the distribution, quality and quantity of fine roots over repeated treatments. Likewise, the decreases in duff depth with repeated fires were predicted to result in changes in distribution of root biomass towards more roots being found in mineral soil where they are protected from combustion in subsequent fire. This suggests that over time, as roots move from fire-susceptible locations in the duff to fire-protected locations in mineral soil, the overall effect on total soil organic matter will be positive (as observed in Australian savanna systems [Richards et al. 2011]). We took 10 whole profile soil cores to a depth of 30 cm (or bed rock) from each of the 12 treatment areas on a quarterly basis in order to estimate fine root biomass. Each of these cores was wet-sieved and all roots <2 mm were separated as live or dead, dried, and weighed for estimates of total fine root biomass and necromass (as in Kitchen et al. 2009). All roots were ground, and analyzed for C and N content using a micro-Dumas combustion technique (as above).

Analysis of treatment effects on vegetation and fuels will be conducted with methods similar to those done previously using repeated-measures analysis of variance, with treatment and year modeled as fixed effects and block as a random effect. To account for differences among years, we interpreted significant treatment and (or) treatment by year interactions ($\alpha = 0.05$), as evidence of treatment effects and made post hoc comparisons using linear contrasts. Because much of the data did not meet the assumption of normality, it was necessary to use data transformations to normalize the distributions. Logarithmic and square root transformations were used in these analyses.

KEY FINDINGS

Finding 1: The mechanical treatment (M) removed the shrub layer but did little else to reach restoration goals.

Chainsaw felling of small trees and shrubs had essentially no impact to the basal area and density of overstory trees (>10 cm dbh) at any time during the study. Basal area gradually increased from 27.3 m^2/ha prior to treatment to 30.3 m^2/ha after the 12th growing season after treatment as trees grew in diameter (Table 1). There were no significant differences in basal area between M treatment units and C units at any time. Overstory stem density decreased over time in M units from 642 stems per ha prior to treatment to 516 stems per ha after the 12th growing season after treatment (Table 1). There were no significant differences in stem density between B and C units at any time. The most dramatic impact of the M treatment was the reduction of density and cover in the shrub layer (> 1 m tall and ≤ 10 cm dbh). Stems of the shrub layer numbered 1,433 per ha prior to cutting with 76.8 percent cover (Table 2). These values were not significantly different from those of C treatment units at the time. One year after treatment, stems of the shrub layer reduced in number and cover to 447 per ha and 8.0 percent, respectively. These values were significantly lower than those in C units. Density and cover of this size class increased over time until there were no significant differences between these variables in M and C treatment units. The second mechanical treatment occurred in year 10 causing stem numbers and density to be significantly lower in M than in C units that year. By year 12, density of stems in the shrub layer had increased and it was not significantly different than density in C units. However, shrub layer cover was still much lower in M than in C units.

Cover of all forest floor plants (≤ 1 m tall) combined was not significantly different from that of C treatment units except during the year after the first treatment and third year after the second treatment (year 12) (Table 4). In both of those years, cover of all species of plants was significantly higher in M units than in C units. Cover of individual species groups (forbs, grasses, shrubs, and trees) was largely unaffected by the M treatment. Forbs had significantly lower cover during year 5 in M units than in C units. Tree cover was significantly higher in M units than in C units during year 12. There were no significant differences in forest floor cover between M units and C units for any other year or species group. Grasses did not differ in cover between M units and C units in any year.

Finding 2: The M treatment did not improve oak regeneration.
The number of tree stems (all species combined) in the regeneration layer (≤ 1 m tall) did not differ significantly between M and C treatment units at any time except year 12 when stems in M units numbered 37,816 per ha while those in C units numbered only 26,167 per ha (Table 3). Even though stems cut by the M treatment were observed to sprout, sprout numbers were not sufficient to significantly increase numbers of stems in this category, other than during the third year after the second M treatment. Oak reproduction followed the same pattern as did all species combined (Table 3). Oaks ≤ 1 m tall in M treatment units did not differ in density from those in C units except during the last year of the study. At that time, oaks numbered 16,482 per ha in M units and 10,984 in C units.

Finding 3: The M treatment greatly increased loading of woody fuels and the depth of the litter layer for up to 5 years.
Weight of 1-hr fuels, weight of 100-hr fuels, and depth of the litter layer were significantly higher the year after cutting small trees and shrubs in M treatment units than in C units (Table 5). By the third year after the first M treatment, weights of all measured fuels were significantly larger in M units and in C units. During the fifth year after treatment, only 100-hr fuels remained significantly greater in M units than in C units. Weights of 1-hr and 10-hr fuels were significantly larger in M treatment units than in C units during year 11. In year 12, M units had significantly greater weights of 10-hr fuels than C units and a significantly thinner litter layer.

Finding 4: Three fires for the burn-only treatment (B) moved stand structure toward restoration goals but failed to create open woodland.
Basal area of overstory trees declined gradually in B units from 26.5 m^2 per ha prior to the first burn to 25.2 m^2 per ha in year 12 (Table 1). Even though basal area was declining in B treatment units and increasing in C units, the difference did not become significant until year 9, just prior to the third prescribed burn. After that year, basal area was always significantly lower in B units than in C or M units and significantly higher than in MB units. Density of overstory trees followed the same pattern. Numbers of overstory trees did not differ significantly in B, C, and M units until year 9 (Table 1). Beginning that year, overstory stems were fewer in B units than in M or C units and greater than in MB units.

Numbers of stems in the shrub layer counted in B treatment units changed rapidly over the course of the study (Table 2). Shrub density was significantly lower in B units than in C units the first year after each prescribed fire (years 1, 5, and 10). However, density was either the same or significantly higher in B units than in C units if time since burning was more than one year (years 3, 9, 11, and 12). Shrub cover was significantly lower in B units than in C units every year except the pretreatment year and the sixth year after the second burn (year 9). There were no significant differences in those years. Cover of plants ≤ 1 m tall was largely unaffected by the B treatment (Table 4) with the exception of cover by trees in this size class. Cover of forbs and grasses was not significantly different in B units than in C units during any year. Shrub cover was significantly lower in B units than in C units in year 1 but was not significantly different during any other year. Cover of regenerating trees was not significantly different in B units than in C units until the first year after the second prescribed fire (year 5). It remained significantly higher through the remainder of the study except during the first year after the third burn (year 10).

Finding 5: The B treatment increased numbers of oak reproduction.
Density of tree reproduction, both in the oak and the all species categories, was significantly higher in B units than in C units almost every year (Table 3). Exceptions were during the pretreatment year and for oaks in the first year after the first burn. During some years, the number of regeneration-sized trees in the all species group was two to three times greater in B units than in C units (years 1, 3, 10, 11, and 12).

Finding 6: The B treatment reduced woody fuels and litter depth for a short time after burning.
The burn-only treatment (B) had little impact on the weight of 1-, 10-, and 100-hr fuels during this study (Table 5). Weights of these fuels did not differ significantly from those in C treatment units except that the weight of 1-hr fuels was significantly lower in B units than in C units the first year after the second burn (year 5). Litter depth was significantly lower in B units than in C units in most measured years. Duff depth was not significantly different between B and C units until year 11, the second year after the third burn. Duff was significantly thinner on B units than on C units in years 11 and 12.

Finding 7: The mechanical + burn treatment (MB) produced stand structure closest to that of open woodland but woody reproduction dominated the regeneration and shrub layers.
Basal area of overstory trees was significantly lower in MB units than in all other treatment units the first year after treatment installation (Table 1). It reduced from 23.8 m^2 per ha to 21.0 m^2 per ha during the first year after the first treatment and continued to decrease almost every year. By year 12, the basal area in MB units had reduced by 37 percent to 14.9 m^2 per ha. Overstory tree density was significantly lower in MB units than in all other treatment units for all years except the pretreatment year and the year following the first prescribed burn. There were no significant differences among any of the treatments during those years.

Density of stems in the shrub layer was significantly higher in MB units than in all other treatment units during every year except during the first year after the first fire and the first year after the third fire. During those years, shrub layer density was significantly lower in

MB units than in C units. Cover in MB units was significantly lower than in C units for every year except year 9, the sixth year after the second burn. Total forest floor cover in MB treatment units was significantly higher in MB units than in all other treatment units except during the pretreatment year and the first year after the first treatment. Significantly higher cover in MB units was detected for forbs each year after the second burn (year 5) and for trees each year after the first treatment (year 1).

Finding 8: The MB treatment increased oak reproduction in the form of sprouts.
Density of tree reproduction was significantly higher in burned treatment units (MB and B) than in unburned units for both oaks and the all species categories (Table 3). In most years there was no significant difference in the number of regeneration-sized trees between B and MB units.

Finding 9: The combination of mechanical and burn treatments (MB) was best for fuel reduction goals.
MB treatment units tended to have the lowest loading of 1-hr and 10-hr fuels and in many cases the differences were significant (Table 5). Weight of 100-hr fuels was significantly lower in MB units than in C units in years 1, 3, and 5 but there were no significant differences in other years. Litter depth was significantly lower in MB units than in unburned units each year after the first treatment. However, it was not significantly different than in B units except year 5, when it was much lower. Duff depth was not significantly different in MB units than in C units until after the second burn (year 5). After that, duff was significantly thinner in MB units than in unburned units and became significantly thinner than in all other treatment units in year 12.

Table 1. Overstory (> 10 cm dbh) basal area and stem density by treatment and years after treatment, Green River Game Land, Polk County, NC.

	Basal Area (m^2/ha)	Density (stems/ha)
Preburn		
B	26.5	632
C	26.5	641
M	27.3	642
MB	23.8	574
Year 1		
B	26.3 b[1]	653
C	27.0 b	642
M	27.6 b	646
MB	21.0a	598
Year 3		
B	26.1 b	581 b
C	28.1 b	608 b
M	28.8 b	643 b
MB	18.3a	456a
Year 5		
B	25.9 b	562 b
C	27.6 b	593 b
M	29.0 b	629 b
MB	16.5a	406a
Year 9		
B	24.5 b	482 b
C	28.8 c	561 c
M	29.5 c	598 c
MB	14.6a	306a
Year 10		
B	24.9 b	407 b
C	29.4 c	533 c
M	29.6 c	511 c
MB	14.6a	165a
Year 11		
B	25.1 b	400 b
C	29.9 c	552 c
M	29.8 c	510 c
MB	14.6a	163a
Year 12		
B	25.2 b	401 b
C	30.4 c	556 c
M	30.3 c	516 c
MB	14.9a	165a

[1] Means followed by the same letter within a column and year are not significantly different at the 0.05 level. The absence of letters indicates there were no significant differences within that column and year.

Table 2. Shrub layer (> 1 m tall and ≤ 10 cm dbh) density and cover by treatment and years after treatment, Green River Game Land, Polk County, NC.

	Density (stems/ha)	Cover (%)
Preburn		
B	1,559	40.0
C	1,863	66.5
M	1,433	76.8
MB	1,596	49.7
Year 1		
B	664ab[1]	39.1 b
C	1,919 c	94.4 c
M	447a	8.0a
MB	758 b	7.1a
Year 3		
B	1,514ab	20.5 b
C	1,983 b	86.6 c
M	1,025a	12.8a
MB	4,246 c	7.2a
Year 5		
B	850a	18.1a
C	1,717 b	71.0 b
M	1,210a	22.1a
MB	2,435 c	2.3a
Year 9		
B	3,376 b	23.6
C	2,082a	66.6
M	1,902a	42.3
MB	7,781 c	35.4
Year 10		
B	309a	8.7a
C	2,018 c	73.1 b
M	284a	6.5a
MB	1,077 b	1.4a
Year 11		
B	2,517 b	13.3a
C	2,020ab	72.9 b
M	716a	6.2a
MB	8,588 c	18.4a
Year 12		
B	3,300 b	17.2a
C	1,991ab	95.8 b
M	1,042a	10.0a
MB	10,169 c	30.7a

[1] Means followed by the same letter within a column and year are not significantly different at the 0.05 level. The absence of letters indicates there were no significant differences within that column and year.

Table 3. Density of tree reproduction (≤ 1 m tall) for oaks and all species combined by treatment and years after treatment, Green River Game Land, Polk County, NC.

	Oaks (stems/ha)	All Species (stems/ha)
Preburn		
B	13,649	33,666
C	13,001	29,450
M	12,315	22,166
MB	15,801	29,116
Year 1		
B	15,400ab[1]	83,214 b
C	11,950a	31,648a
M	11,117a	22,331a
MB	20,116 b	80,468 b
Year 3		
B	30,882 b	129,334 c
C	15,484a	45,917a
M	11,500a	30,949a
MB	28,850 b	90,968 b
Year 5		
B	23,134 bc	65,332 b
C	13,701a	36,183a
M	18,117ab	39,982a
MB	28,417 c	69,281 b
Year 9		
B	20,333 bc	54,750 b
C	13,098a	29,899a
M	14,867ab	29,751a
MB	21,099 c	47,384 b
Year 10		
B	24,893 b	76,652 b
C	13,484a	32,683a
M	16,868a	30,784a
MB	38,633 c	87,517 b
Year 11		
B	25,051 b	79,601 b
C	13,884a	32,699a
M	16,282a	40,051a
MB	29,751 b	70,516 b
Year 12		
B	21,366 bc	69,849 d
C	10,984a	26,167a
M	16,482 b	37,816 b
MB	21,499 c	50,366 c

[1] Means followed by the same letter within a column and year are not significantly different at the 0.05 level. The absence of letters indicates there were no significant differences within that column and year.

Table 4. Forest floor cover (percent) by species group, treatment, and years after treatment, Green River Game Land, Polk County, NC.

	Forbs	Grass	Shrubs	Trees	Total
Preburn					
B	5.4	0.2	9.2	6.2	21.0
C	5.3	0.7	22.9	7.2	25.1
M	2.7	0.3	15.6	5.2	23.9
MB	5.0	0.3	17.2	6.7	29.3
Year 1					
B	3.4	0.5	3.5a	6.2a	13.5a
C	5.8	0.7	10.5 b	5.9a	23.0 b
M	3.4	0.4	14.3 c	6.4a	24.5 c
MB	3.5	0.8	6.2ab	7.8 b	18.2ab
Year 3					
B	3.2	0.7	7.9a	9.6a	21.4a
C	4.3	0.7	10.4a	6.5a	22.0a
M	2.8	0.4	19.8 b	7.9a	30.9a
MB	5.3	2.2	14.6ab	17.3 b	39.4 b
Year 5					
B	3.3 b[1]	1.0ab	12.2	10.6 b	27.1a
C	3.5 b	0.9a	12.8	6.9a	24.2a
M	2.2a	0.3a	20.2	7.1a	29.8a
MB	5.8 c	3.1 b	21.1	14.7 b	44.6 b
Year 9					
B	4.5 bc	1.1	15.1	16.2 b	37.0a
C	3.6ab	1.1	14.0	8.9a	27.6a
M	2.3a	0.4	22.0	9.9a	34.6a
MB	6.6 c	2.4	26.1	19.0 b	54.0 b
Year 10					
B	5.1ab	0.2	5.3	11.2a	21.8a
C	4.8a	0.7	8.3	7.0a	20.8a
M	3.0a	0.2	8.7	6.4a	18.2a
MB	8.0 b	0.3	10.6	19.6 b	38.5 b
Year 11					
B	7.0a	0.2	9.7	13.1 b	30.1a
C	5.0a	0.7	8.4	6.9a	21.0a
M	3.8a	0.1	14.8	9.8ab	28.5a
MB	12.8 b	0.5	18.7	21.6 c	53.5 b
Year 12					
B	7.7a	0.3	11.2	12.1 b	31.4ab
C	4.8a	0.7	10.4	6.2a	22.1a
M	4.8a	0.1	19.7	10.8 b	35.4 b
MB	13.0 b	0.4	21.2	16.2 c	50.8 c

[1] Means followed by the same letter within a column and year are not significantly different at the 0.05 level. The absence of letters indicates there were no significant differences within that column and year.

Table 5. Loading of woody fuels and forest floor depth by treatment and years after treatment, Green River Game Land, Polk County, NC.

	1-hr	10-hr	100-hr	Litter	Duff
	---------- Mg per ha ----------			------- cm -------	
Preburn					
B	0.4	2.0	4.5	4.8	4.6
C	0.3	1.8	5.2	5.1	3.6
M	0.3	1.8	3.4	4.6	4.1
MB	0.4	1.8	4.7	5.1	4.6
Year 1					
B	0.5a[1]	2.0ab	4.5ab	1.0a	3.6
C	0.5a	1.8ab	3.8a	4.3 b	3.6
M	0.8 b	3.2 b	6.3 c	5.6 c	5.3
MB	0.4a	1.7a	5.4 bc	0.5a	3.0
Year 3					
B	0.6a	1.6ab	4.7a	4.1ab	2.8a
C	0.6a	1.3a	4.0a	4.6 b	3.0a
M	0.8 b	2.4 c	6.5 b	5.8 c	4.1 b
MB	0.6a	1.9 b	6.5 b		
	3.3a	3.0a			
Year 5					
B	0.9 b	2.1	5.6a	5.3 b	3.0 b
C	1.1 c	2.1	5.4a	5.3 b	3.0 b
M	1.1 c	2.4	7.6 b	6.1 b	2.8 b
MB	0.5a	1.8	7.4 b	0.5a	1.3a
Year 9					
B	0.6	2.7	6.5	6.4	3.6
C	--[2]	--	--	--	--
M	--	--	--	--	--
MB	0.7	3.1	6.5	7.1	4.1
Year 10					
B	0.8	2.7	7.4	2.3	3.0
C	--	--	--	--	--
M	--	--	--	--	--
MB	0.6	2.4	7.6	1.8	2.3
Year 11					
B	0.9a	3.0a	7.4	4.6a	3.0a
C	1.0a	2.8a	6.7	7.1 b	4.1 b
M	1.3 b	4.0 b	7.4	7.4 b	4.6 b
MB	0.8a	2.7a	7.4	4.1a	1.8a
Year 12					
B	0.9	2.8a	6.7	5.6a	2.5 b
C	0.8	2.6a	5.2	6.9 c	3.6 c
M	1.2	3.6 b	7.0	6.6 b	3.8 c
MB	0.9	3.0ab	7.4	5.1a	1.8a

[1] Means followed by the same letter within a column and year are not significantly different at the 0.05 level. The absence of letters indicates there were no significant differences within that column and year.

[2]Fuels data were not collected in C and M treatment units in years 9 and 10.

MANAGEMENT IMPLICATIONS

Mechanical Treatment (M)

Restoration. From a restoration standpoint, the M treatment failed to create an open overstory and a diverse forest floor of graminoids and forbs, which are two of three woodland characteristics. While the dense shrub layer was reduced, repeated application of this treatment will be necessary to keep reproduction – chiefly from ericaceous resprouts and undesirable mesophytic hardwoods such as yellow-poplar (*Liriodendron tulipifera*), birches (*Betula* spp.) and maples (*Acer* spp.) – from growing into this size class. Graminoids and forbs, many of which are light-demanding ruderals, are unlikely to establish and persist in an environment where the overstory remains intact, midstory competition is only temporarily reduced, and litter and duff depth increase (Keyser et al. 2012). Although alternative mechanical treatments, such as mastication, have proven effective at restoring forest structure in other regions (Kreye et al. 2014, Stottlemyer et al. 2015), we conclude that our stand structure goals will be difficult to attain solely via chainsaw felling of shrubs and small trees. The efficacy of M could perhaps be increased with targeted herbicide application to control mesophytic resprouts, as has been done in other forest communities (Kochenderfer et al. 2012). However, the manager would incur this additional cost on top of an already expensive treatment and the overstory would remain dense.

Oak regeneration. Oak reproduction increased slightly, but this did not occur until after the second M treatment. Almost all new reproduction was of sprout origin, which suggests that the requisite conditions for acorn germination and seedling establishment are not created by the M treatment. The entire regeneration process, from acorn to sapling, can take up to 25 years (Carvell and Tryon 1961, Clark and Watt 1971, Sander 1972). Along with an abundance of acorns (which we did not quantify), successful oak regeneration from seed requires seedbed preparation, competition control, abundant sunlight, and a number of other factors. Both litter depth and duff depth should be reduced and sunlight should be increased. Historically these would have been accomplished by periodic burning (Brose et al. 2014); thus M was not an effective fire surrogate for an oak regeneration objective. In the absence of fire, competition from the established overstory and the resprouting shrubby midstory makes it unlikely that many of the oak resprouts will grow into larger size classes (Beck and Hooper 1986, Waldrop et al. 2008). Mechanical treatment alone does not appear to be a viable option for promoting oak regeneration. Without sufficient oak reproduction, overstory oaks will likely be replaced by non-oak species when they die (Brose et al. 2014).

Fuel reduction. Fuels decreased by reducing the shrub layer but at the expense of increased fine fuels. Until these fuels decompose, they may make the stand more susceptible to wildfire. Predictive models suggest that these wildfires would be very intense and have rapid spread rates (Waldrop et al. 2010). If such fires were to “ladder” into the canopy, desirable levels of overstory mortality, herbaceous layer establishment, and oak regeneration could occur. However, relying on a wildfire to meet restoration objectives is not recommended.

Burn-only Treatment (B)

Restoration. Burning reduced overstory density only slightly, although delayed mortality of overstory trees may occur in future years, especially if periodic burning continues. The shrub layer was decreased but woody sprouts dominated the forest floor. Burning alone may eventually create a woodland condition but another fire regime may be necessary. Currently, nearly all prescribed burns in the southern Appalachians are conducted during the dormant season (Brose et al. 2014). Growing season fires, which not only burn at a warmer time of year, but also consume vegetation when a greater portion of their carbohydrates are stored aboveground, may be highly effective at eliminating unwanted hardwoods and encouraging graminoids and forbs (Hutchinson et al. 2005, Knapp et al. 2009). However, evidence from other regions in the US suggests that growing season burns must be repeated for many consecutive years before undesirable hardwood resprouts can be eliminated. For example, in loblolly pine (*Pinus taeda*) forests of the coastal plain of South Carolina, annual growing season burns were conducted for 20 years without interruption before graminoids and forbs replaced hardwoods such as sweetgum (*Liquidambar styraciflua*) in the understory. Periodic growing season fires (every 2 years) were markedly less effective, since the fire-free intervals gave the established hardwoods opportunities to recover (Waldrop et al. 1992). A similar pattern would likely hold true in the southern Appalachians, but it remains to be seen if land managers would be receptive to using growing season burns in an environment where burning windows are short and extreme topography makes fire behavior difficult to predict. However, if desirable stand conditions could be achieved with repeated growing season burns, this forest structure could potentially be maintained by periodic low-intensity surface fires, including dormant season burns, like those that previously occurred (Brose et al. 2001). Herbicides could also be used to control undesirable resprouts.

Oak regeneration. In the absence of fire, unfavorable seedbed conditions and intense competition make it very difficult for oak seedlings to establish (Brose et al. 2014). Burning resulted in favorable reductions in litter and duff depth, but these were only temporary, lasting 2 years or less after each burn. While oak reproduction increased after the first burn and remained above C levels for the remainder of the study period, the majority new reproduction appeared to be of sprout origin. As was the case with M, these oak sprouts and any scattered germinants will likely compete unfavorably with the other resprouting hardwoods. Additional reductions in litter and duff depth, along with reductions in overstory and midstory shade, will likely be necessary for acorns to germinate and for these seedlings to grow into larger size classes. This could potentially be accomplished by burning in the growing season, as properly timed fires can be highly effective at “releasing” young oaks from their mesophytic competitors. Such fires are especially effective when they are timed when large amounts of young advance reproduction are present (Arthur et al. 2012). Because oak seedlings and saplings have comparatively larger root systems than do most other hardwoods, and they have abundant latent buds below the root collar, they are more likely to sprout back vigorously following a growing season burn (Brose and Van Lear 2004).

Fuel reduction. Live fuel loads decreased due to the removal of the shrubby midstory layer. Fine fuels increased but probably are not highly flammable since they were mostly hardwood leaves and twigs that were partially consumed by the fire before falling to the ground later. Such fuels tend to lie flat, which decreases their potential for burning, especially in protected

sites where fire behavior is constrained by high humidity. Since periodic fires reduce the rate of fuel accumulation in B, relative to M, the potential for high-intensity fire is reduced compared to that treatment (Waldrop et al. 2010). The consumption of 10-hour fuels by fire was offset by new additions from top-killed shrubs and saplings, which explains why there was little to no reduction in fuel volumes under this treatment scenario.

Mechanical and Burn Treatment (MB)

Restoration. The failure of the M and B treatments to achieve stand structure goals suggests that a more aggressive approach may be necessary. Fuel management strategies that combine both fire and mechanical treatment have proven effective at restoring forest structure in other regions, particularly in areas where high levels of fuel accumulation make would make B alone dangerous or impractical (e.g. the wildland-urban interface) (Albrecht et al. 2006, Glitzenstein et al. 2006). While overstory trees were not targeted for removal with MB, this treatment contributed to substantial reductions in overstory basal area over time. This in turn allowed more sunlight to reach the forest floor. The shrub layer was decreased but woody sprouts dominated the understory. However, the combination of increased sunlight, decreased competition and decreased litter and duff depth may be responsible for the nascent herbaceous layer. Increased light availability is particularly important for graminoids, which typically require <50% canopy coverage in order to proliferate (Starver et al. 2011). Reductions in basal area due to midstory removal and delayed overstory mortality signal a slow shift toward a desirable forest structure and will further facilitate graminoids and herbs if hardwood sprouts can becontrolled. But the control of these hardwood sprouts probably cannot be achieved without the application of growing season burns or herbicide, as described above.

Oak regeneration. Mechanical treatments to reduce basal area, followed by burning, have proven effective for promoting oak reproduction in the southern Appalachians and adjacent Piedmont (Iverson et al. 2008). However, such treatments often involve 2-step overstory removal (e.g. shelterwood systems), followed by a release burn (Brose and Van Lear 1998). Such a strategy provides the requisite conditions for oak seedling establishment, and gives these young trees a competitive advantage over their mesophytic hardwood competitors. In this study, oak reproduction was increased but almost all new reproduction was of sprout origin. Also problematic is the fact that litter and duff thickness remained relatively high, despite temporary post-treatment reductions. Additional reductions in basal area – perhaps overstory thinning – in concert with burning may be necessary to encourage oak regeneration from seed.

Fuel reduction. Fuels decreased by reducing the shrub layer. As was the case with B, the fine fuels were comprised primarily of leaves which are not highly flammable. However, there was a greater proportion of fine live fuels (graminoids and herbs) relative to the other treatments. Reductions in basal area increased exposure, which combined with a more flammable fuel bed may facilitate fire in MB stands. However, predicted and observed fire intensity in the MB treatment was low relative to the other treatments (Waldrop et al. 2010).

RELATIONSHIP TO OTHER FINDINGS AND FUTURE WORK NEEDED

A survey of Appalachian fire managers indicated a need for much research, particularly on reaching restoration goals, improving oak regeneration, and reducing fuels. The Appalachian site of the National Fire and Fire Surrogate Study provides some information for each of these research needs. There, fuel reduction treatments were designed to restore hardwood sites, with dense shrub layers, to open woodlands by restoring function (B), structure (M), or a combination of both (MB). Treatment units were established to include sites of varying quality. However, our results cannot represent every combination of slope, aspect, soil moisture and other variables found in the southern Appalachian Mountains.

After three fires and two mechanical treatments, stand structure was not altered enough by any of these treatments to produce the desired community. Each fuel reduction treatment changed stand structure differently resulting in different degrees of success. M reduced the shrub layer but did not reduce overstory cover or improve species richness along the forest floor. The canopy was reduced slightly with the B treatment and the shrub layer was removed. However, numerous sprouts of trees and shrubs probably out-competed any grasses and forbs that may have occurred on the forest floor. The MB treatment produced a stand structure most like that of open woodlands by killing a large portion of overstory trees and top-killing almost every stem in the shrub layer. However, tree and shrub sprouts were numerous and may have prevented an increase in herbaceous regeneration. B and MB may eventually produce the desired stand condition but many repeated fires are needed. Burning more frequently or in a different season may speed the process. Combining fire with herbicides and/or mastication may eventually kill all sprouts of trees and shrubs and allow regeneration of a rich herbaceous forest floor. However, information is lacking.

Numbers of regenerating oak stems significantly increased on treatment units immediately after burning (B and MB) and remained higher than on C or M treatment units throughout the study. The majority of oak reproduction was observed to be from multiple sprouts from a stem that was top-killed by fire or the mechanical treatment. Gains in oak reproduction numbers in B and MB treatment units indicate that there were no negative short-term impacts to oak. However, those gains may be only in the short term as sprouts self-thin or as they are replaced by herbaceous species over time as open woodland condition is created.

In this study, fuel reduction treatments were designed to reduce forest floor fuels, down woody fuels, and vertical fuels. Each treatment reduced one or more of these types of fuel. The M treatment eliminated the vertical fuel component but added litter and woody fuels which could cause a wildfire to be more intense for up to 5 years. Prescribed burning alone or in combination with the mechanical treatment consumed the litter layer. However, this effect lasted less than 3 years, emphasizing the need for frequent burning to maintain protection from wildfire. Fine woody fuels were increased by all treatments. This effect is common among studies of prescribed burning as small trees and shrubs are top killed and the burned limbs and stems fall to the ground. Fuels created in by burning in B and MB units probably would not be consumed in a subsequent wildfire. All active treatments decreased the shrub layer which then led to prolific sprouting of trees and shrubs. Vegetation of this size class is common throughout much of the

southern Appalachian Mountains but is not found throughout. In those cases, fuel reduction may not be critical. There, burning is used for other purposes and would produce different results.

While it may be possible to obtain each of the three objectives of this study (open woodland, oak reproduction, and fuel reduction) simultaneously, it will be a challenge to reduce hardwood and shrub sprouting without also impeding oak regeneration. Continued burning and periodic re-measurement of treatment units in this study is necessary. Managers may need to decide between open woodland with a diminishing overstory over time through frequent burning or a more woody community that has ingrowth to the overstory through infrequent burning.

This study represents a considerable effort over 12 years to reach management objectives for restoration, oak regeneration, and fuel reduction. The study provides a better understanding of the effort, time, and expense required to convert dense Appalachian hardwood forests to open woodlands, after three prescribed fires and two mechanical treatments. Our most intense treatment, MB, is approaching the desired structure but many additional treatments are needed to eliminate sprouting, perhaps as often as every 2 years. Fuel reduction objectives will be met by B or MB, especially as restoration objectives are met. Both restoration and fuel objectives may require that burning be conducted more frequently, in a different season, and/or in combination with other treatments. Herbicides or mastication could speed the process of restoration. The objective of increasing oak reproduction was met by all active treatments. Managers should consider the advantages and disadvantages shown for each of these treatments when trying to meet management goals.

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DELIVERABLES CROSS-WALK TABLE

Proposed	Delivered	Status
Field tours – approximately 3 per year	Tours given to graduate students at Clemson University, undergraduate students at the University of Kentucky and Clemson University, and students of the Bent Creek Silvicultural Workshop	Completed annually 2012 – 2015.
Refereed paper/Conference presentation	Comparison of fuel reduction treatments to nitrification rates in Appalachian soils.	Data analysis completed; manuscript in preparation
Refereed paper/Conference presentation Effects of repeated fuel reduction treatments on woody regeneration, understory species diversity, and exotic species invasion. AFE/CAFMS Appalachian Fire Science Conference.	Presentation cancelled because of federal shutdown, October 2013. Proceedings published containing the paper. Autumn 2014. 1. Proceedings: Waldrop, Thomas A., ed. 2104. Proceedings: Wildland fire in the Appalachians: discussions among fire managers and scientists. Gen. Tech. Rep. SRS-199. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 206 p. 2. Paper: Waldrop, T.A.; Mohr, H.H.; Phillips, R.J.; Simon, D.A. 2014. The National Fire and Fire Surrogate Study: 11 years of Fuels Management Research in the Southern Appalachian Mountains. pp. 34-41, In: Waldrop, Thomas A., ed. Proceedings: Wildland fire in the Appalachians: discussions among fire managers and scientists. Gen. Tech. Rep. SRS-199. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 206 p. Additional papers using data from this study: 3. Mohr, Helen H.; Waldrop, Thomas A. 2013. Impact of rainfall on the moisture content of large woody fuels. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 519-524. 4. McIver, James; Stevens, Scott; and others including Waldrop, Thomas; 2012. Ecological effects of alternative fuel-reduction treatments: highlights of the National Fire and Fire Surrogate Study (FFS). International Journal of Wildland Fire. 2013, 22:63–82 http://dx.doi.org/10.1071/WF11130 5. Greenberg, Cathryn H.; Waldrop, Thomas A.; Tomcho, Joe; Phillips, Ross J.; Simon, Dean. 2013. Bird response to fire severity and repeated burning in an upland hardwood forest. Forest Ecology and Management. 304(2013) 80-88.	Completed or in press: 2012 - 2015

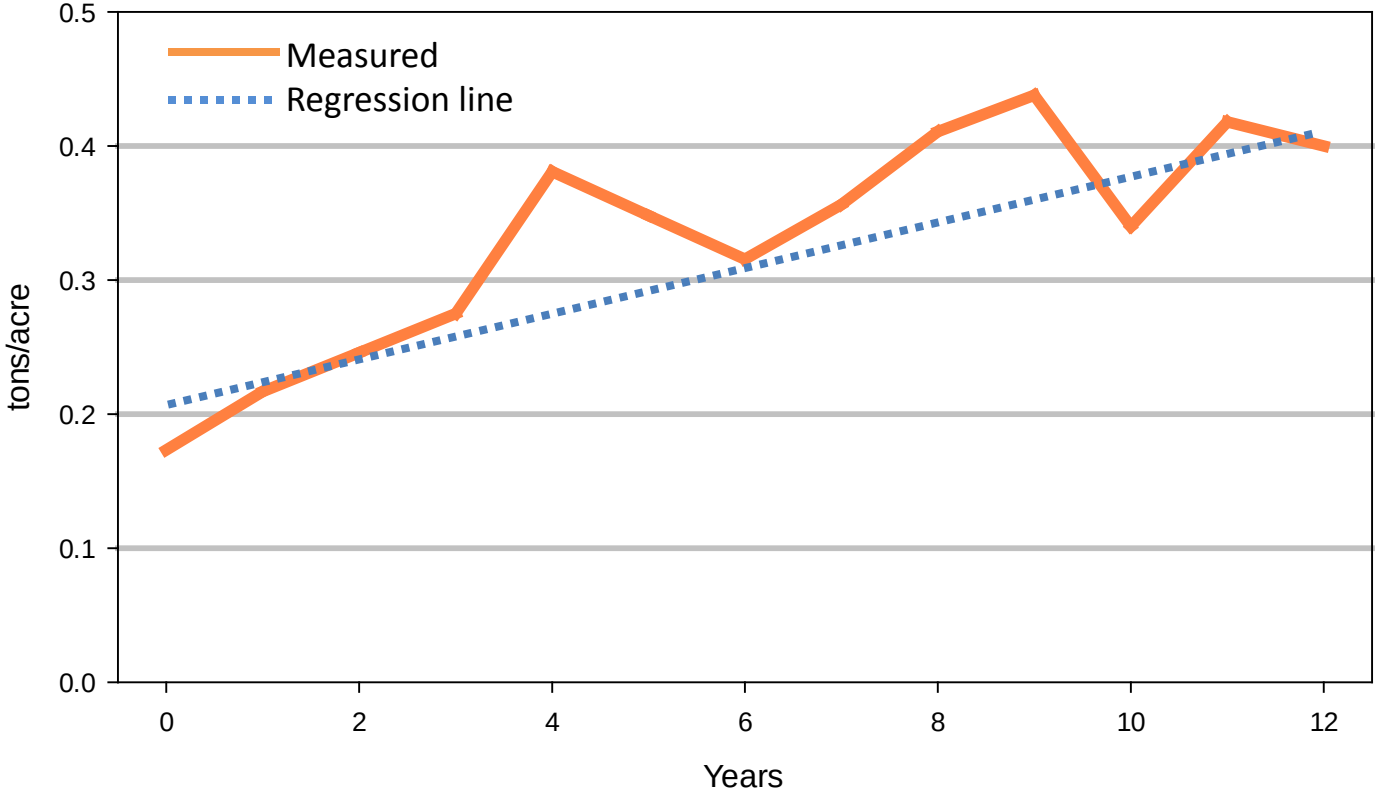
	6. Phillips, Ross J.; Waldrop, Thomas A. 2013. Fuel loading following fuel-reduction treatments and impacts from natural disturbances. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 533-540. 7. Phillips, Ross J.; Waldrop, Thomas A.; Stottlemyer, Aaron D. 2013. Occurrence and spread of nonnative invasive plants in stands treated with fire and/or mechanical treatments in the upper piedmont of South Carolina. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 525-531. 8. Greenberg, Cathryn H.; Waldrop, Thomas A.; Tomcho, Joe; Phillips, Ross J.; Simon, Dean. 2014. Bird response to fire severity and repeated burning in an upland hardwood forest. pp. 81-84, In: Waldrop, Thomas A., ed. Proceedings: Wildland fire in the Appalachians: discussions among fire managers and scientists. Gen. Tech. Rep. SRS-199. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 206 p. 9. Pitt, Amber L.; Tavano, Joseph J.; Baldwin, Robert F.; Waldrop, Thomas A. 2014. Effects of fuel reduction treatments on movement and habitat use of American toads in a southern Appalachian hardwood forest. Forest Ecology and Management: 310(2013):289-299. 10. Waldrop, Thomas A. 2014. Restoration in the Southern Appalachians: a dialog among scientists, planners, and land managers. Portions throughout, In: Rankin, W.T.; Herbert, N. eds. Gen. Tech. Rep. SRS-189. Asheville, NC: Dept. of Agriculture Forest Service, Southern Research Station. 48 p. 11. Stambaugh, M.C., J.M. Varner, R.F. Noss, D.C. Dey, N.L. Christensen, R.F. Baldwin, R.P. Guyette, B.B. Hanberry, C.A. Harper, S.G. Lindblom, and T.A. Waldrop. 2015. Clarifying the role of fire in the deciduous forests of eastern North America: reply to Matlack. Conservation Biology. [In press]. 12. Waldrop, Thomas A.; Mohr, Helen H.; Phillips, Ross J. 2014. Structure may be the key to predicting function during restoration of southern Appalachian forests. In:	

	Wade, D.D. ed. Proc. 4th Fire Behavior and Fuels Conference. 19-21 Feb 2013; Raleigh, NC. International Association of Wildland Fire. [In press]. 13. Waldrop, Thomas A.; Phillips, Ross J. Restoring Fire-Adapted Forests in Eastern North America for Biodiversity Conservation and Hazardous Fuels Reduction. Chapter in Stanturf, J.A., P. Madsen, D. Lamb, eds. A Goal-Oriented Approach to Forest Landscape Restoration. [In press]. 14. Coates, T. Adam; Shelburne, Victor B.; Waldrop, Thomas A.; Hill, Hoke S., Jr.; 2015. Size of destructive soil samplers for bulk density estimation is bigger better? Submitted to Clatterbuck, Wayne K. ed. Proc. 18th Biennial Southern Silvicultural Research Conference, 2 – 5 March 2015. Knoxville, TN. [In press].	
Websites - Results will be added to the Encyclopedia of Southern Forest Science and the facts page of cafms.org	This will remain an ongoing project until the new CAFMS website (appalachianfire.org) is launched.	December 2015
Webinar	Repeated fuel reduction treatments: impacts to Appalachian vegetation, fuels, and soils. Too be added to the webpage for the Fifth Fire in Eastern Oaks Conference. http://easternfire.as.ua.edu/	Summer 2015
Workshop	Fire Knowledge for the Southern Appalachians: Results from Experience and Research. CAFMS Workshop for managers and students. Black Mountain, NC. Autumn 2014.	August 2014
Refereed paper/Conference presentation	Successional changes and predictions from studies on prescribed fire. Presented at the Fifth Fire and Oak Conference, Tuscaloosa, AL. Paper submitted to Fire Ecology: 1. Waldrop, T.A., D.L. Hagan, and D.A. Simon. 2016. Repeated application of fuel reduction treatments in the southern Appalachian Mountains: implications for achieving management goals. Fire Ecology x(x): xx-xx.	March 2015 July 2015
Final Report	Repeated fuel reduction treatments: impacts to Appalachian vegetation, fuels, and soils.	August 2015

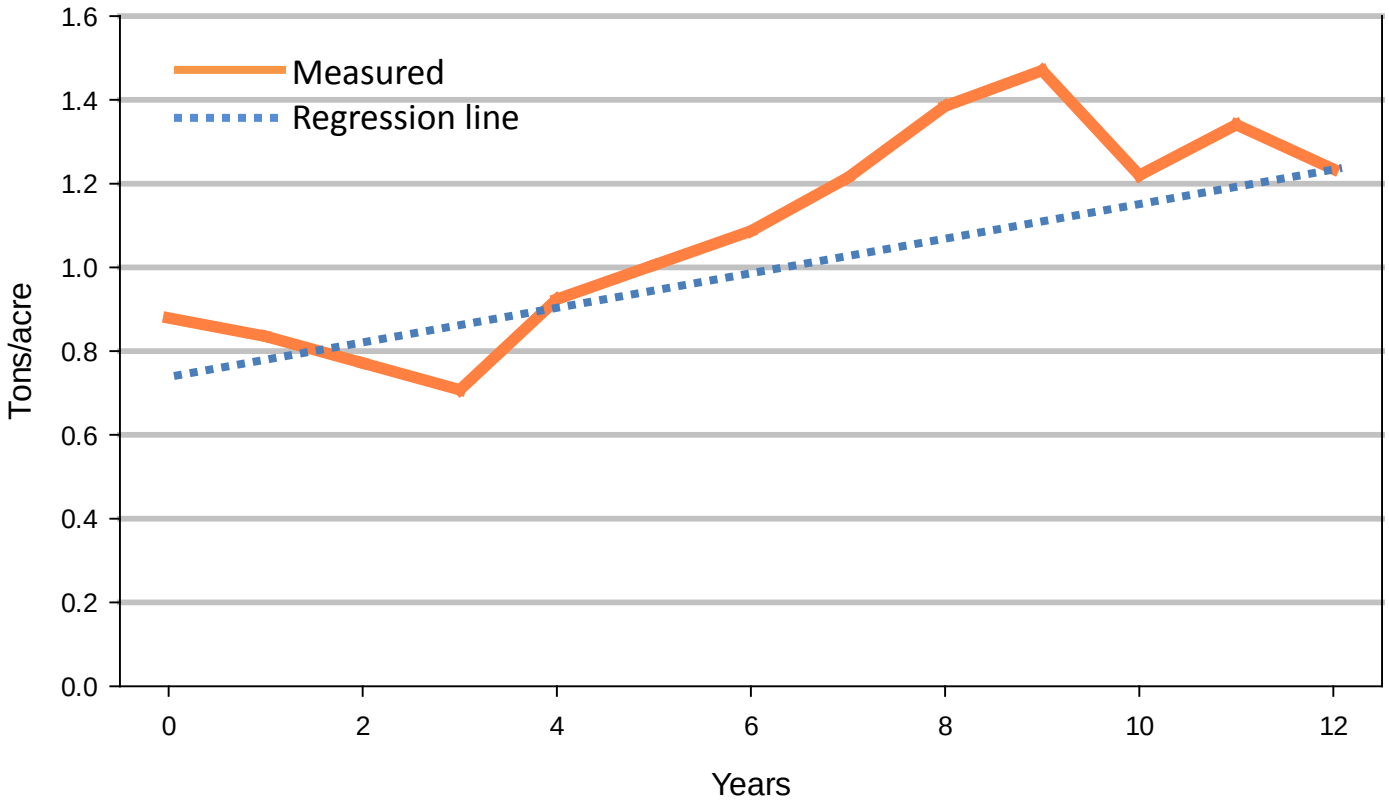
APPENDIX

The following graphs provide a detailed view of the response of most variables measured at the species, species group, and individual fuel category level. Orange lines represent the actual changes that occurred over time. Dashed blue lines represent a simple linear regression line calculated from the measured data. Positive or negative slopes indicate if the measurements of individual variables are increasing or decreasing, thus providing a general indication of whether each variable is moving toward stated management goals (restoration, oak regeneration, fuel reduction).

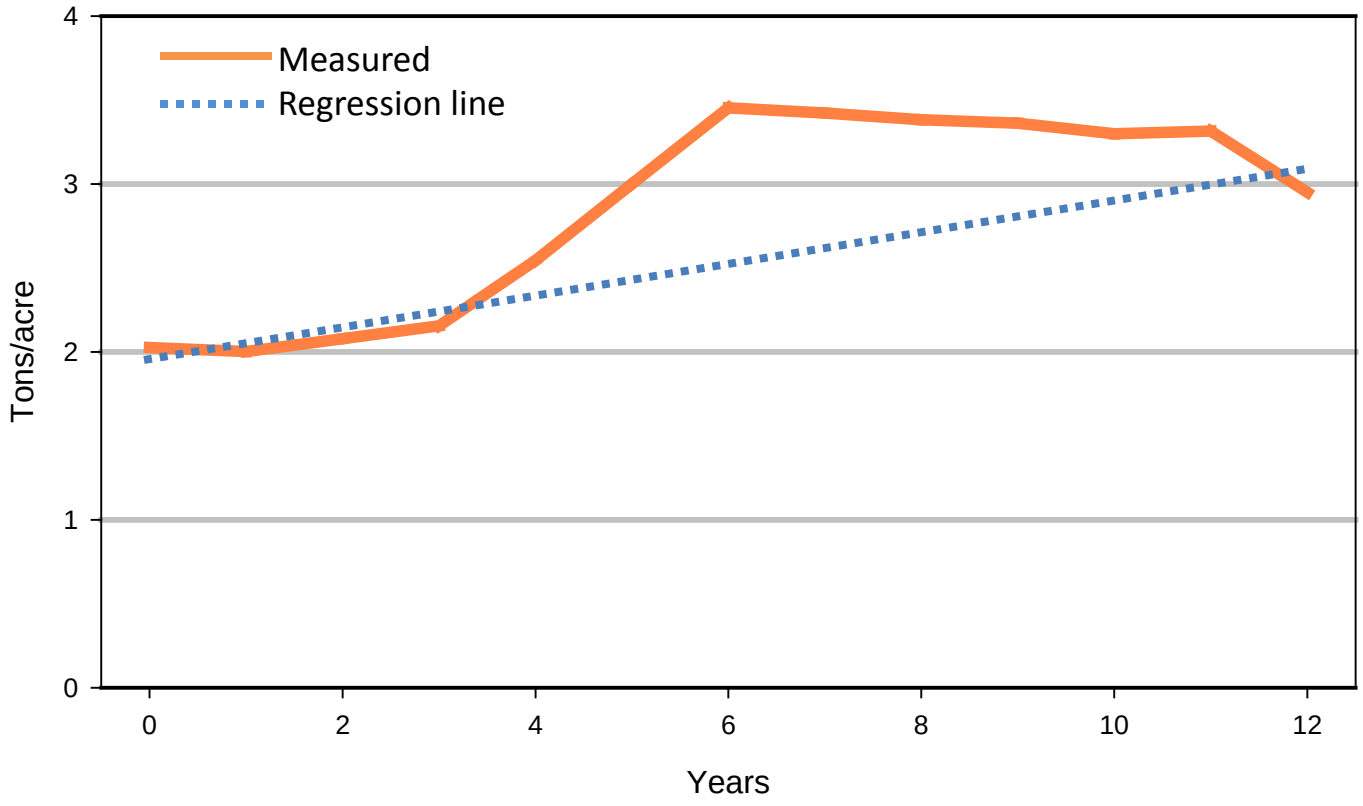
Burn Only: 1-hour Fuels



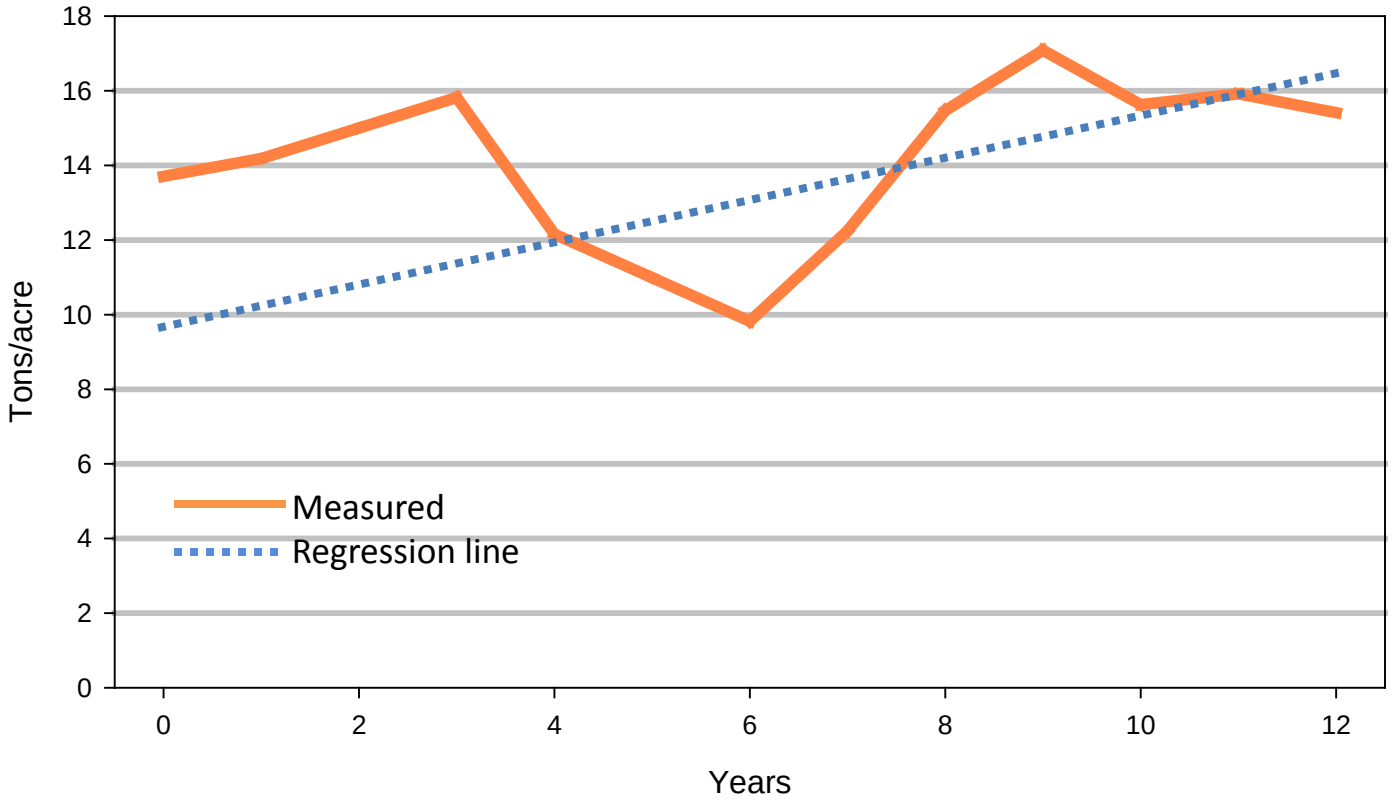
Burn Only: 10-hour Fuels



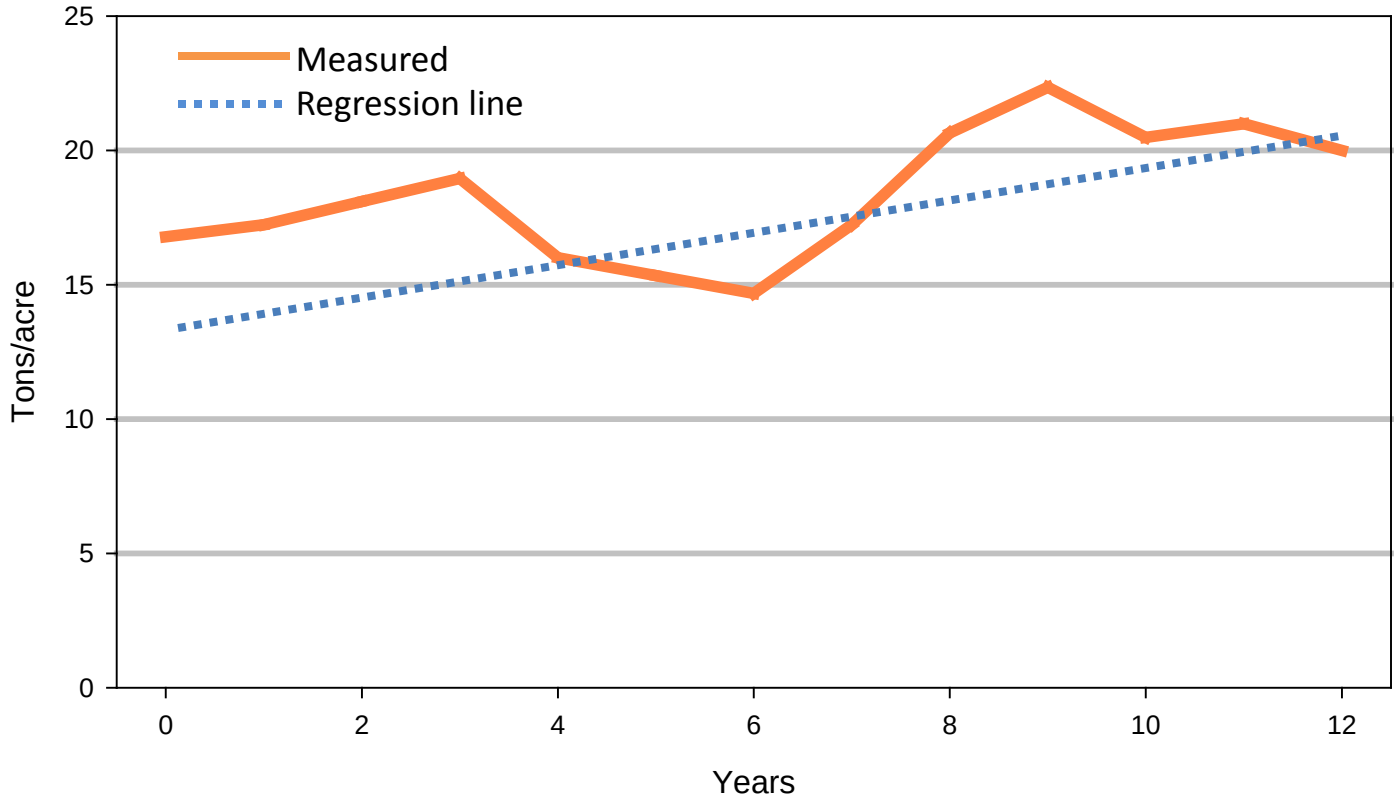
Burn Only: 100-hour Fuels



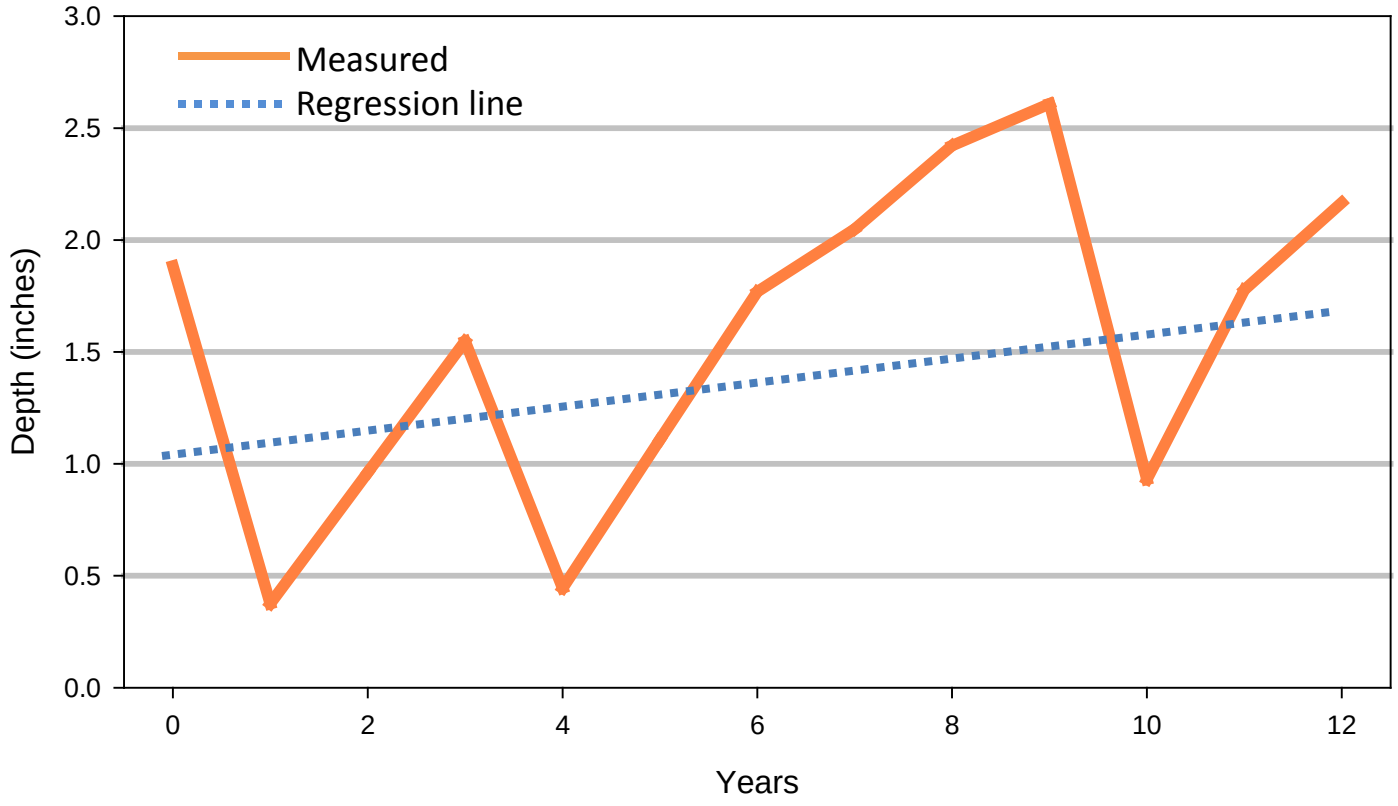
Burn Only: 1,000-hour Fuels



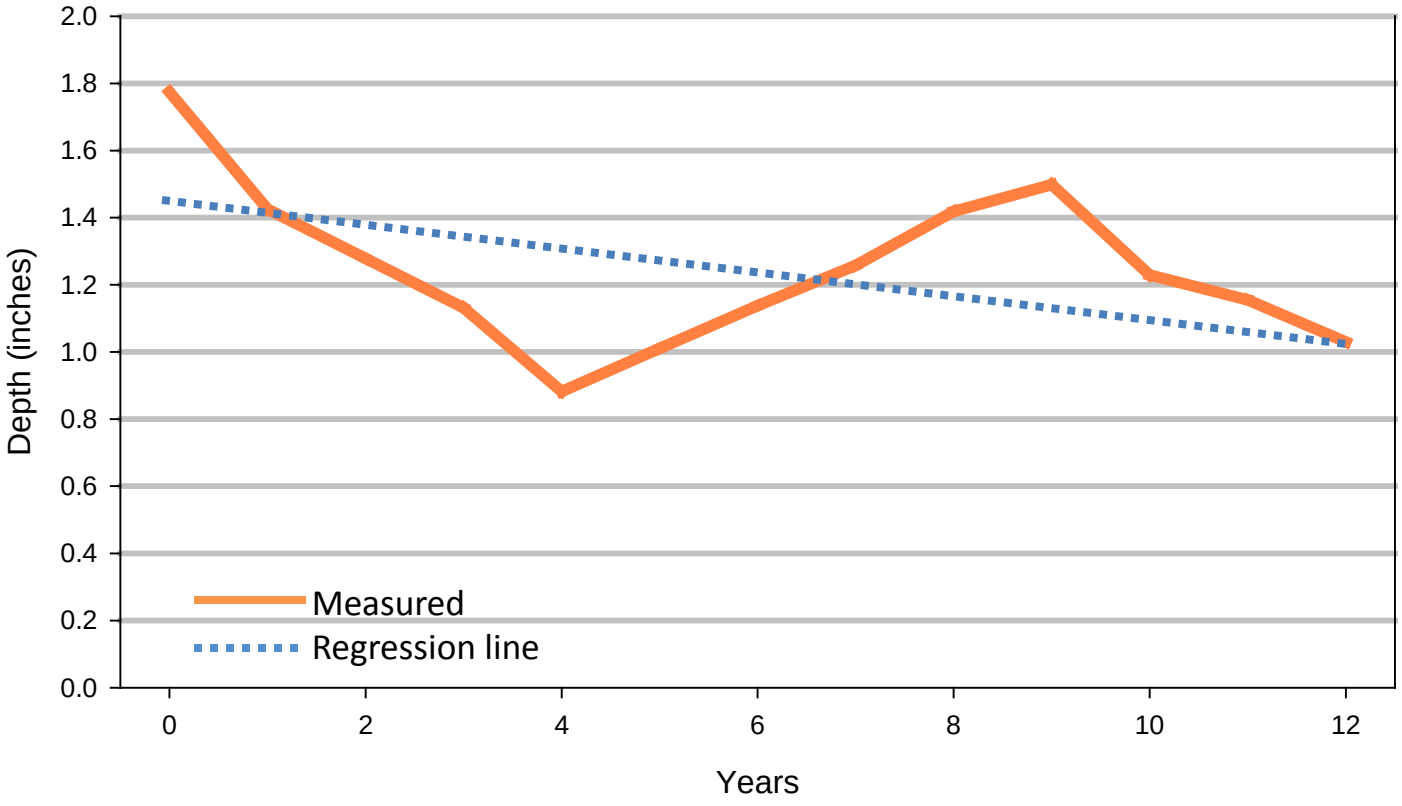
Burn Only: Total Woody Fuels



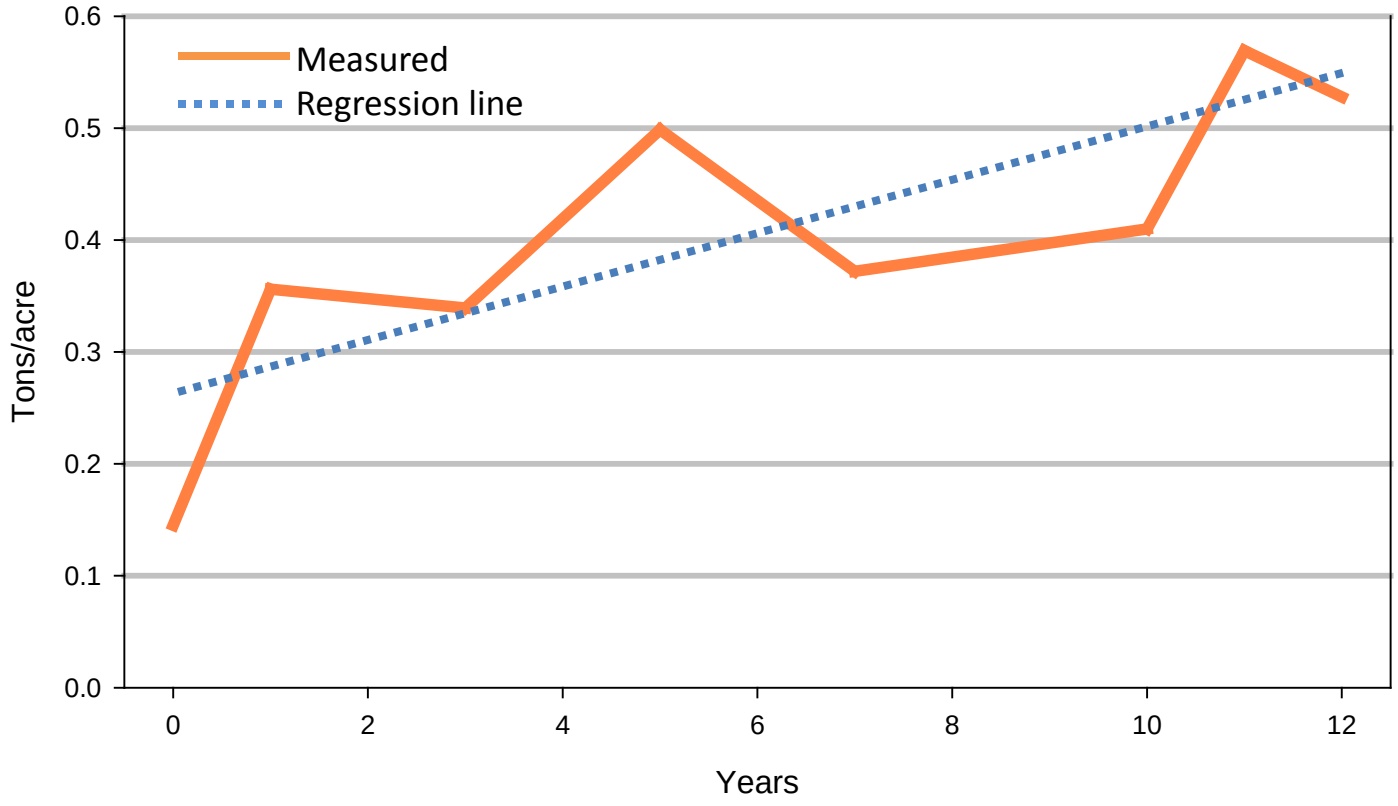
Burn Only: Litter Depth



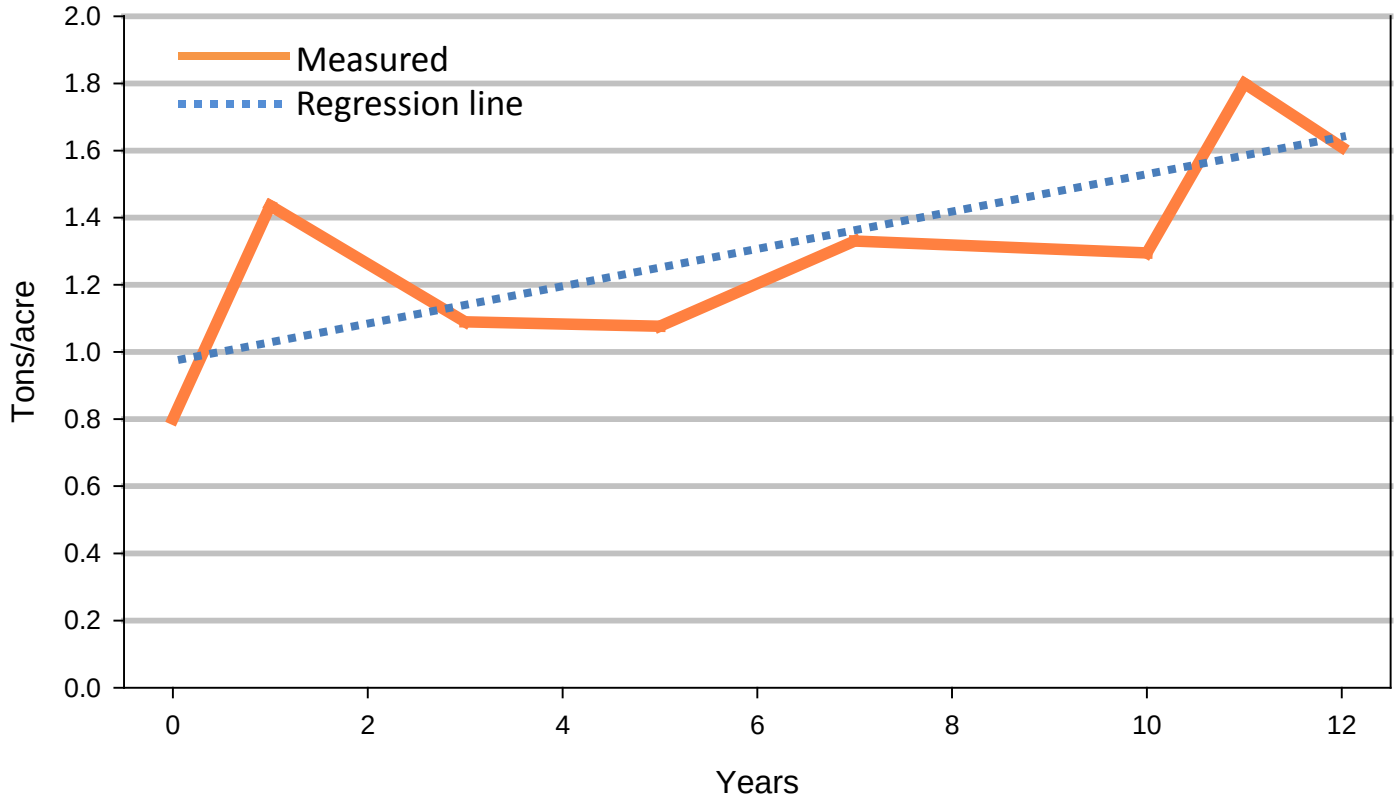
Burn Only: Duff Depth



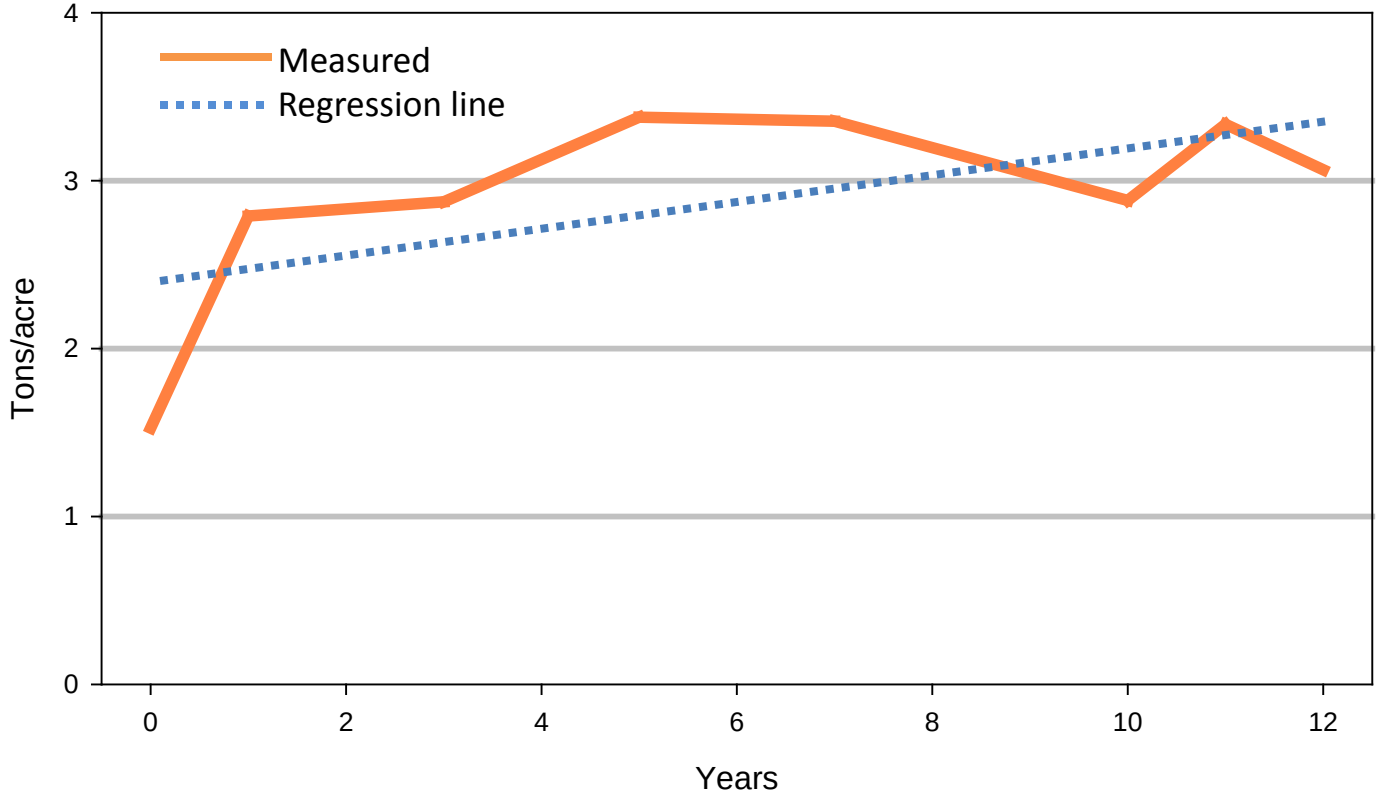
Mechanical Only: 1-hour Fuels



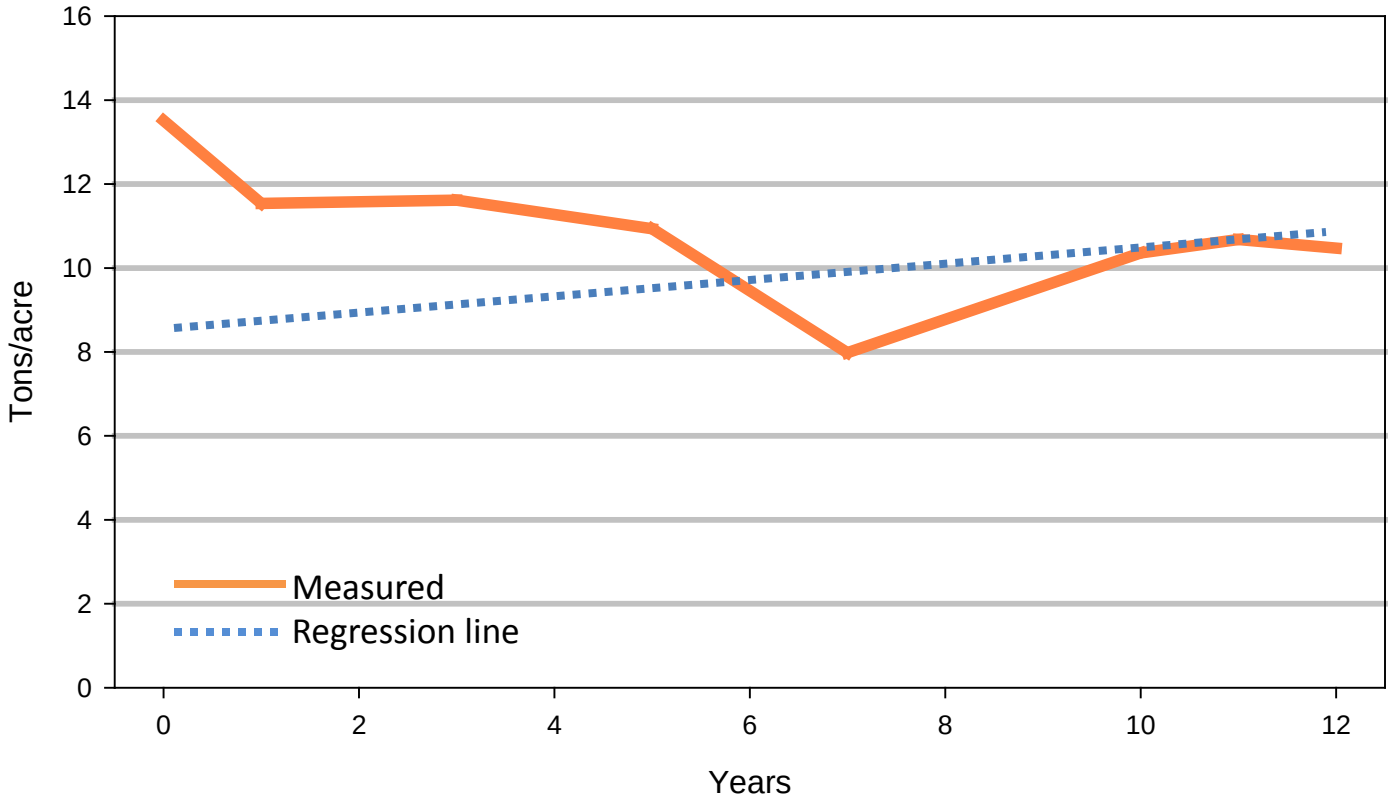
Mechanical Only: 10-hour Fuels



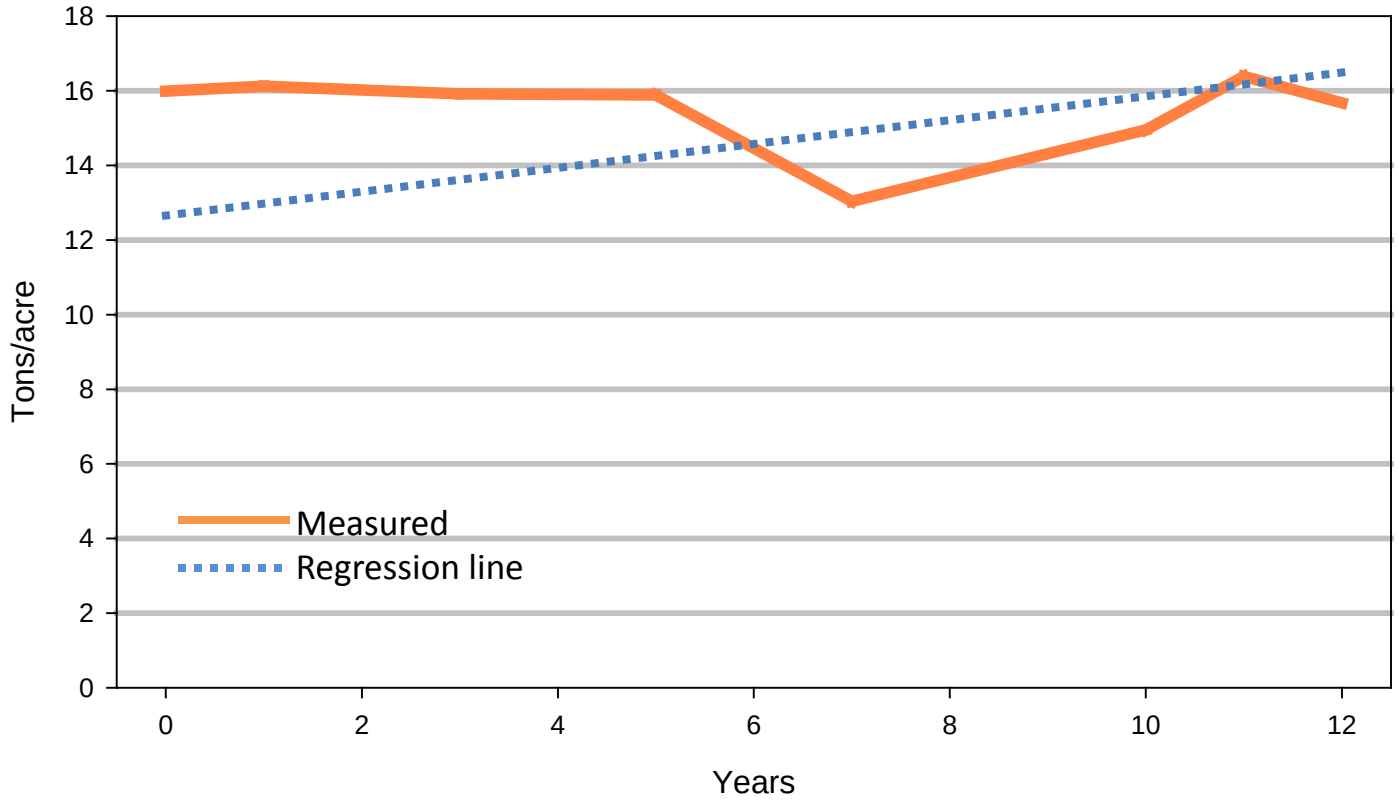
Mechanical Only: 100-hour Fuels



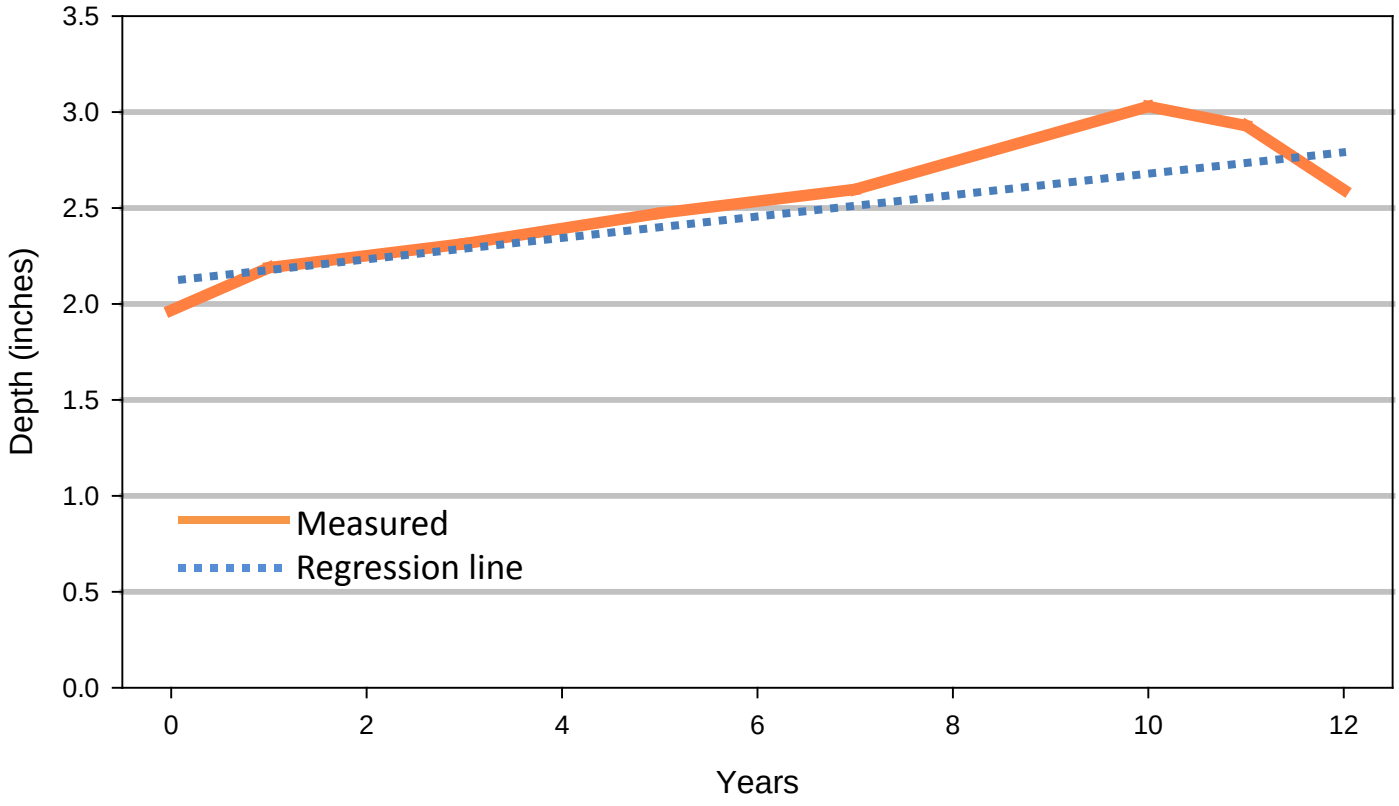
Mechanical Only: 1,000-hour Fuels



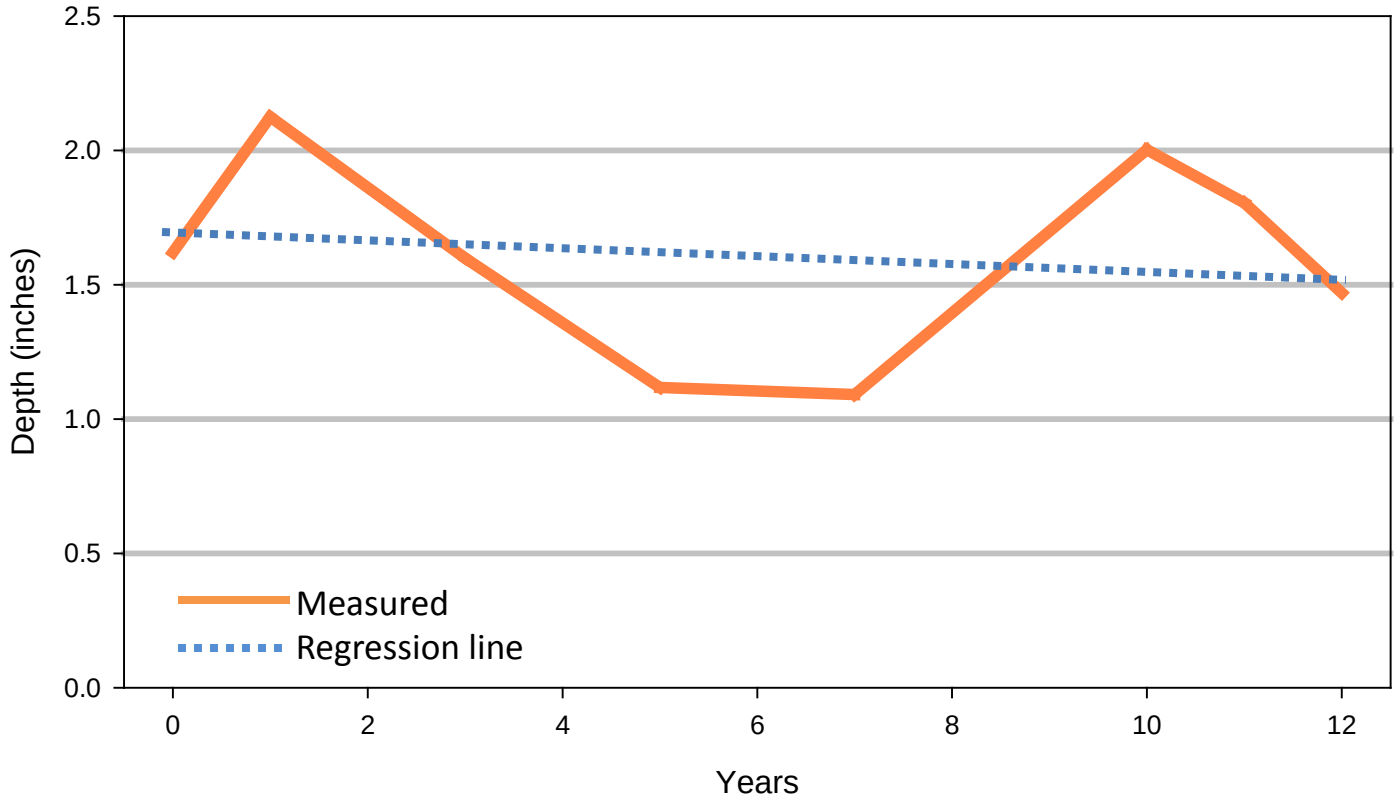
Mechanical Only: Total Woody Fuels



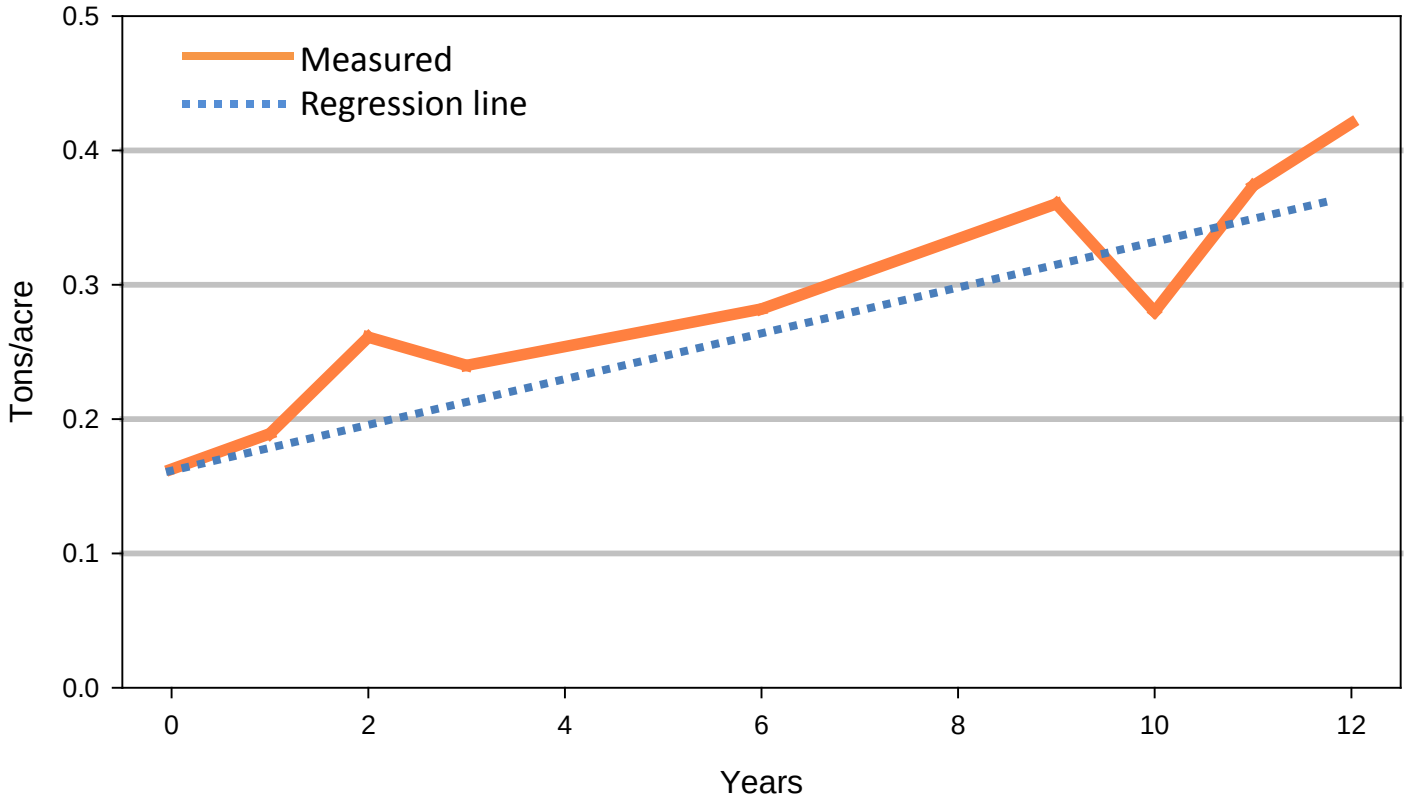
Mechanical Only: Litter Depth



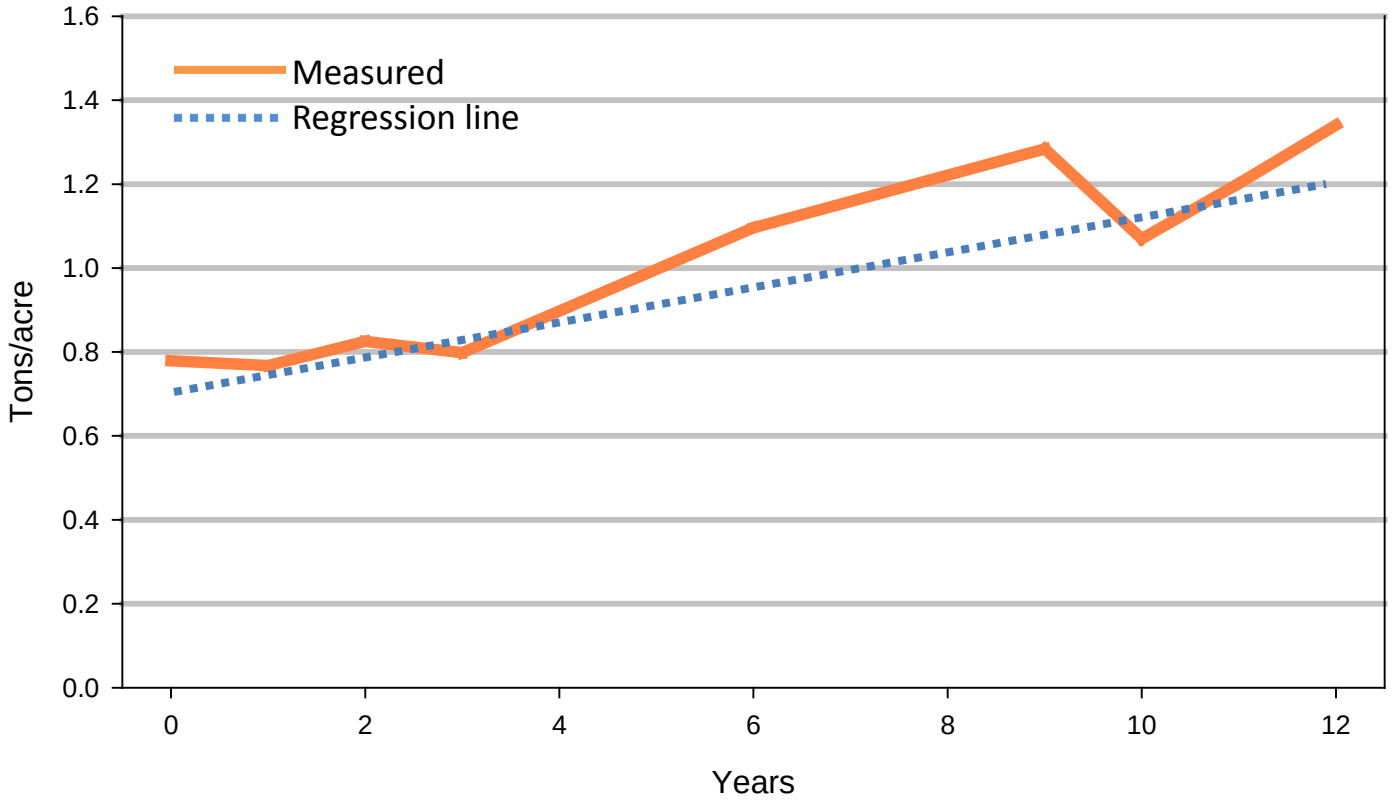
Mechanical Only: Duff Depth



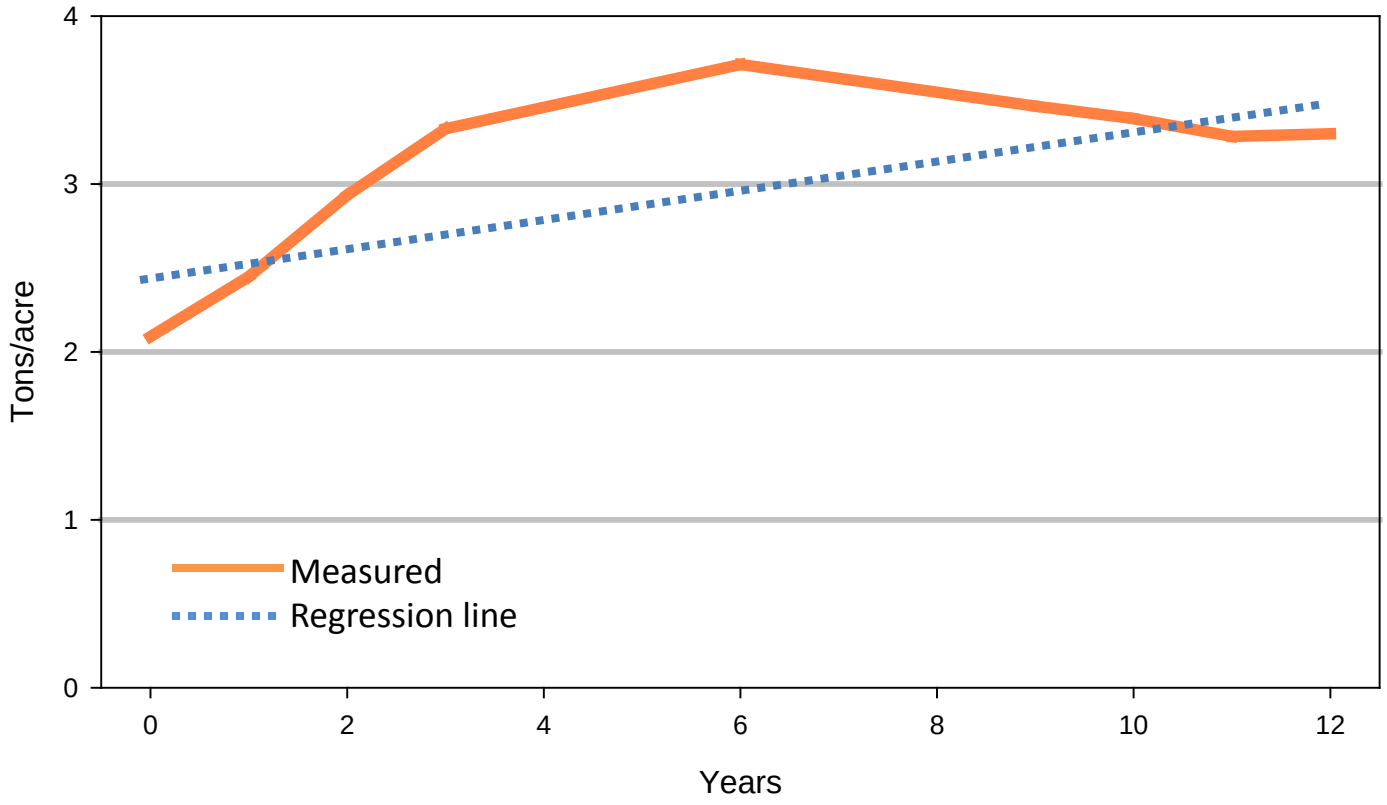
Mechanical +Burn: 1-hour Fuels



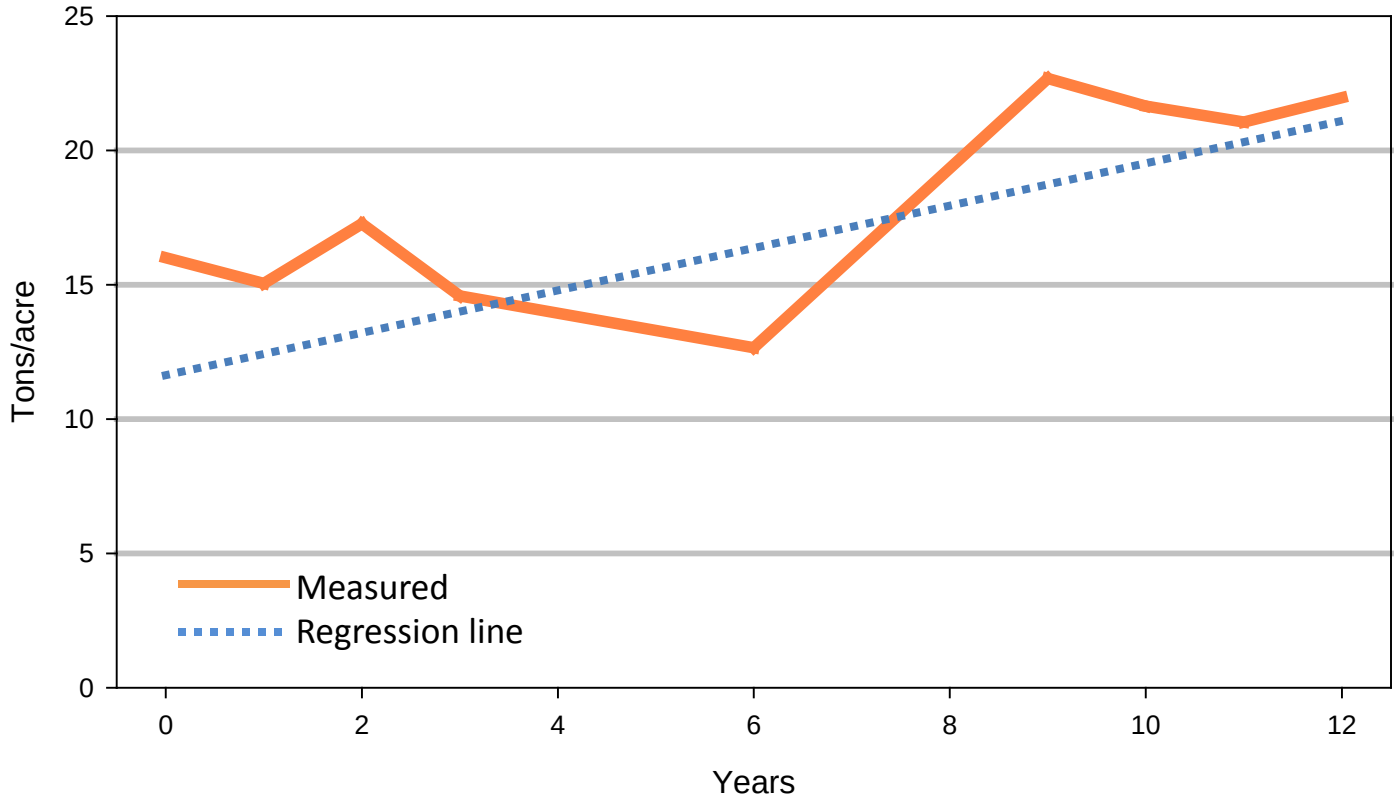
Mechanical + Burn: 10-hour Fuels



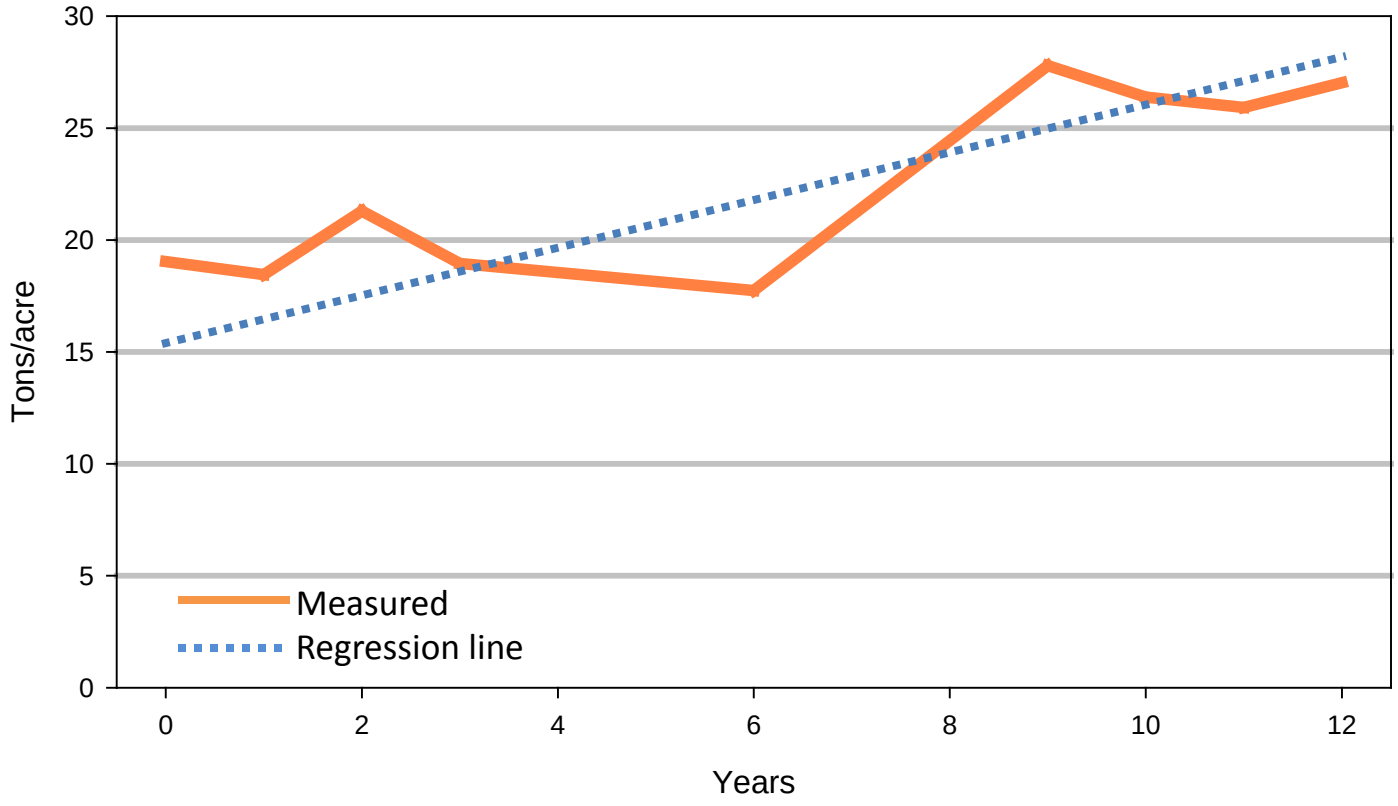
Mechanical + Burn: 100-hour Fuels



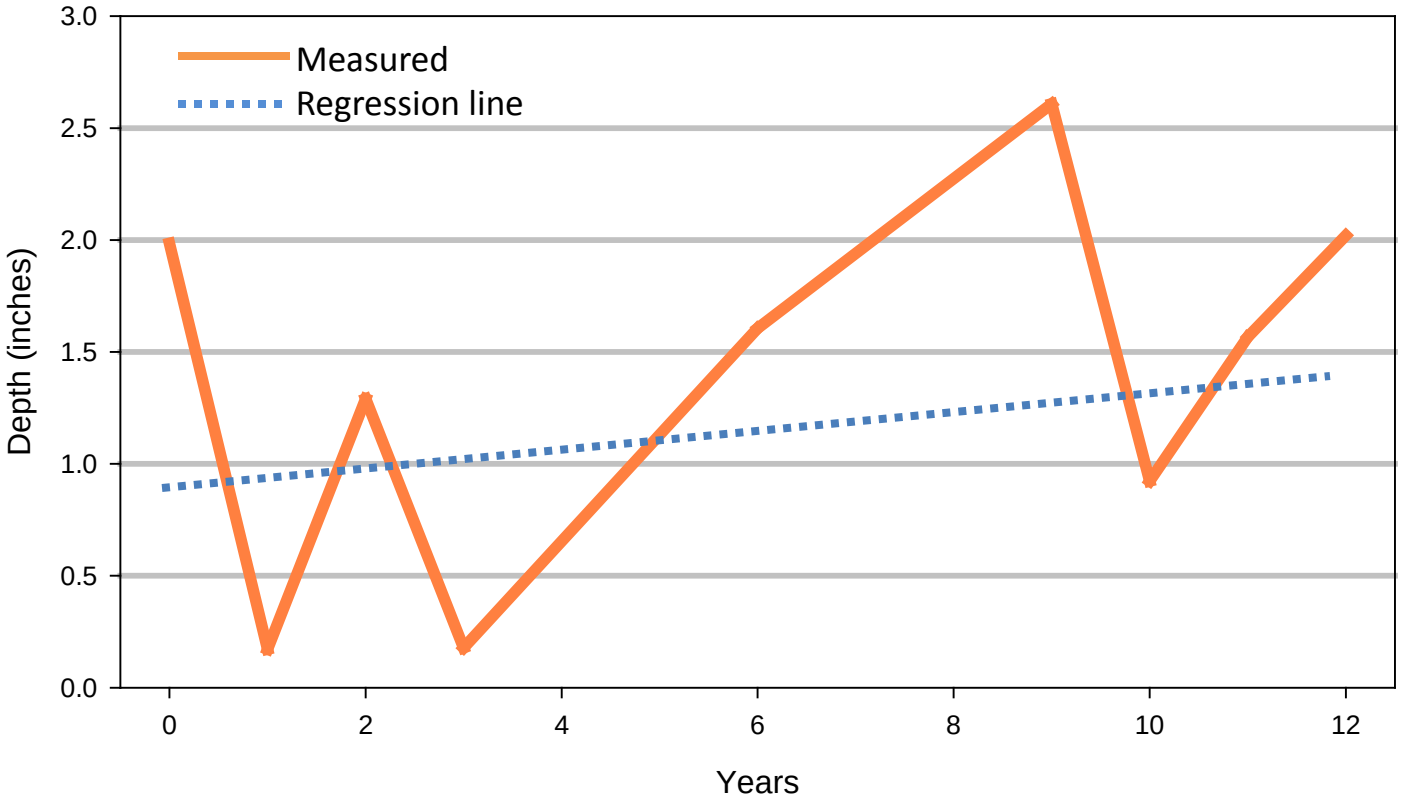
Mechanical + Burn: 1,000-hour Fuels



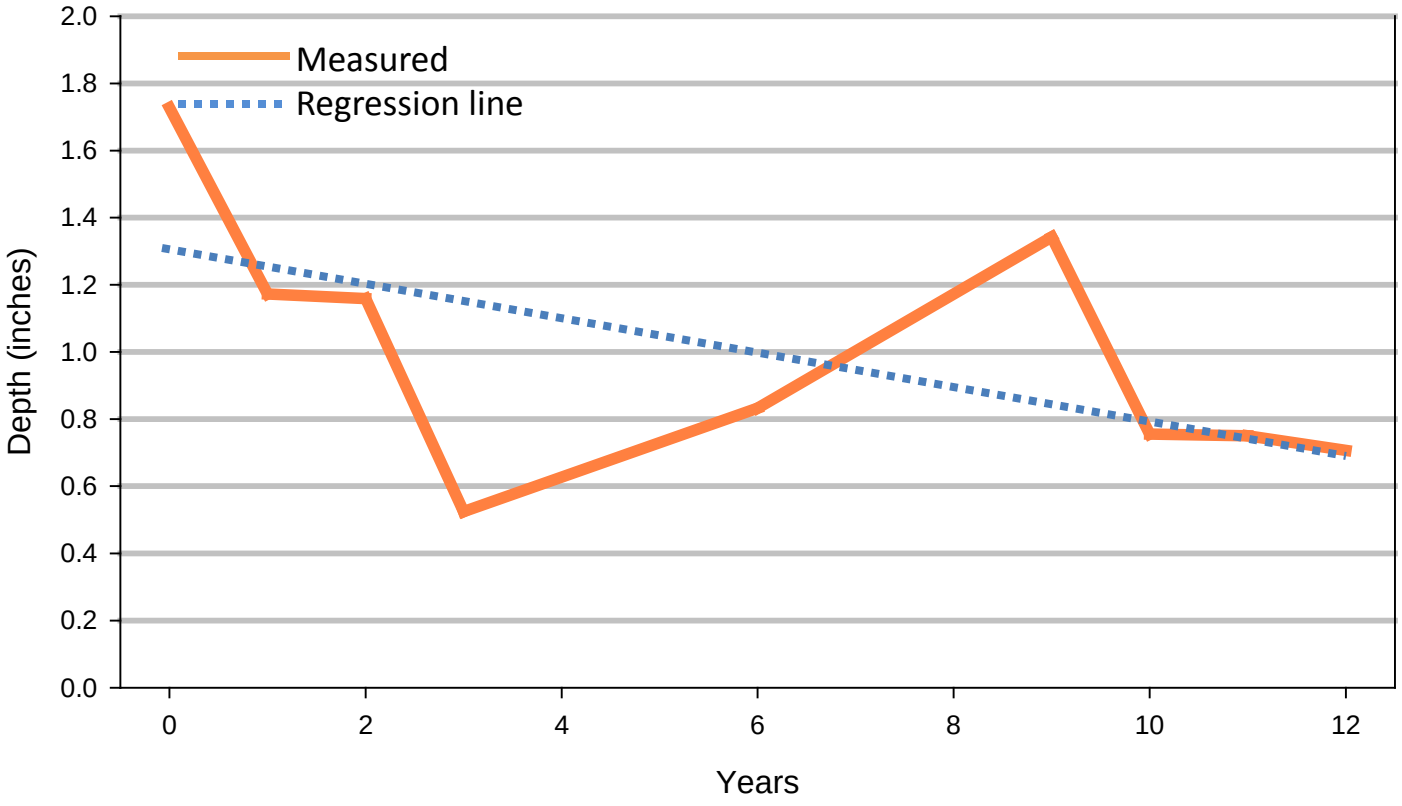
Mechanical + Burn: Total Woody Fuels



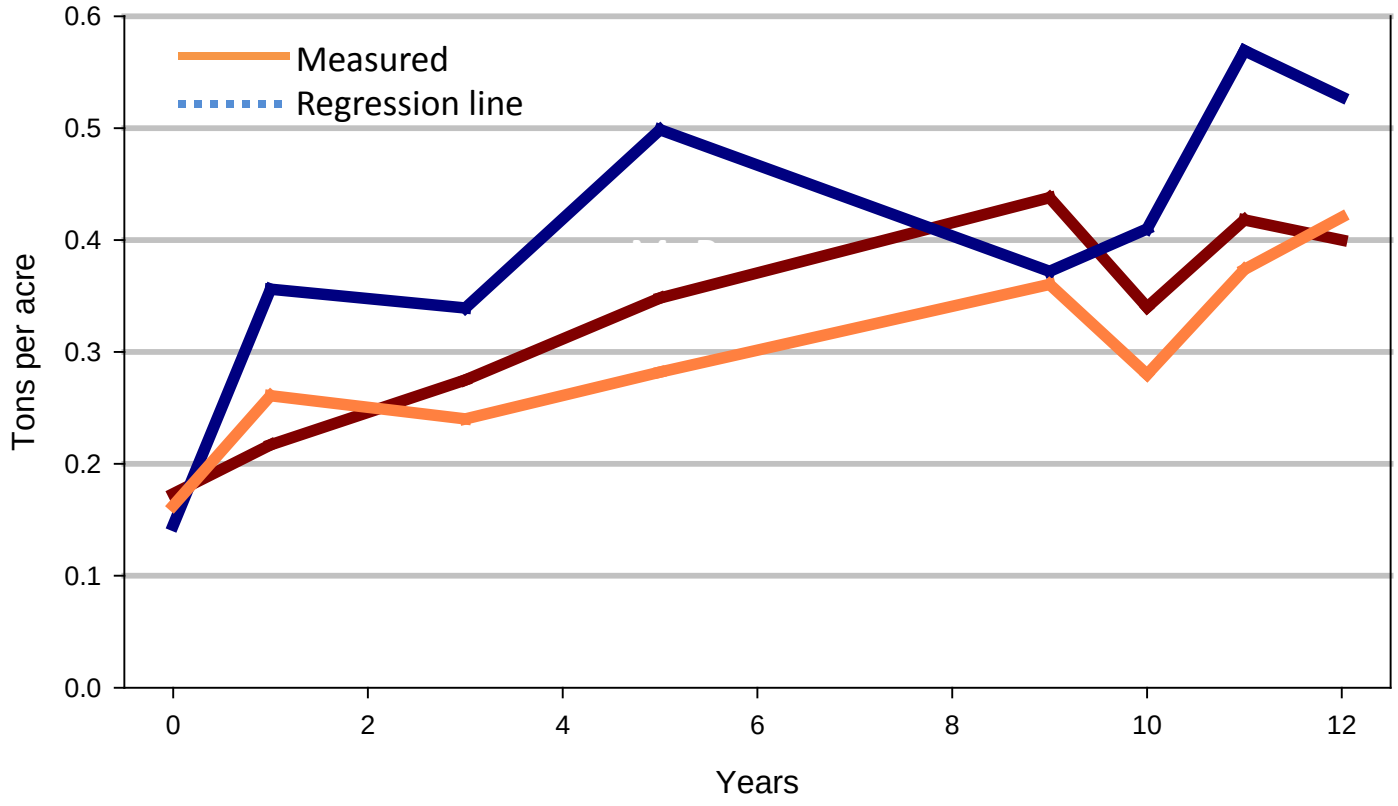
Mechanical + Burn: Litter Depth



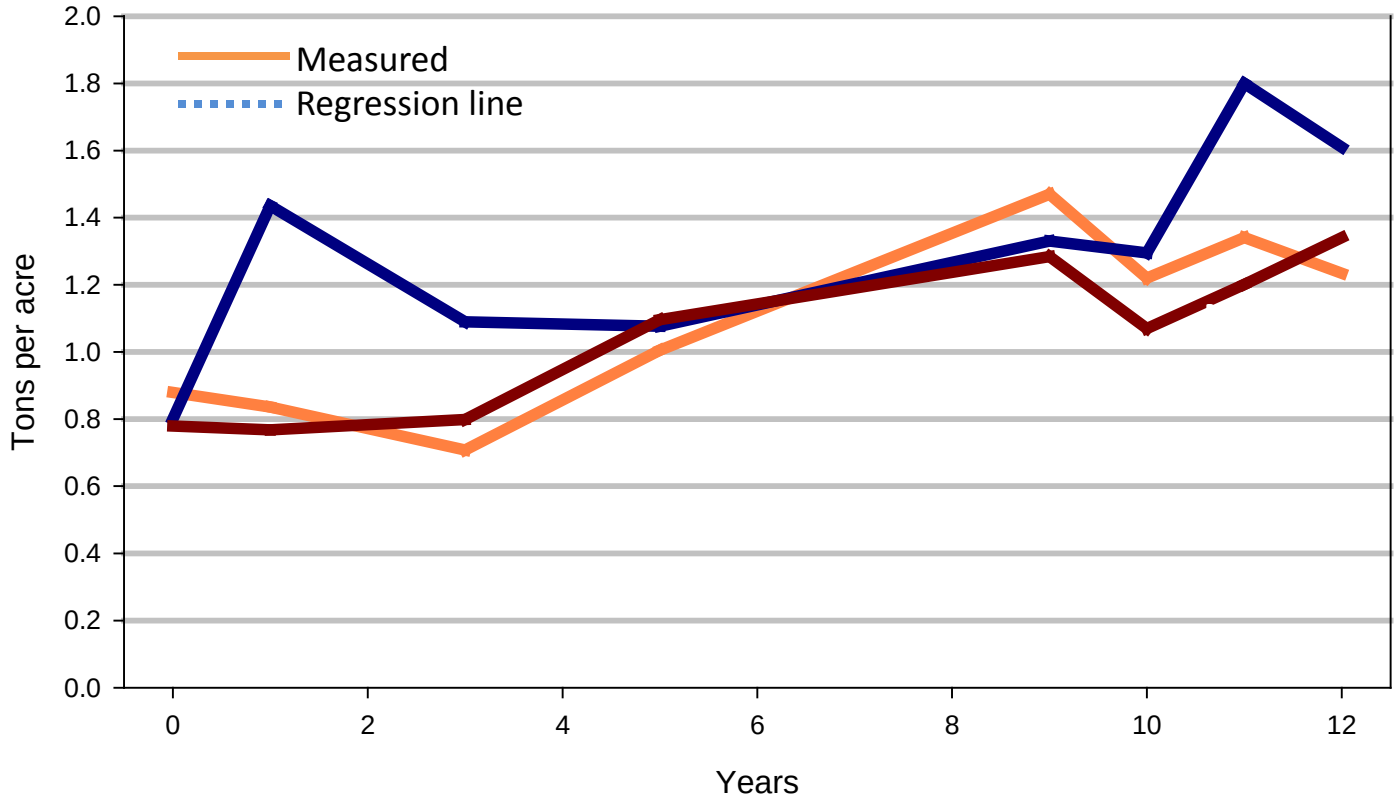
Mechanical + Burn: Duff Depth



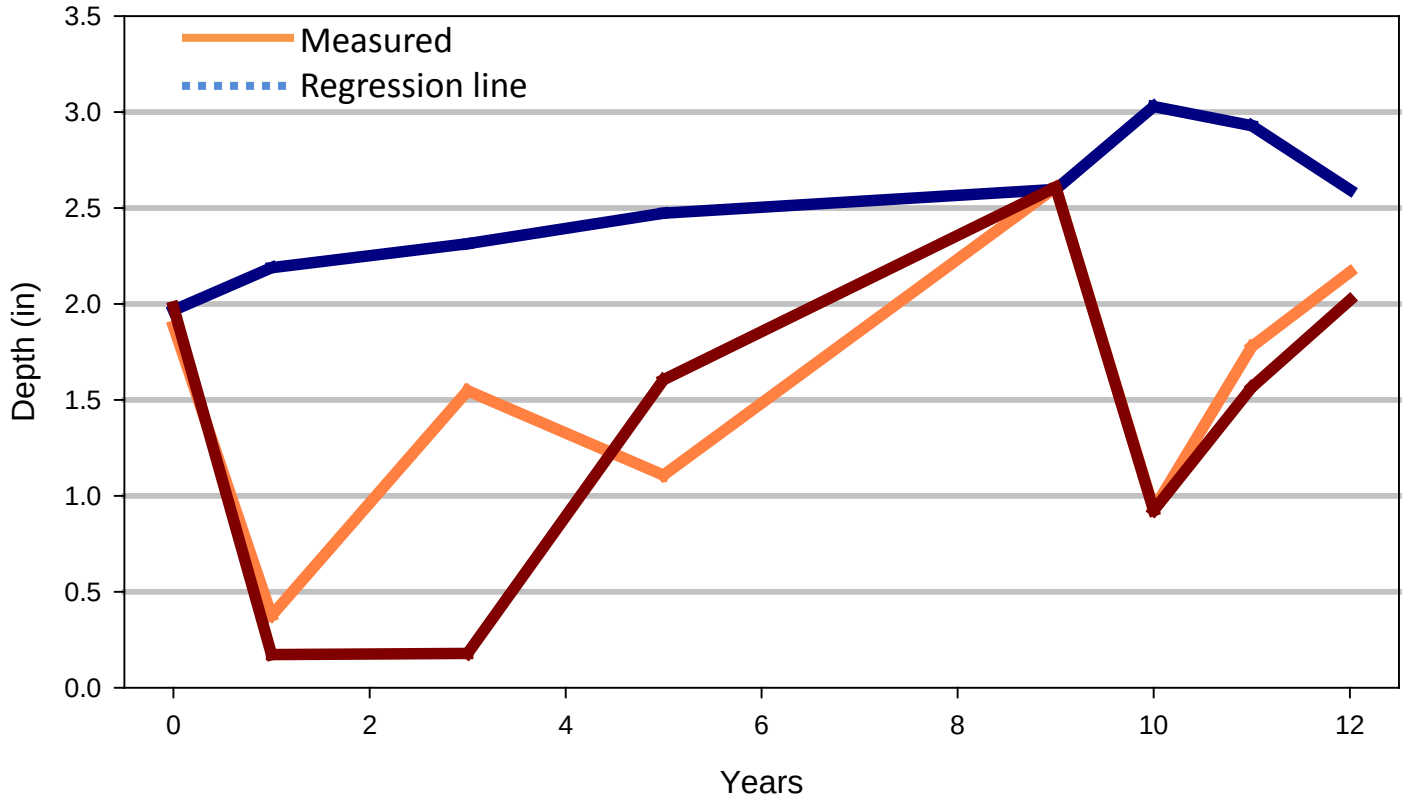
All Treatments: 1-hour Fuels



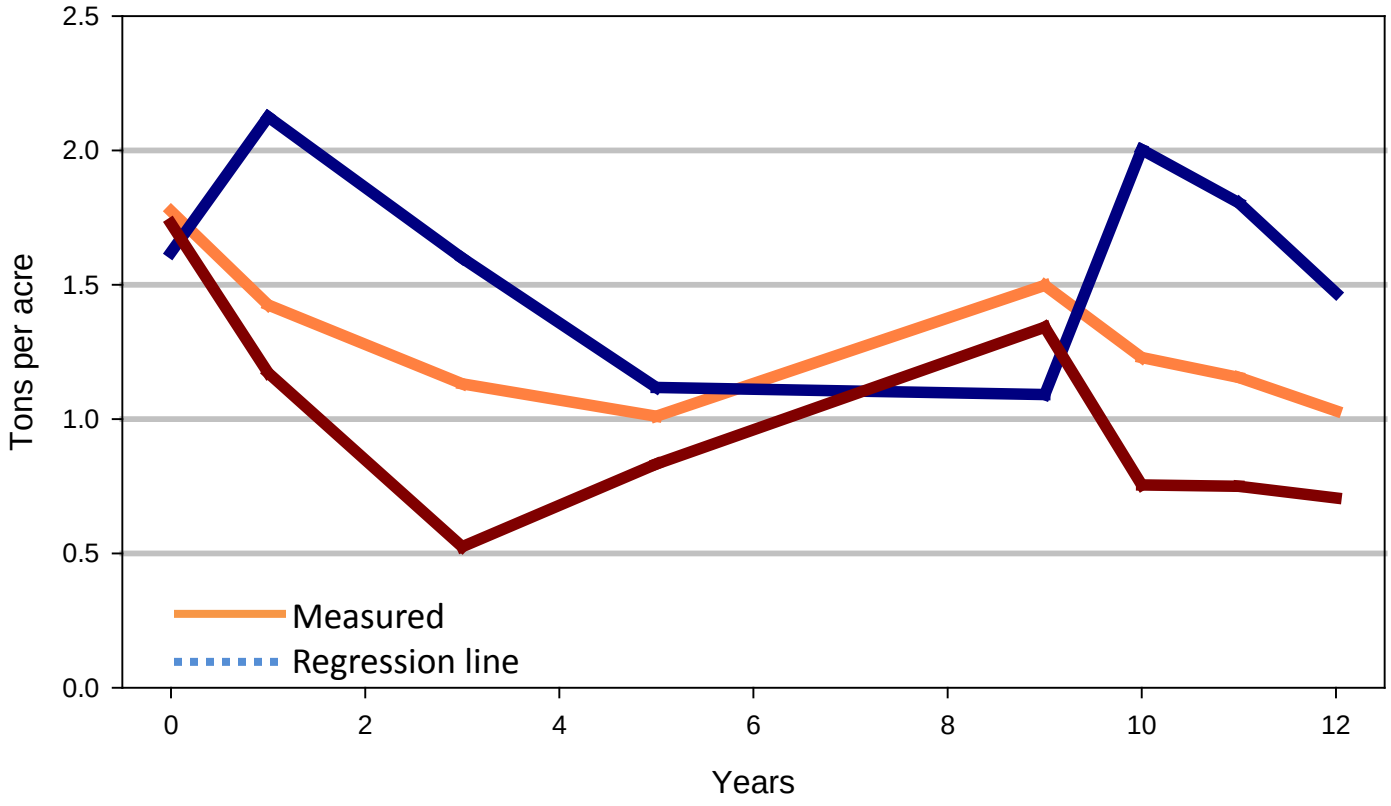
All Treatments: 10-hour Fuels



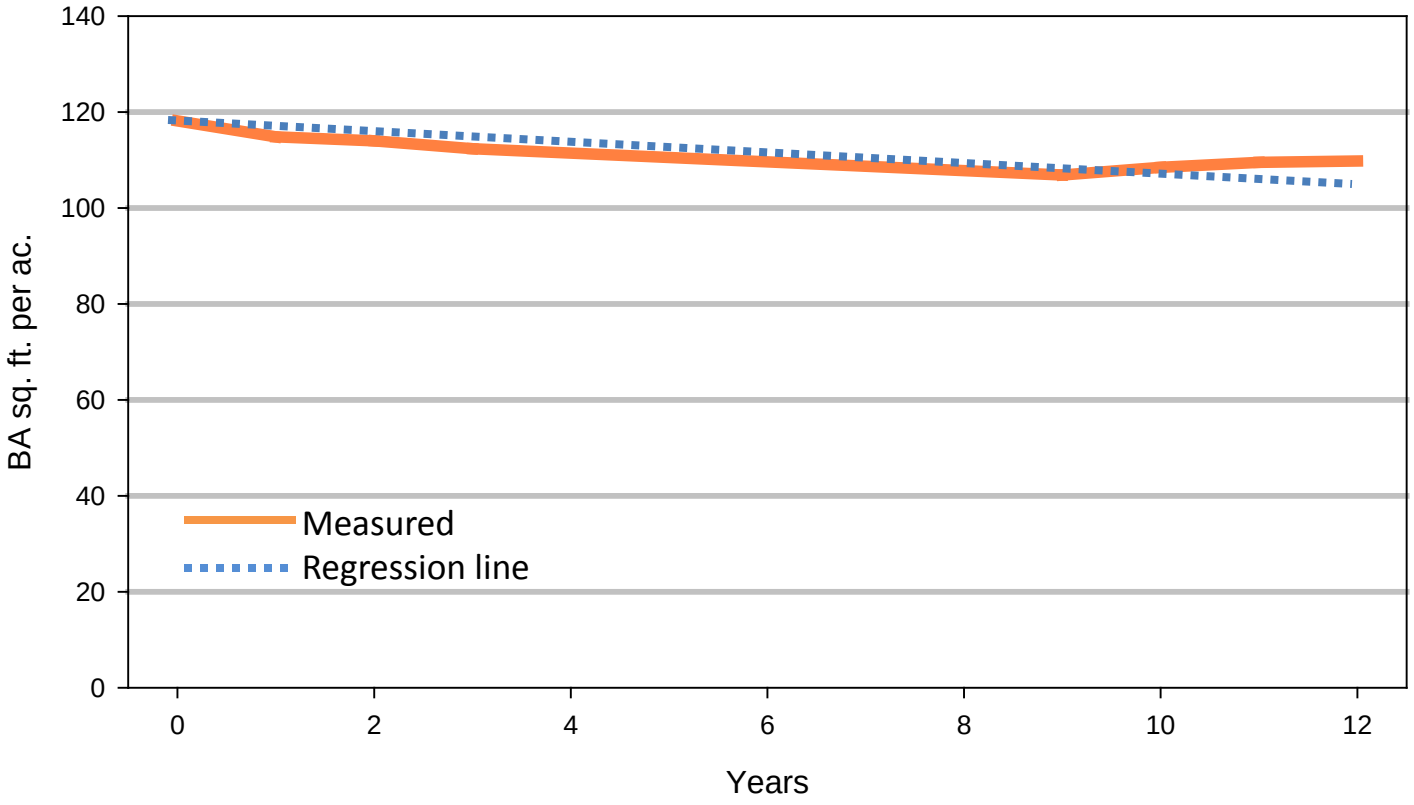
All Treatments: Litter



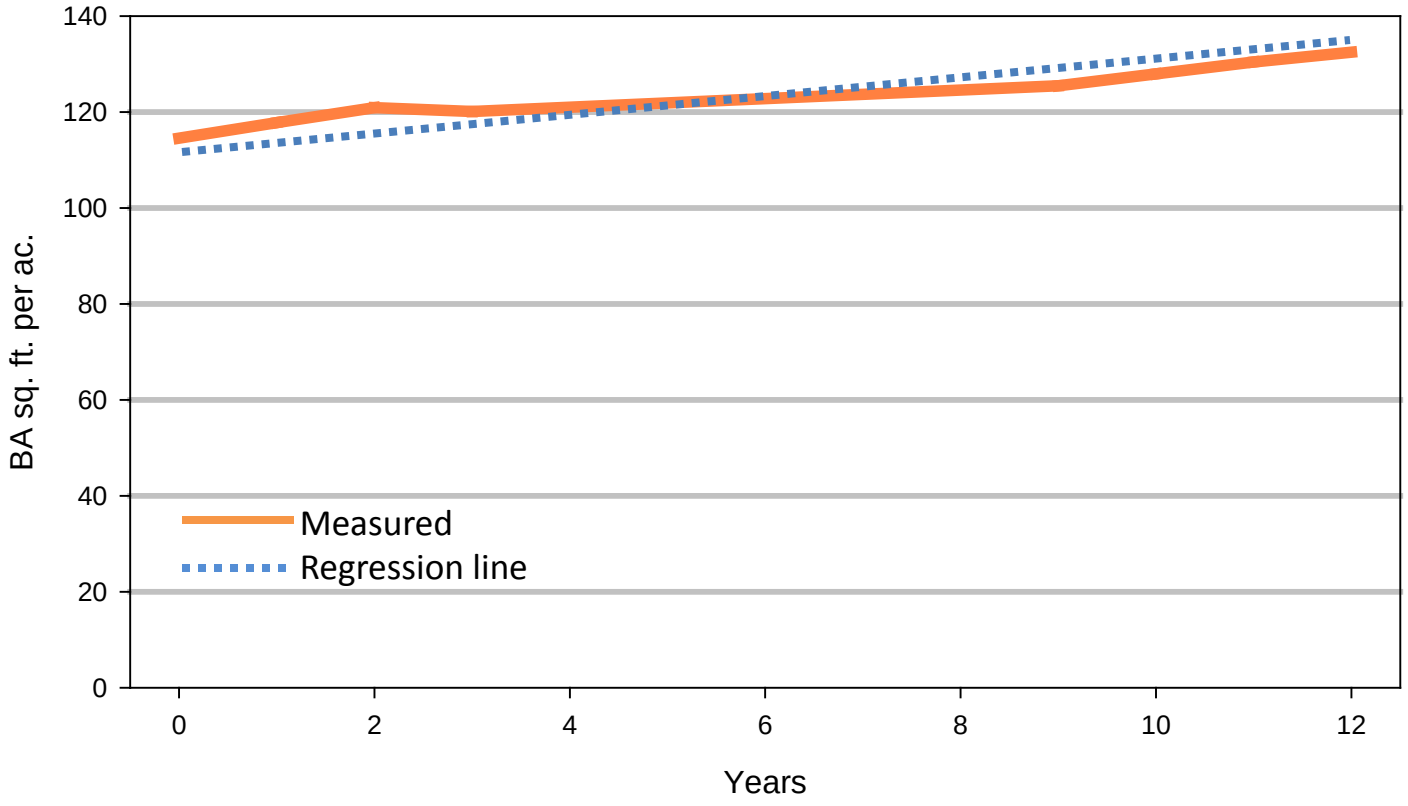
All Treatments: Duff



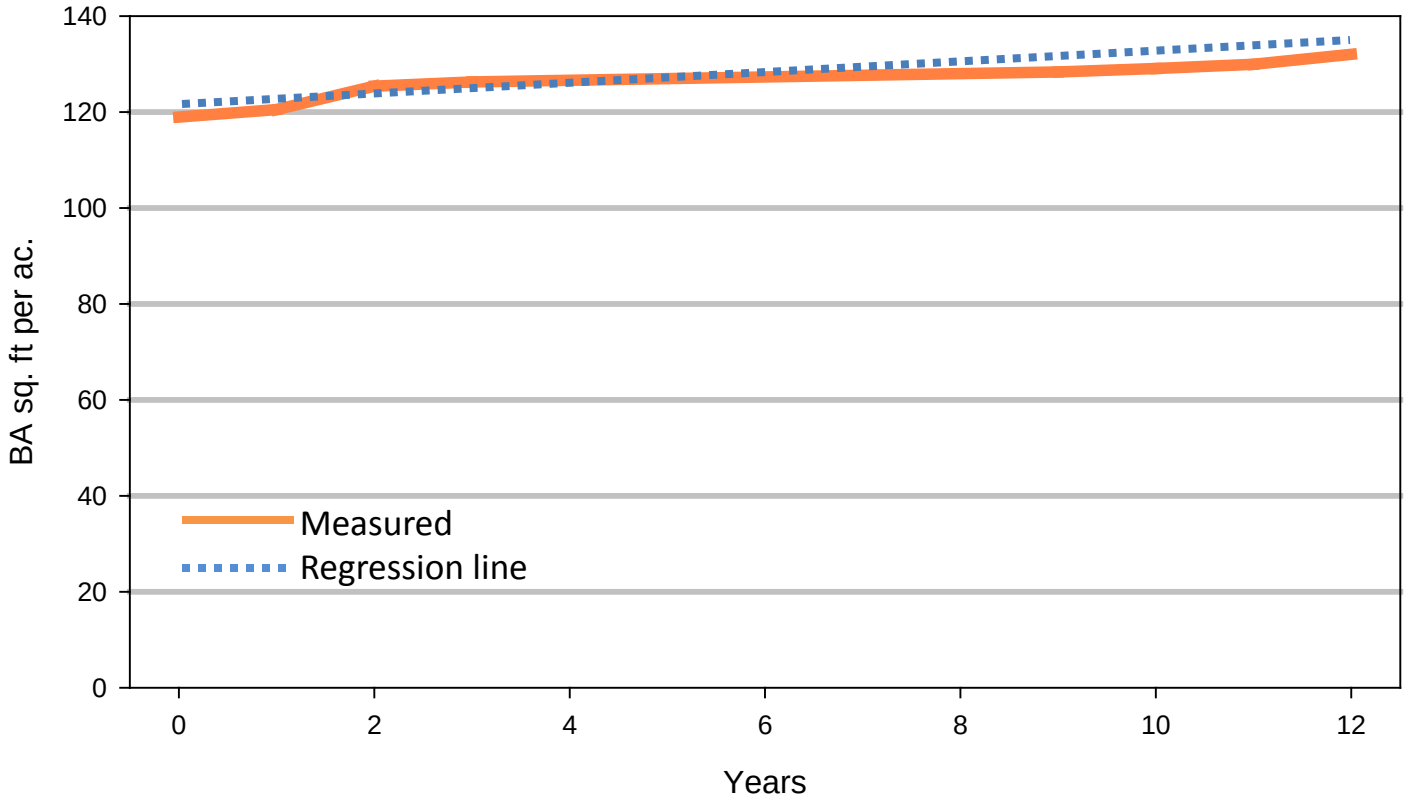
Burn Only: Basal Area



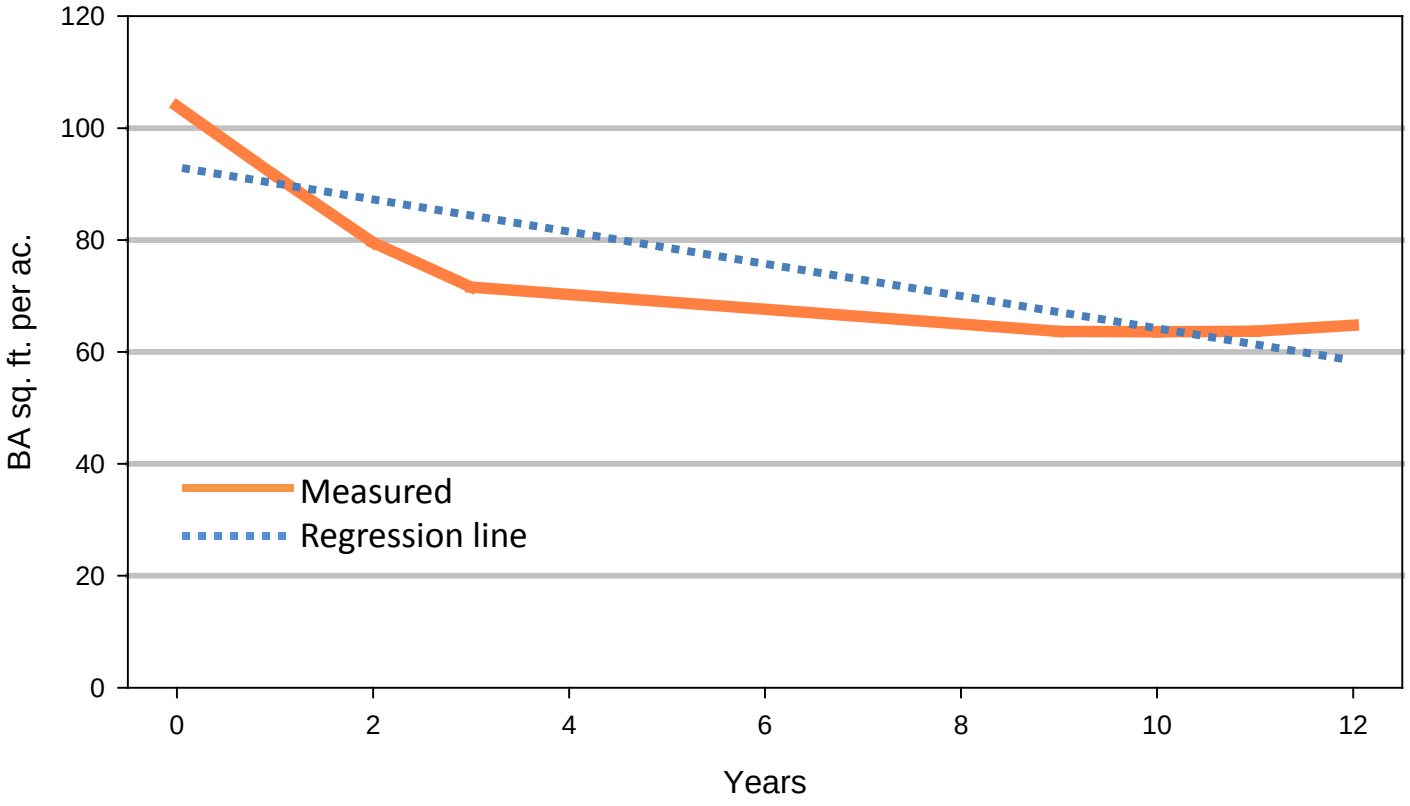
Control: Basal Area



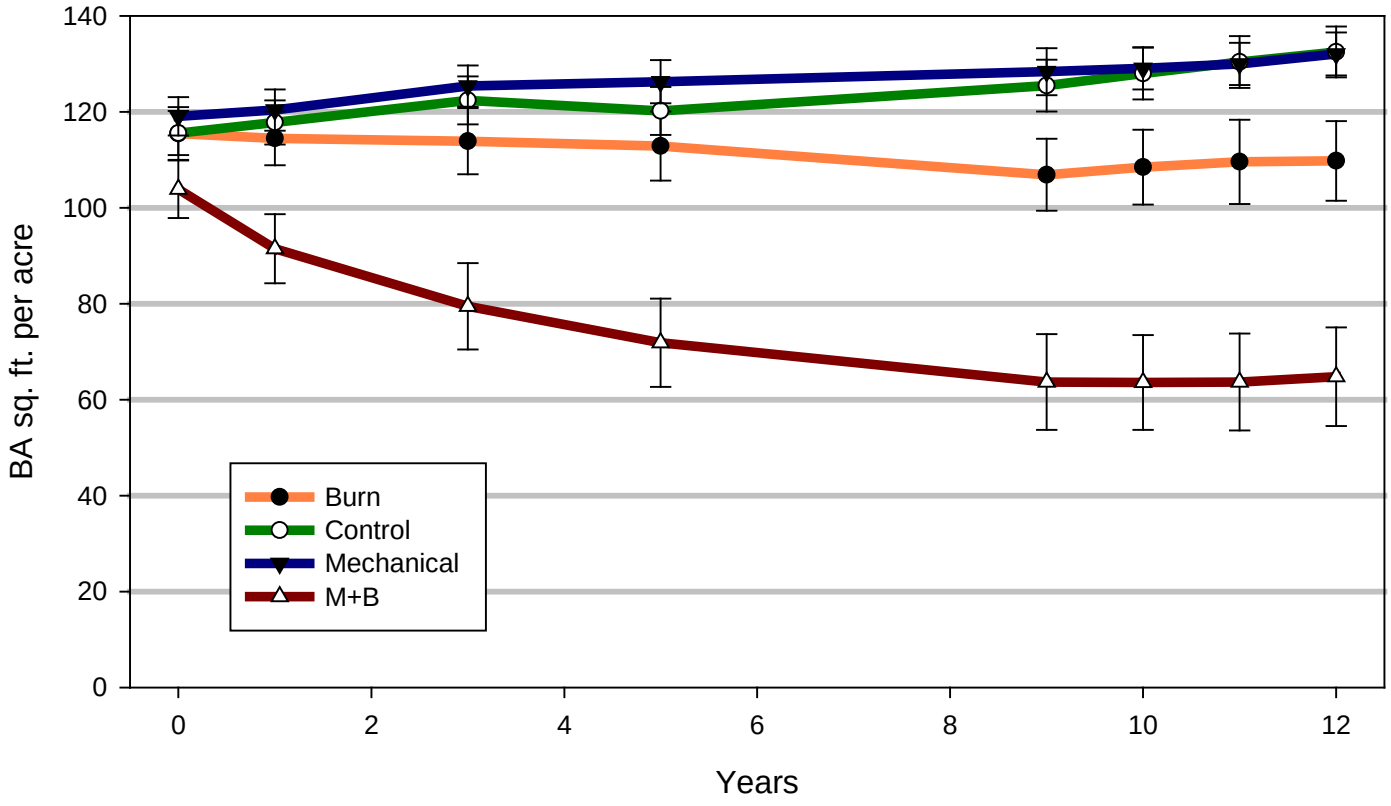
Mechanical Only: Basal Area



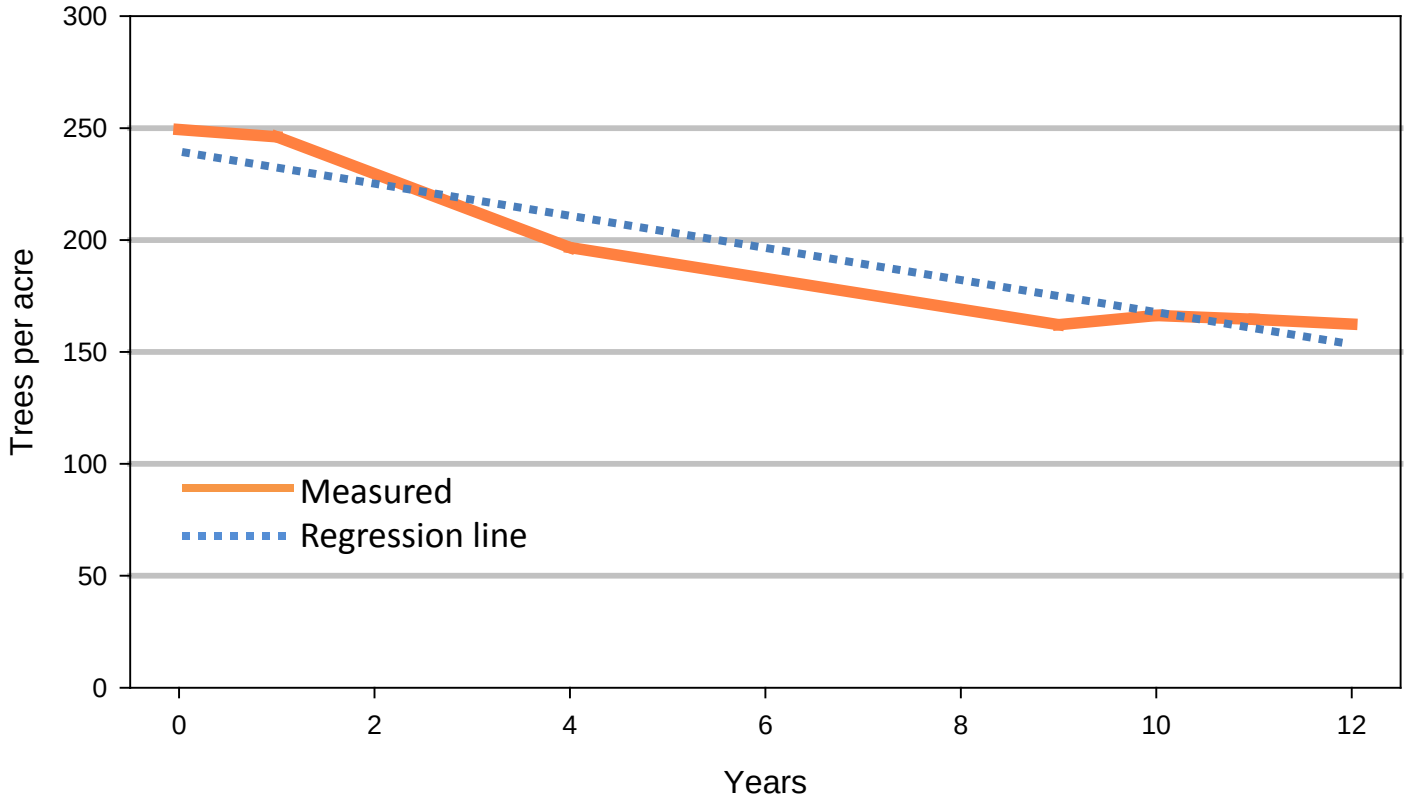
Mechanical + Burn: Basal Area



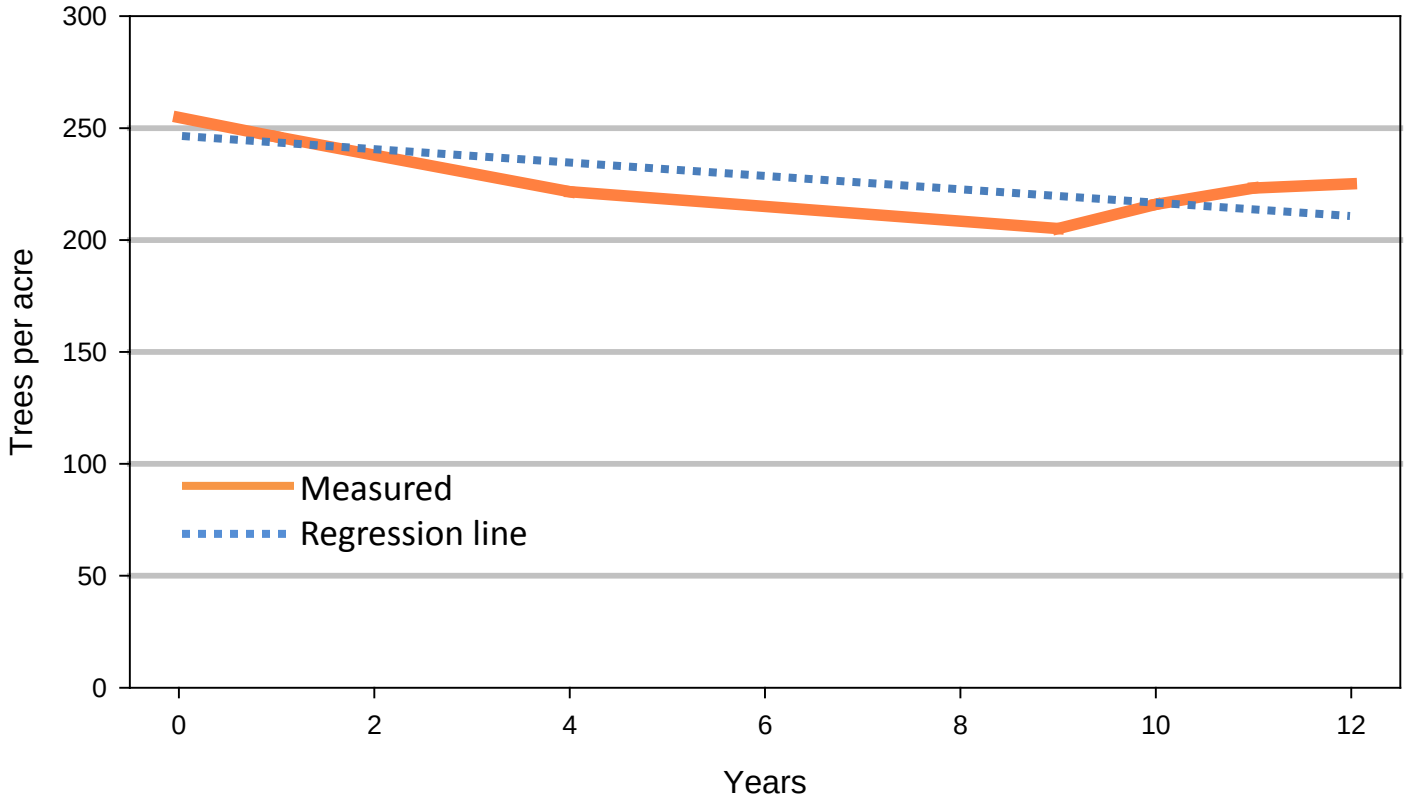
Basal Area by Treatment



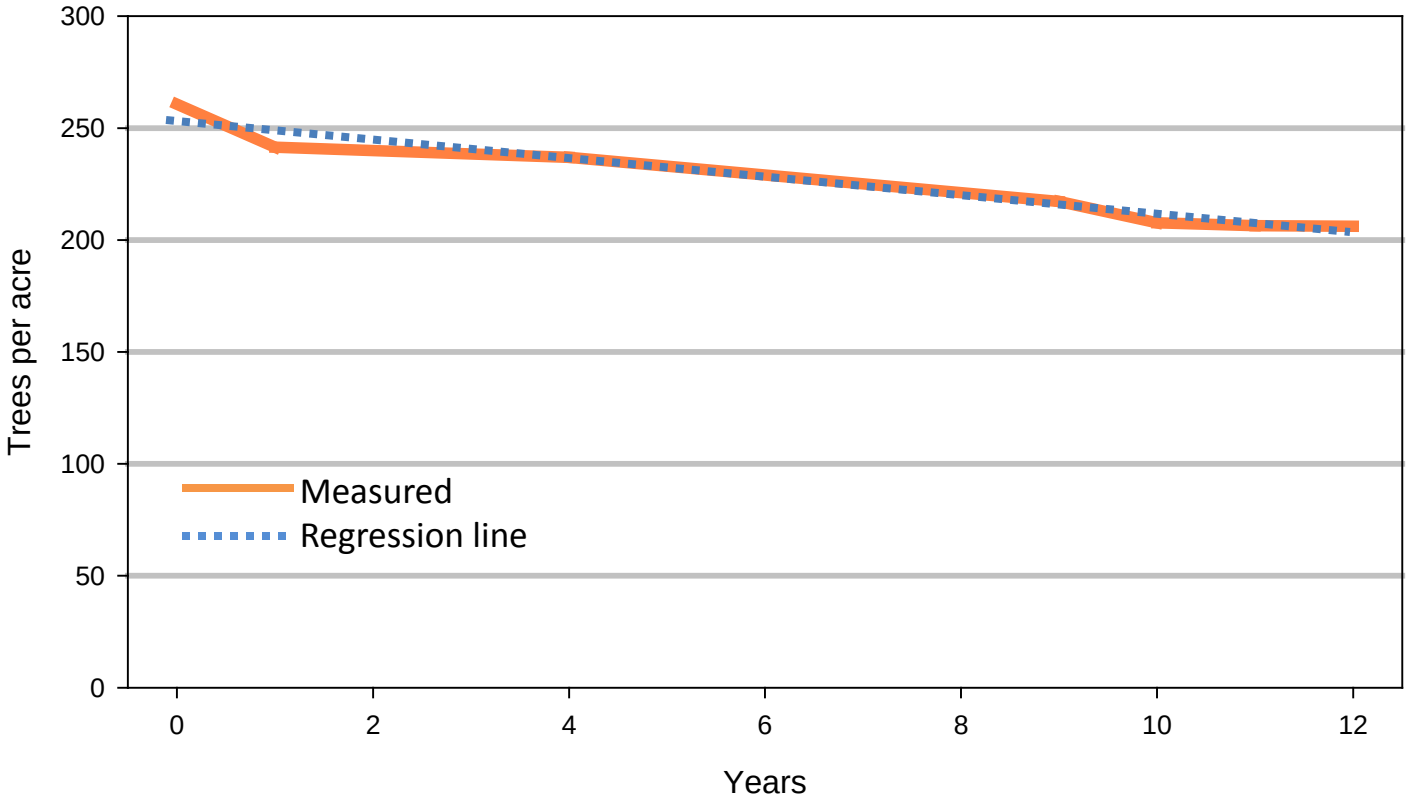
Burn: Overstory Density



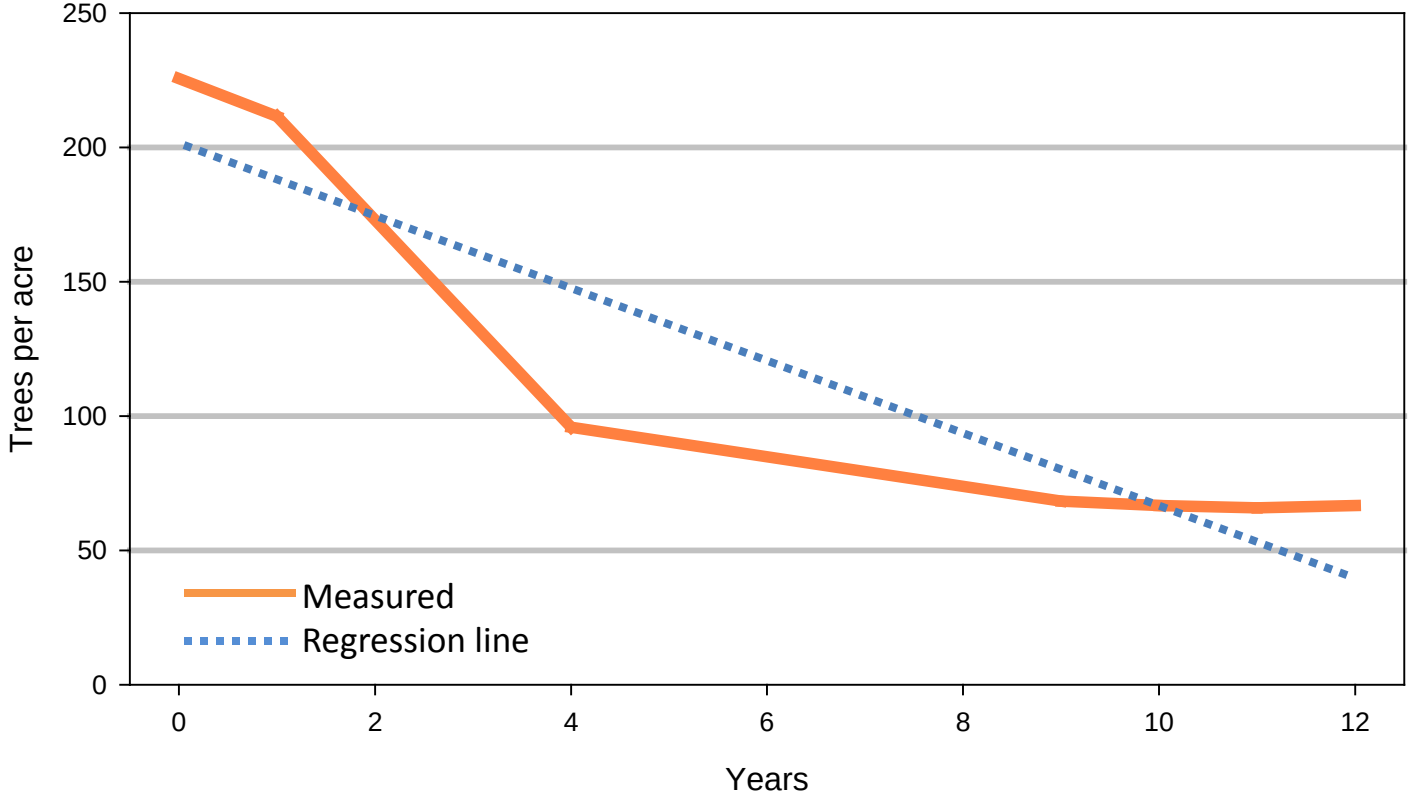
Control: Overstory Density



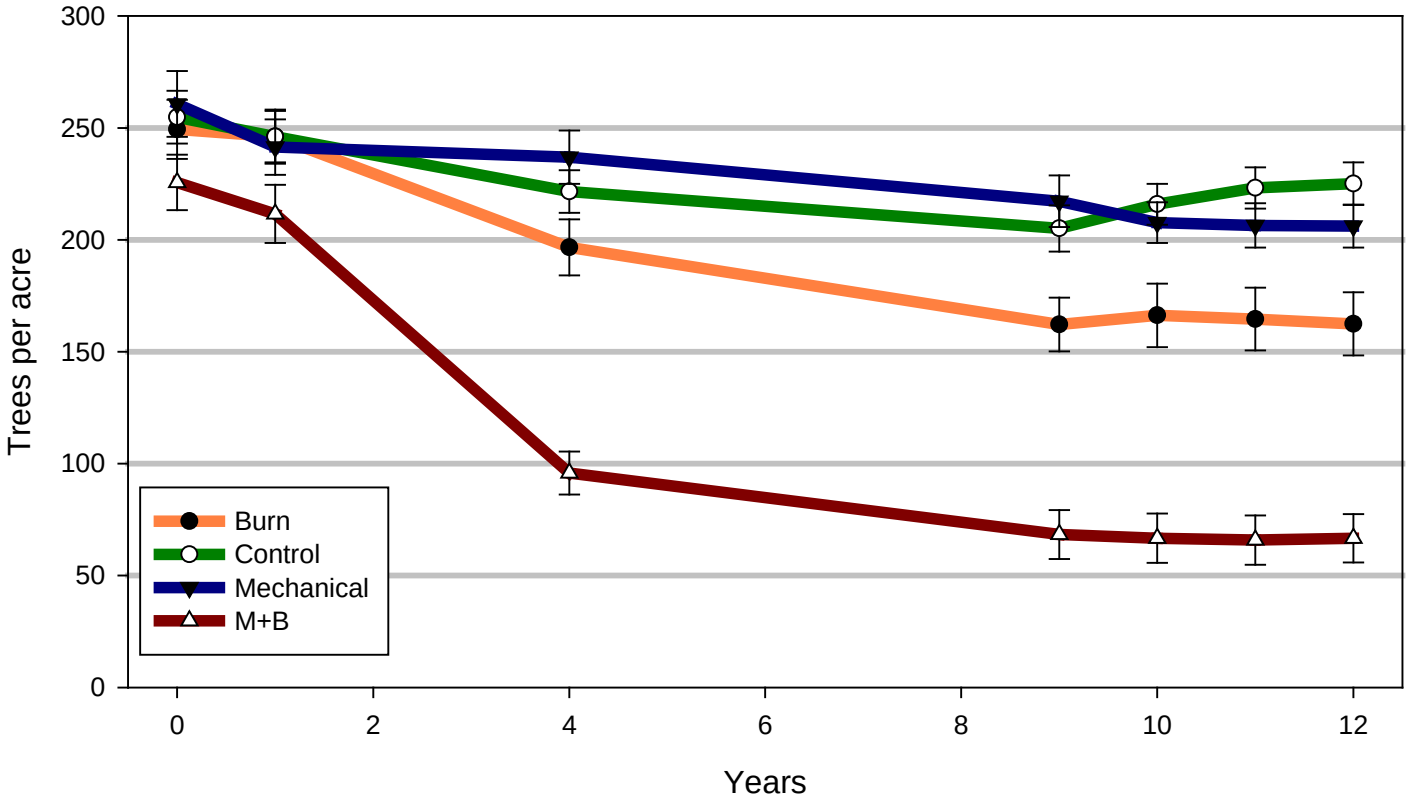
Mechanical: Overstory Density



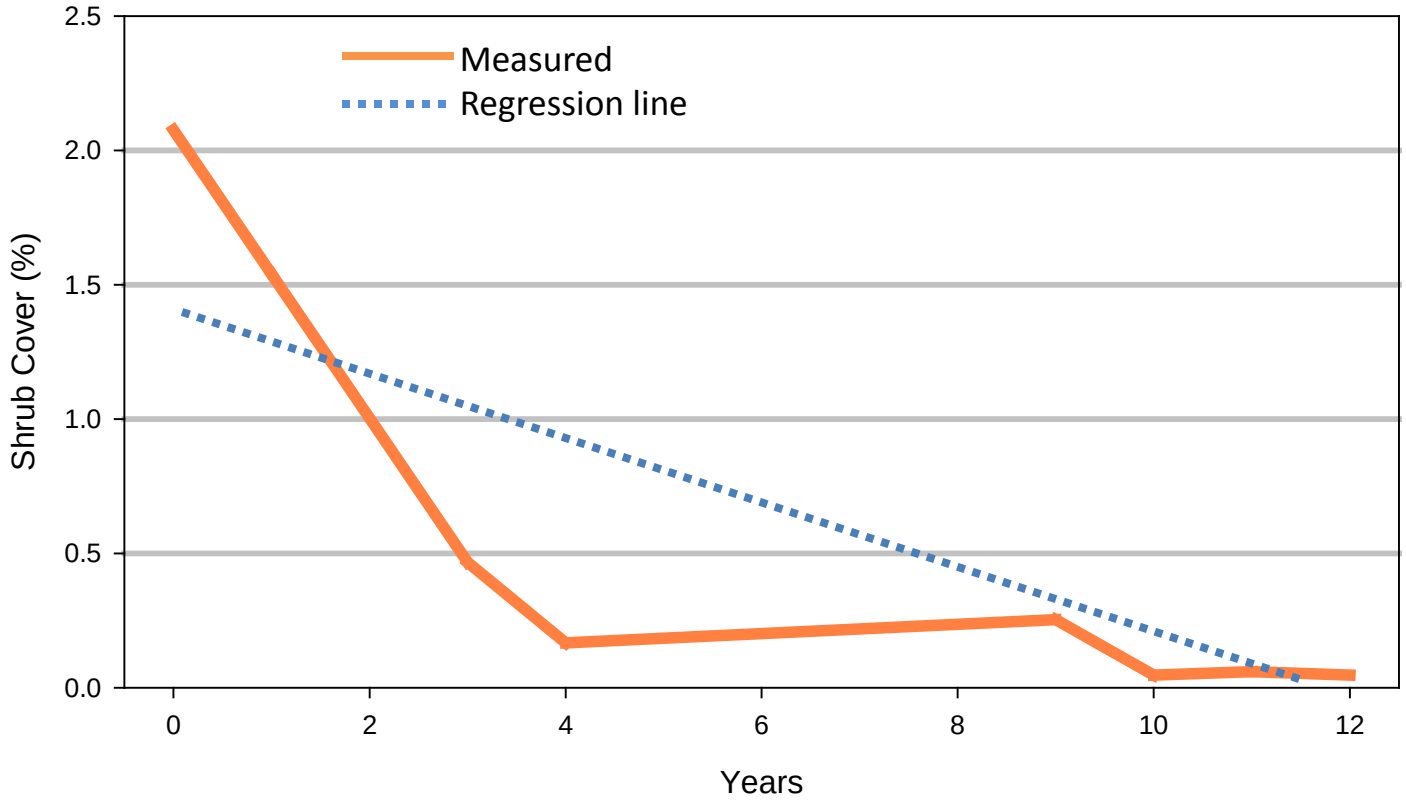
Mechanical + Burn: Overstory Density



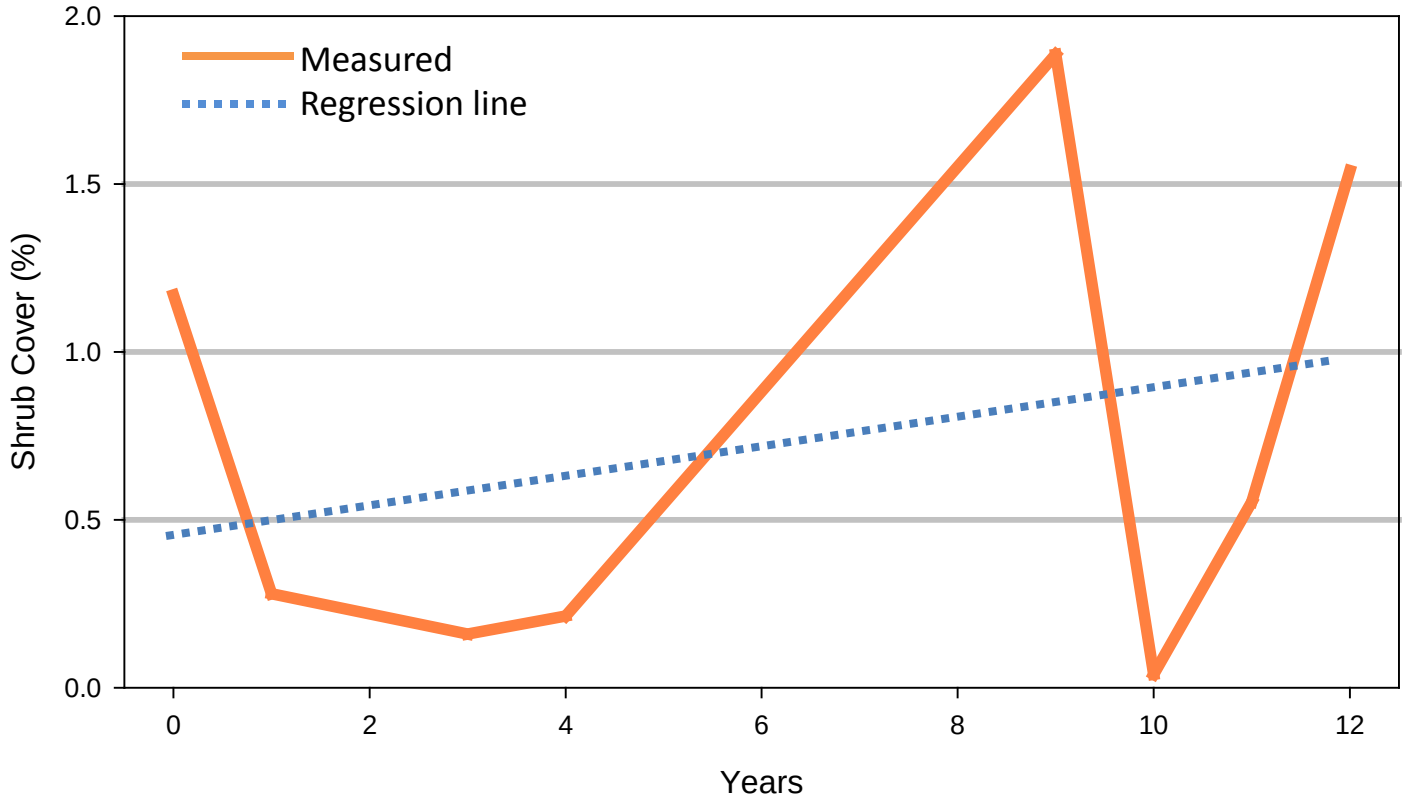
Overstory Density by Treatment



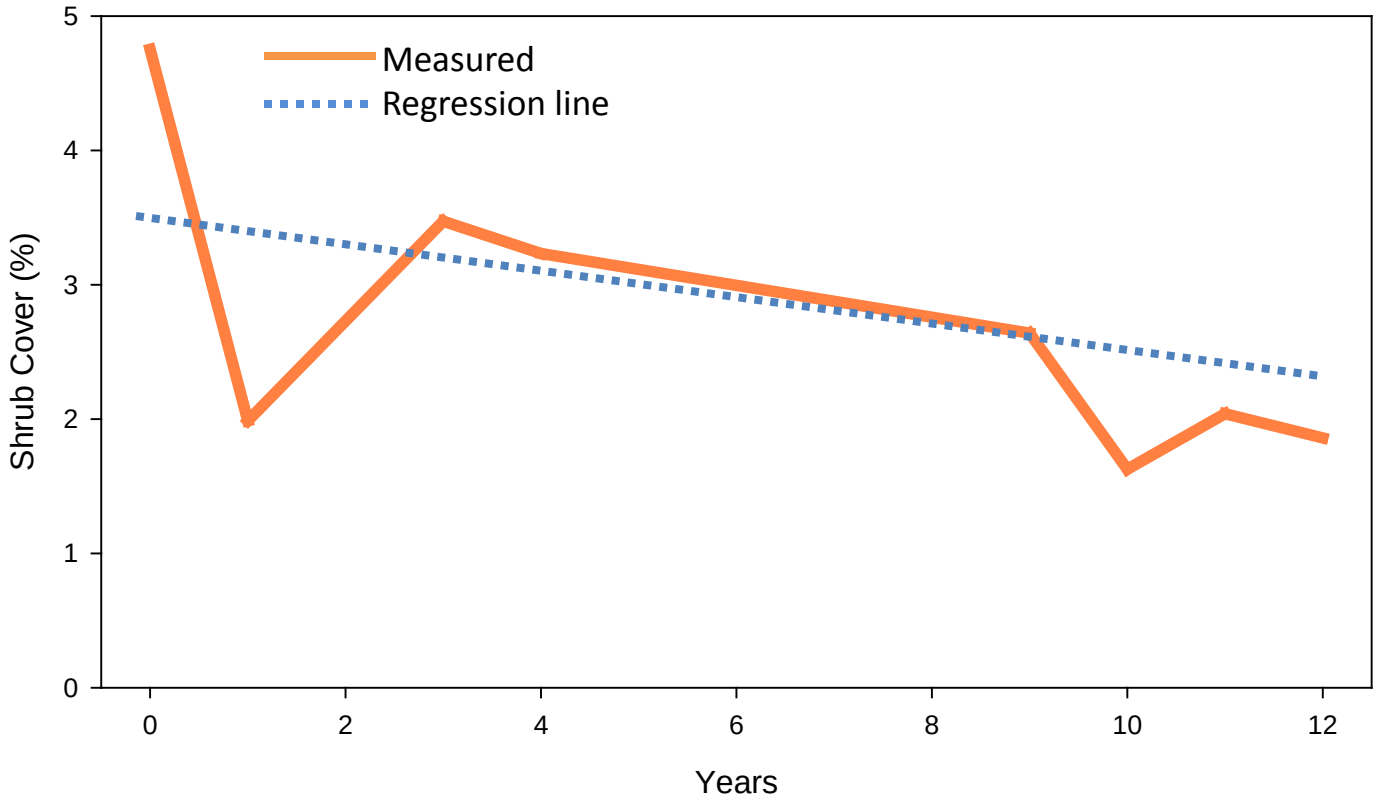
Burn Only: Mountain Laurel Cover (%)



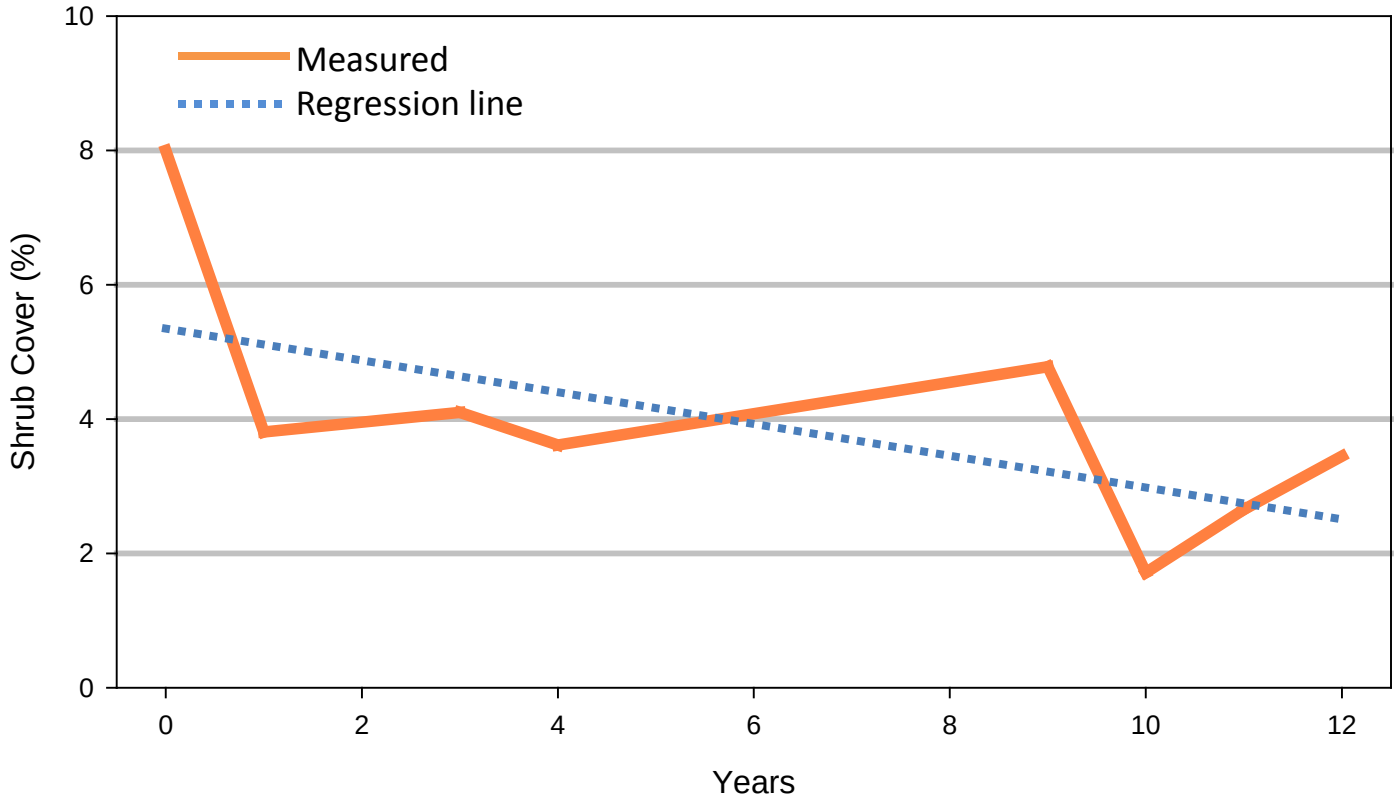
Burn Only: Other Species Cover (%)



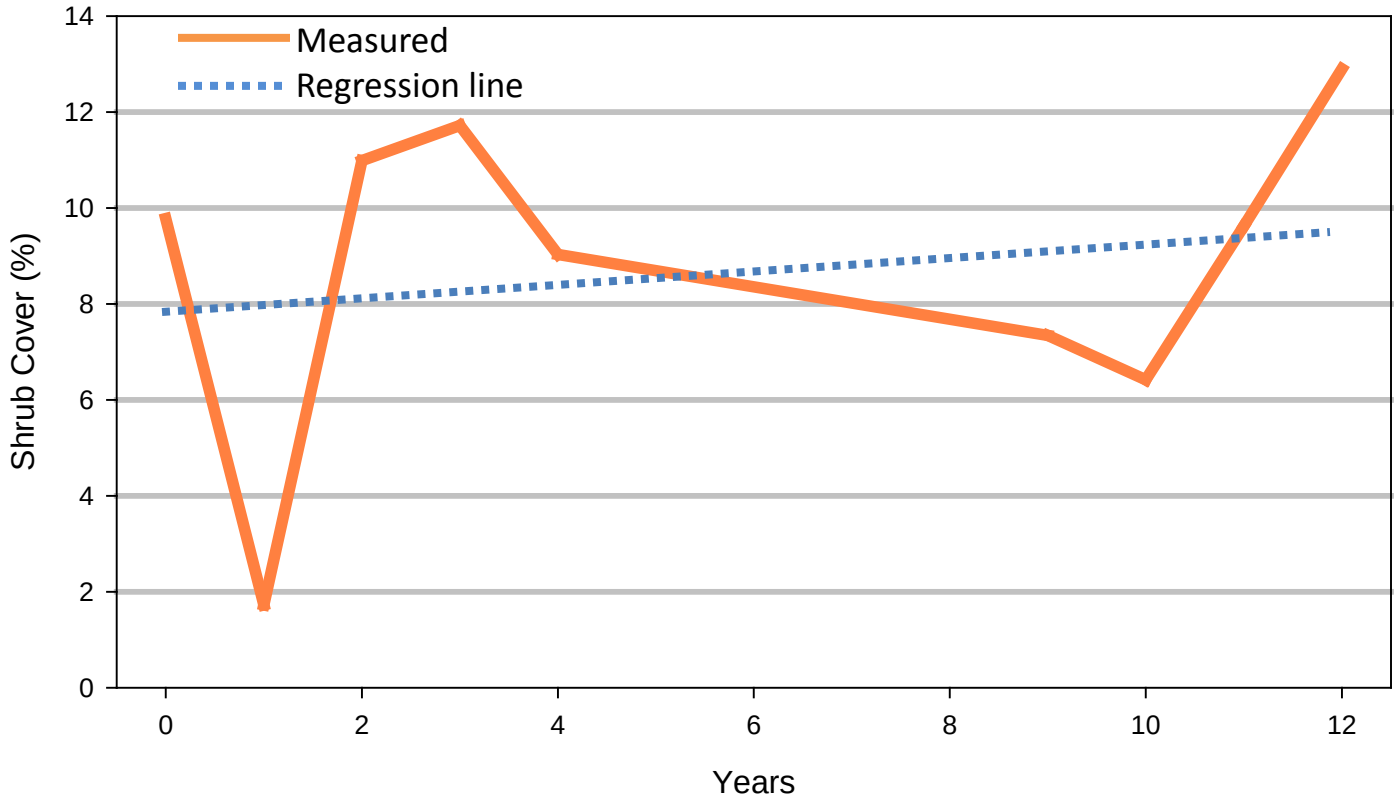
Burn Only: Rhododendron Cover (%)



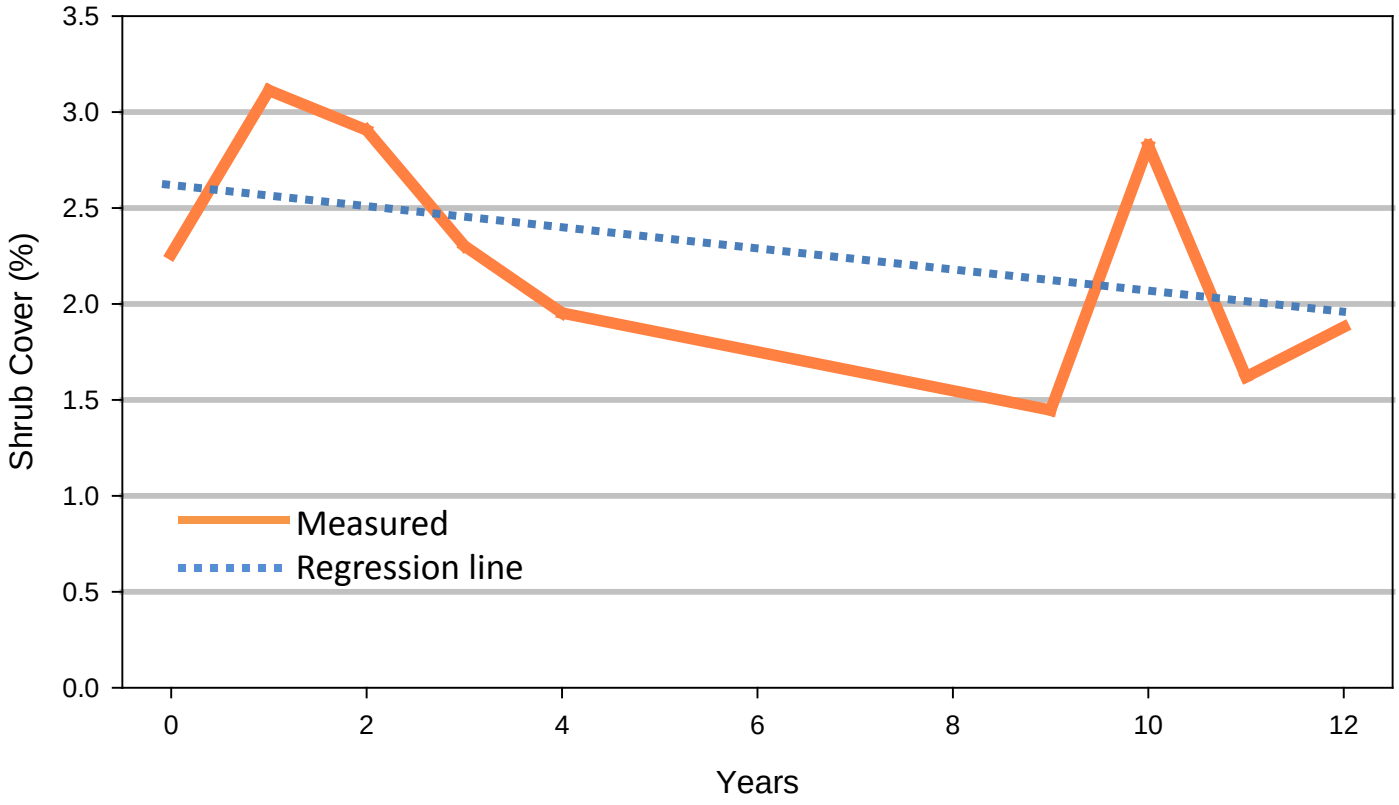
Burn Only: All Species Cover (%)



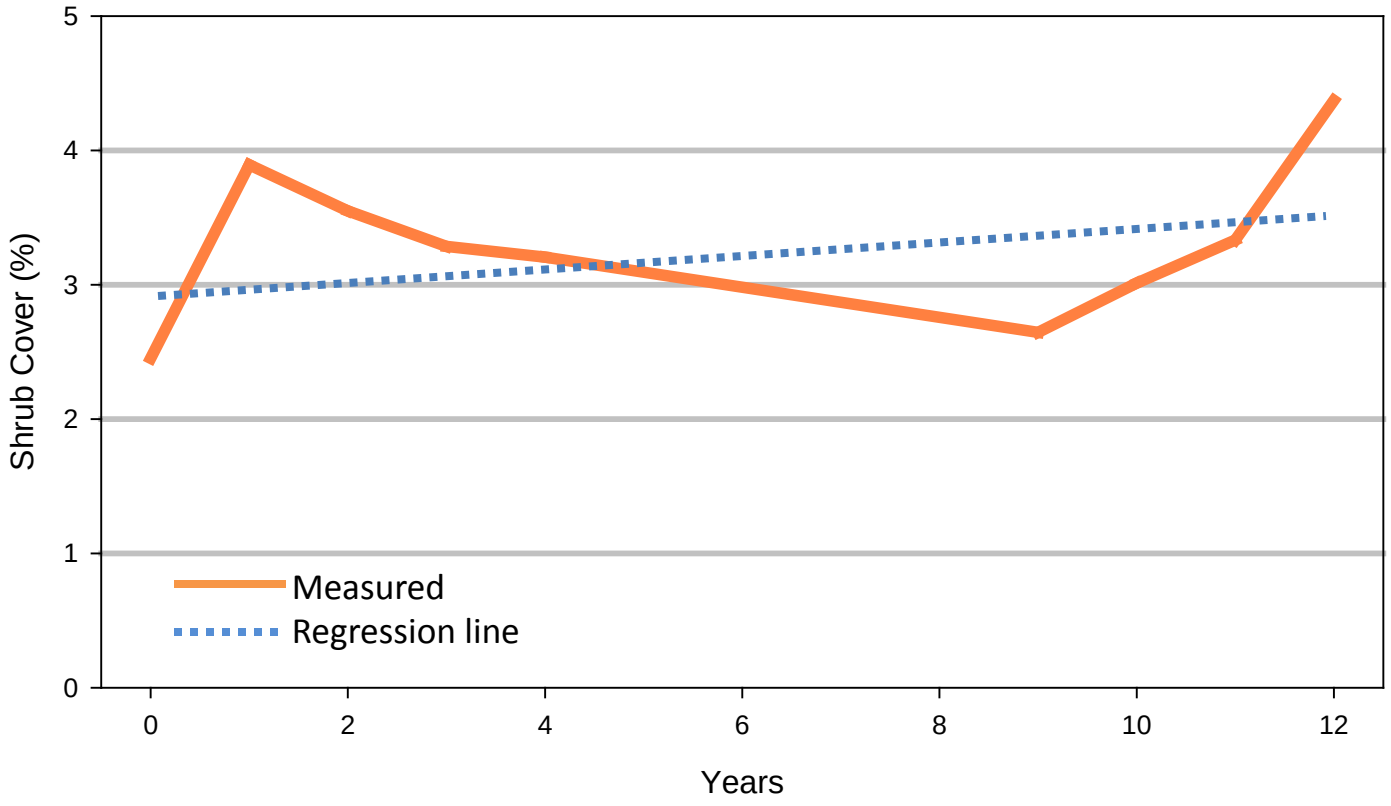
Control: Mountain Laurel Cover (%)



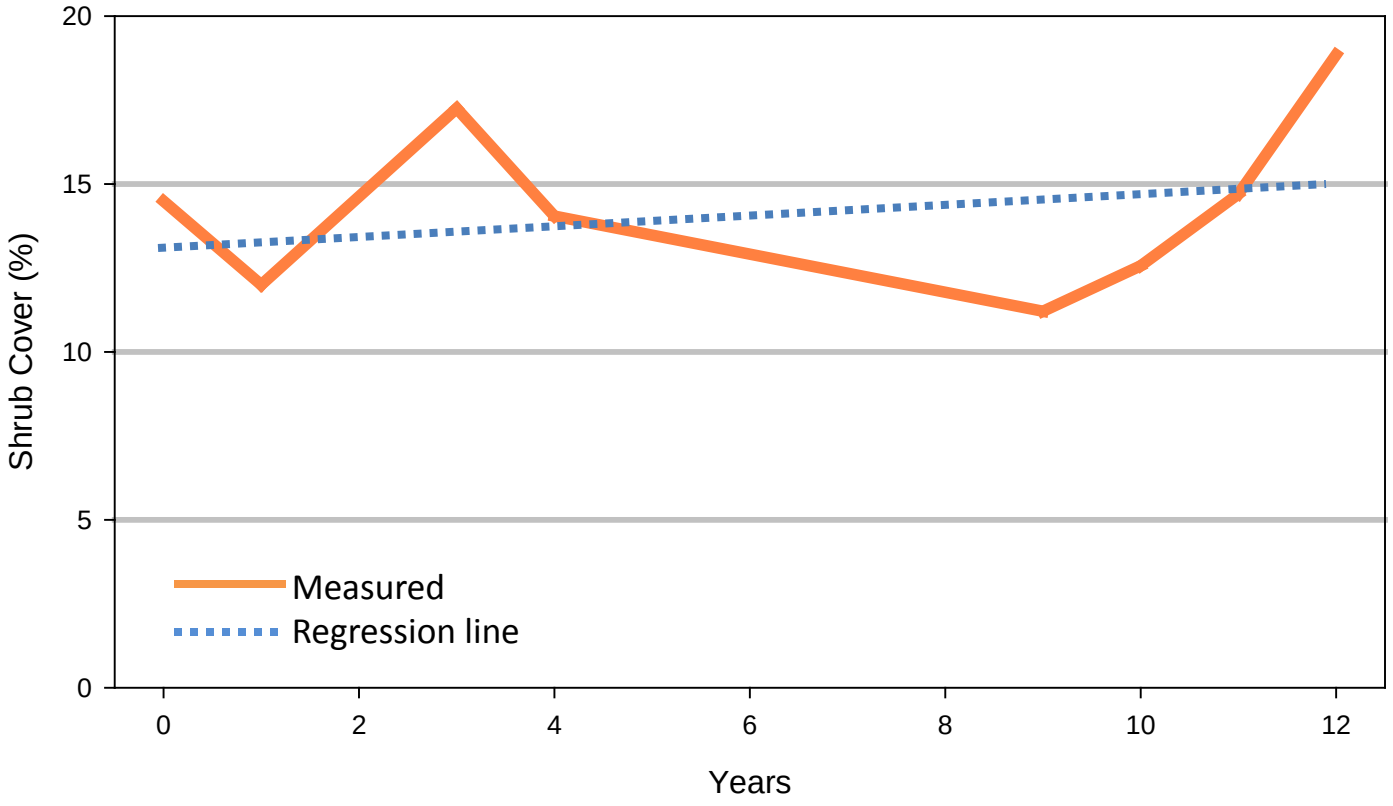
Control: Other Species Cover (%)



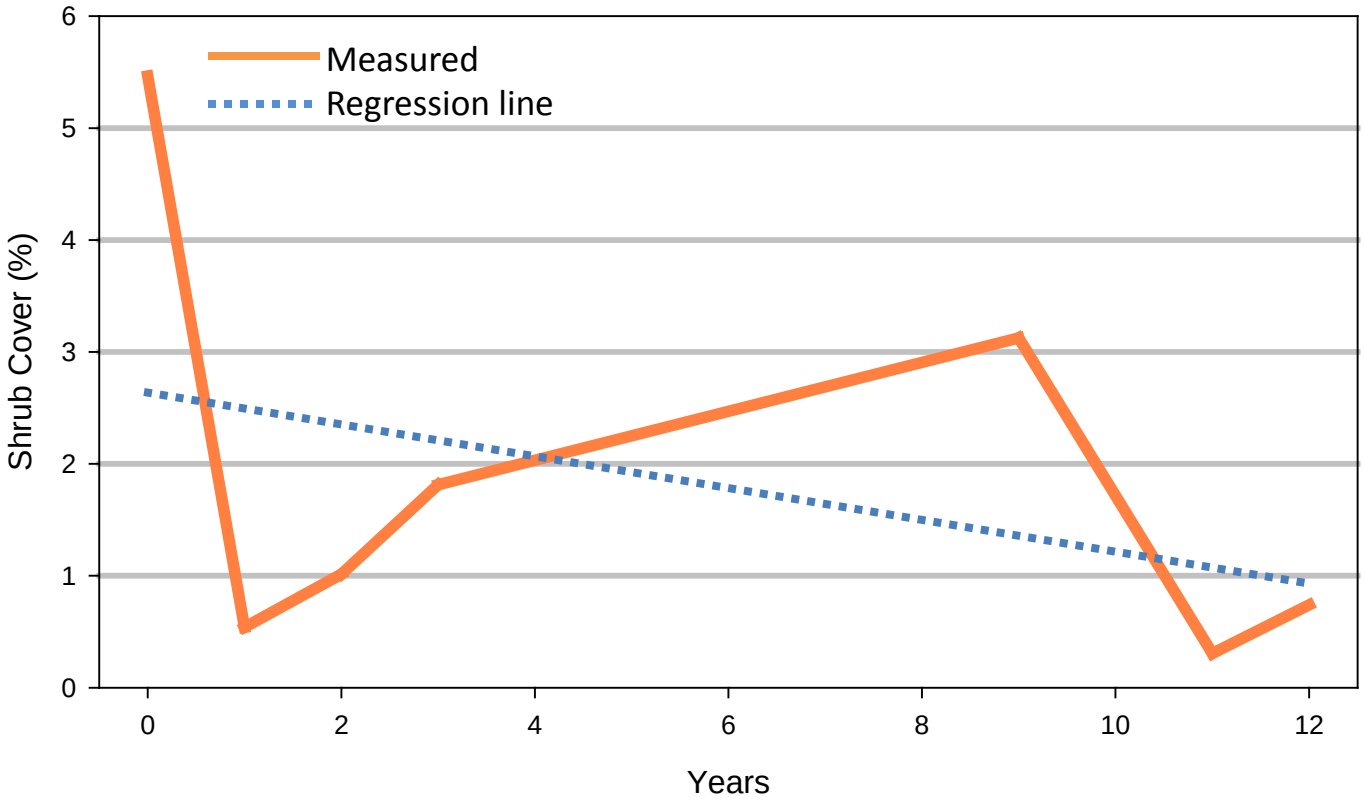
Control: Rhododendron Cover (%)



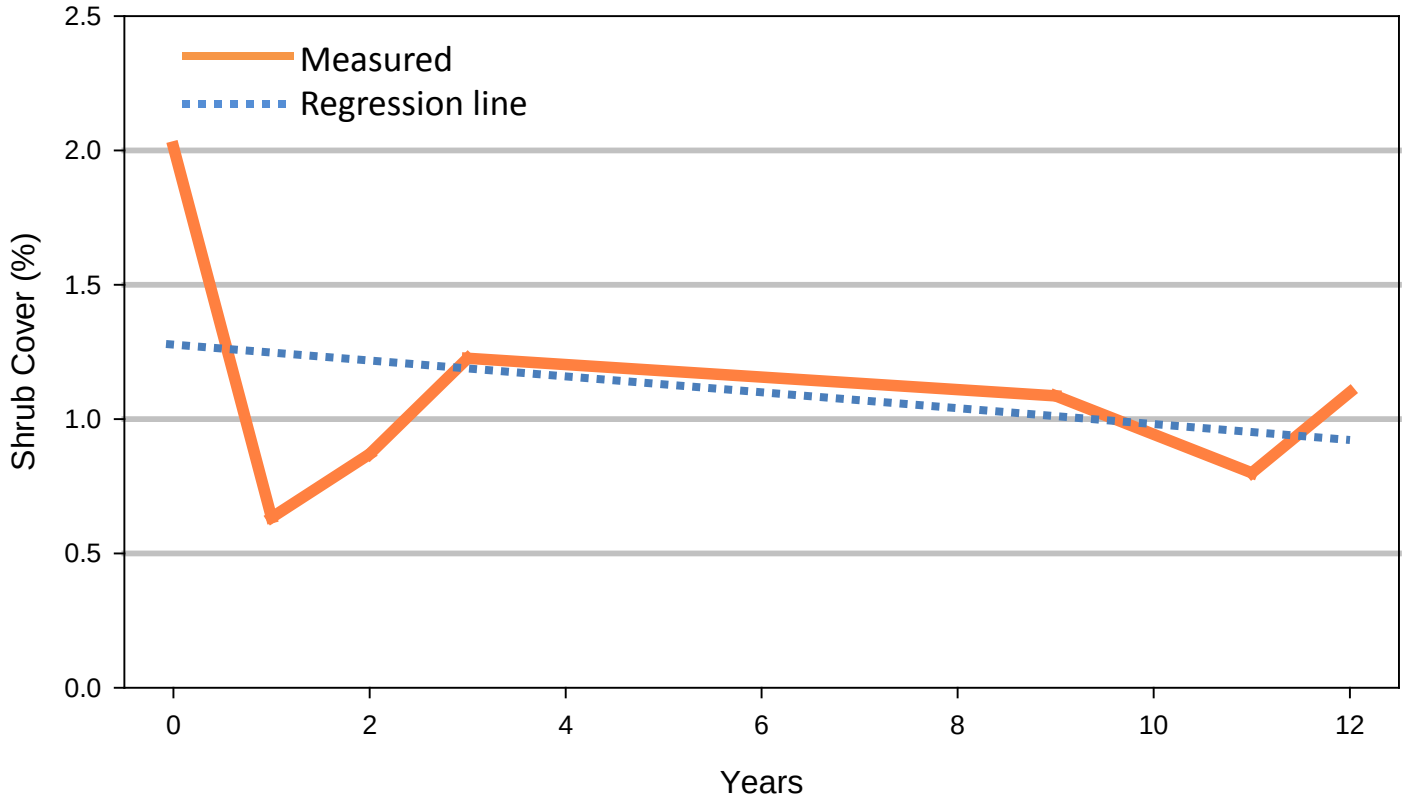
Control: All Species Cover (%)



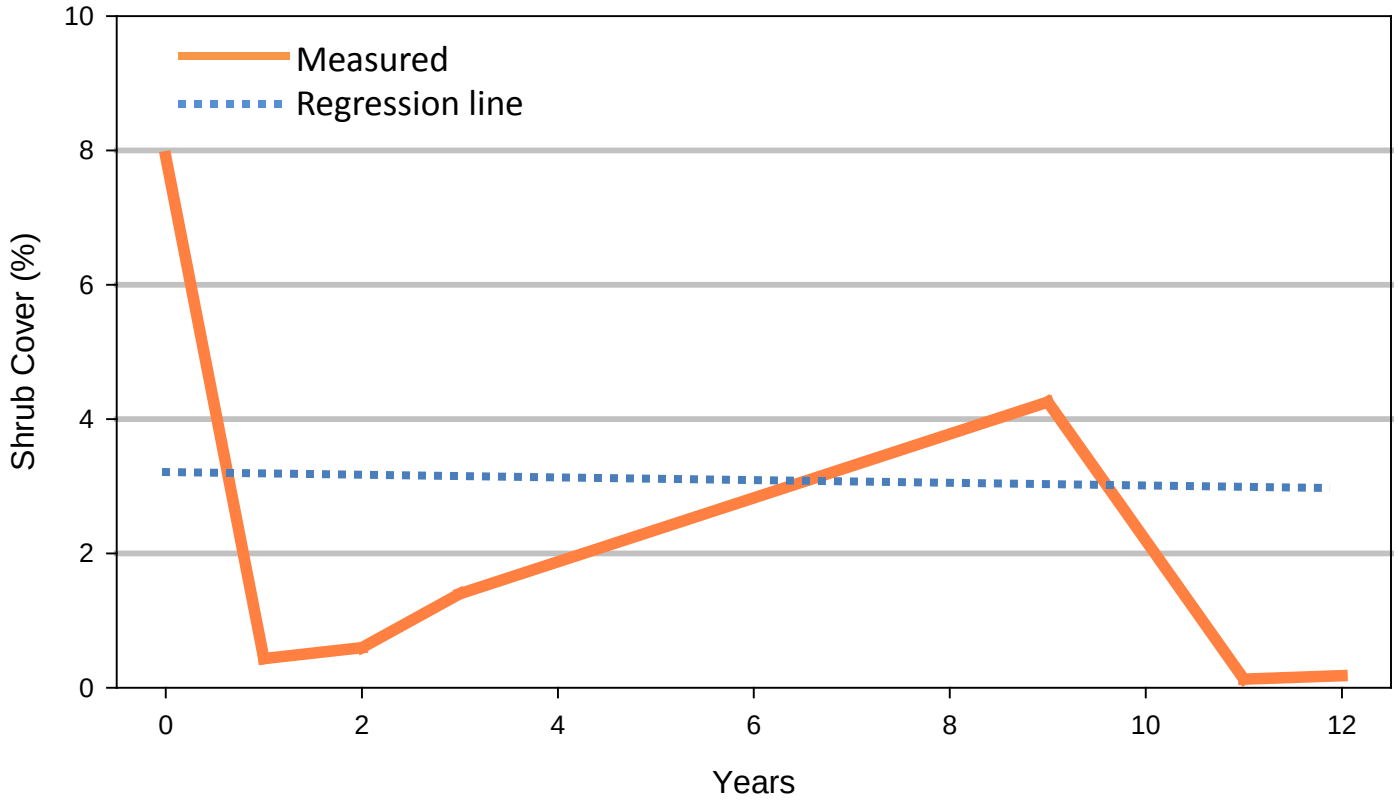
Mechanical Only: Mountain Laurel Cover (%)



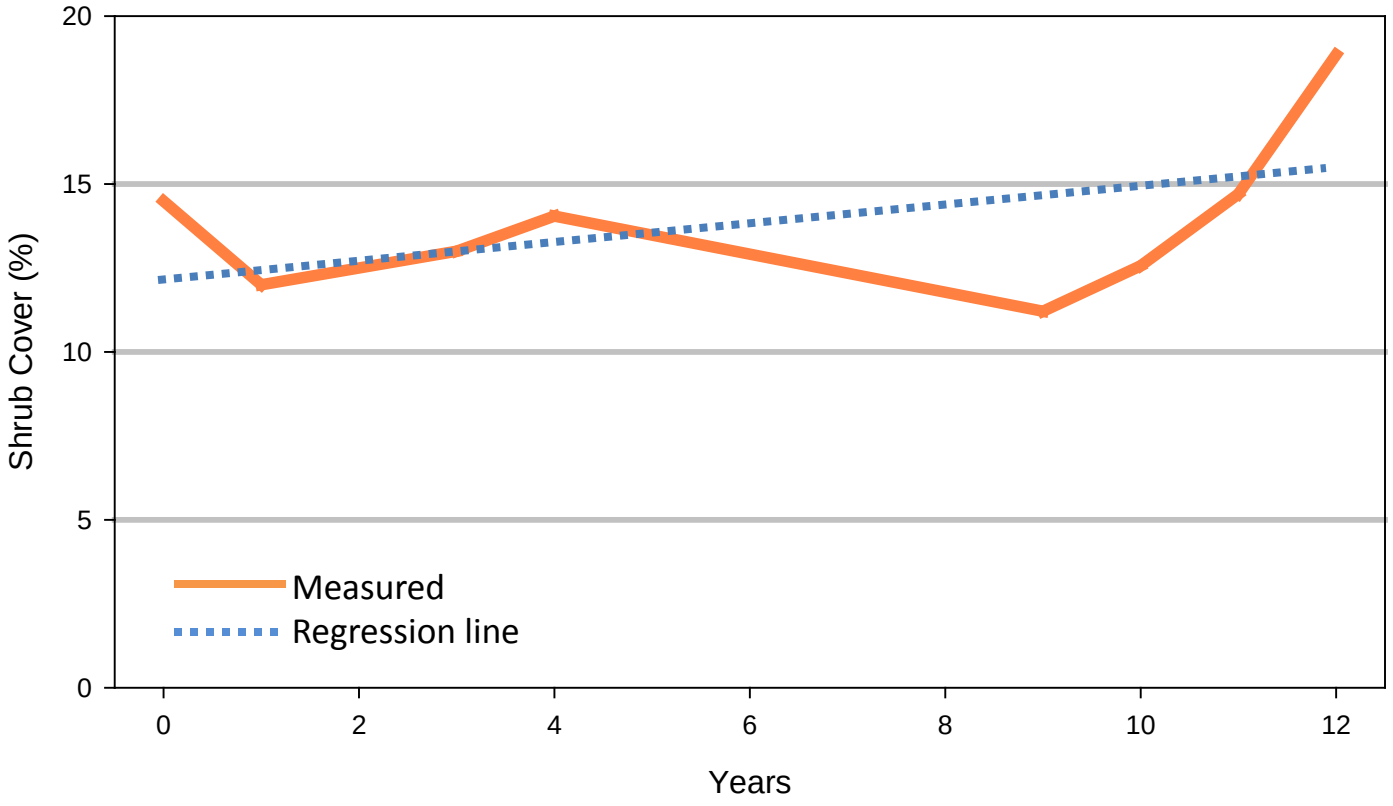
Mechanical Only: Other Species Cover (%)



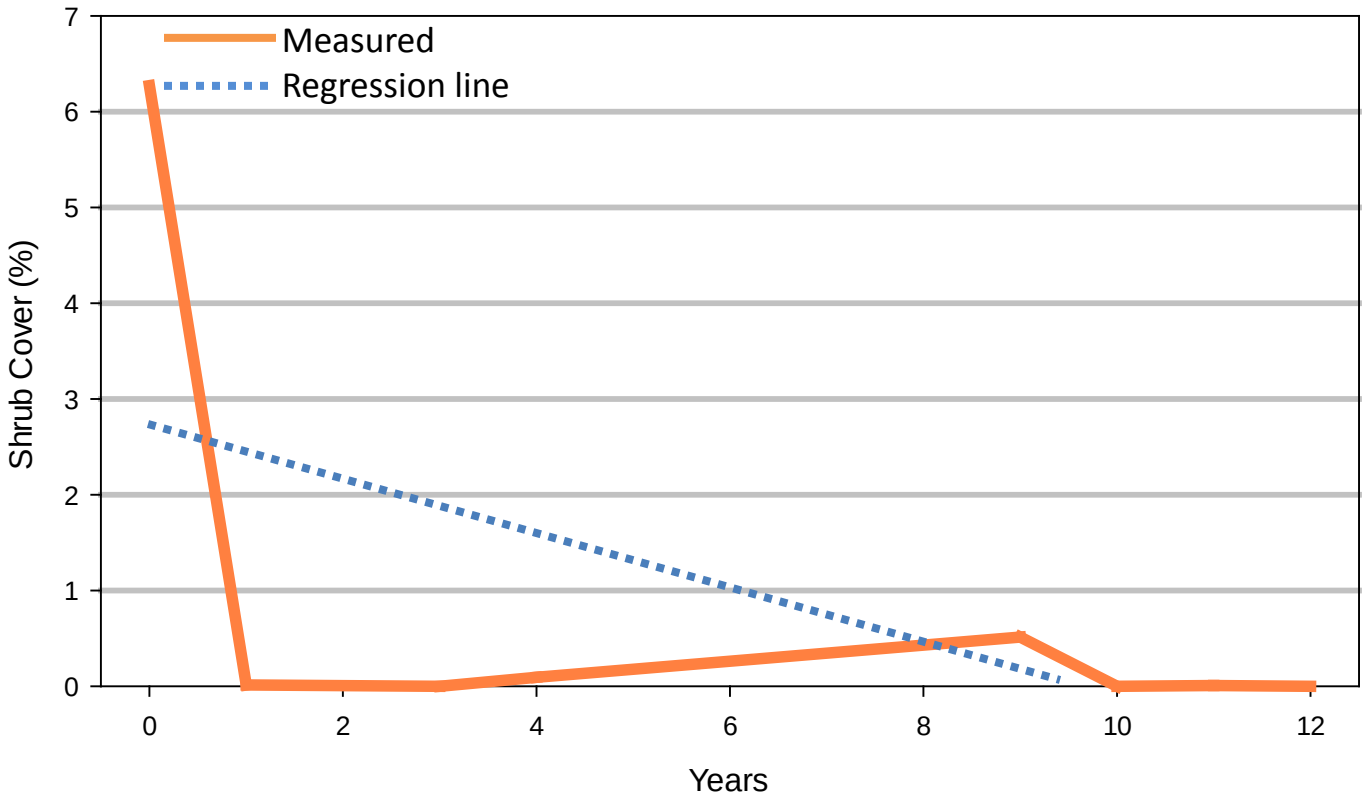
Mechanical Only: Rhododendron (%)



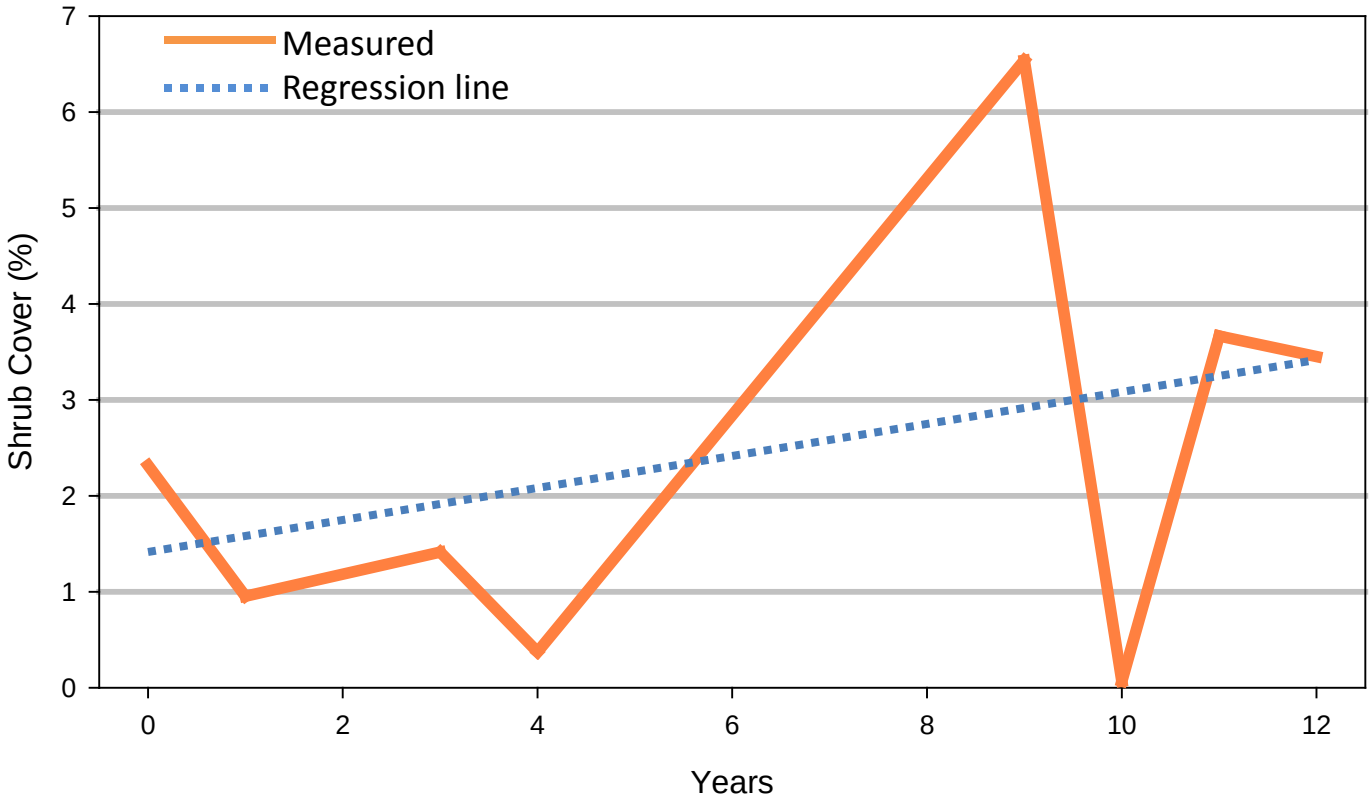
Mechanical Only: All Species (%)



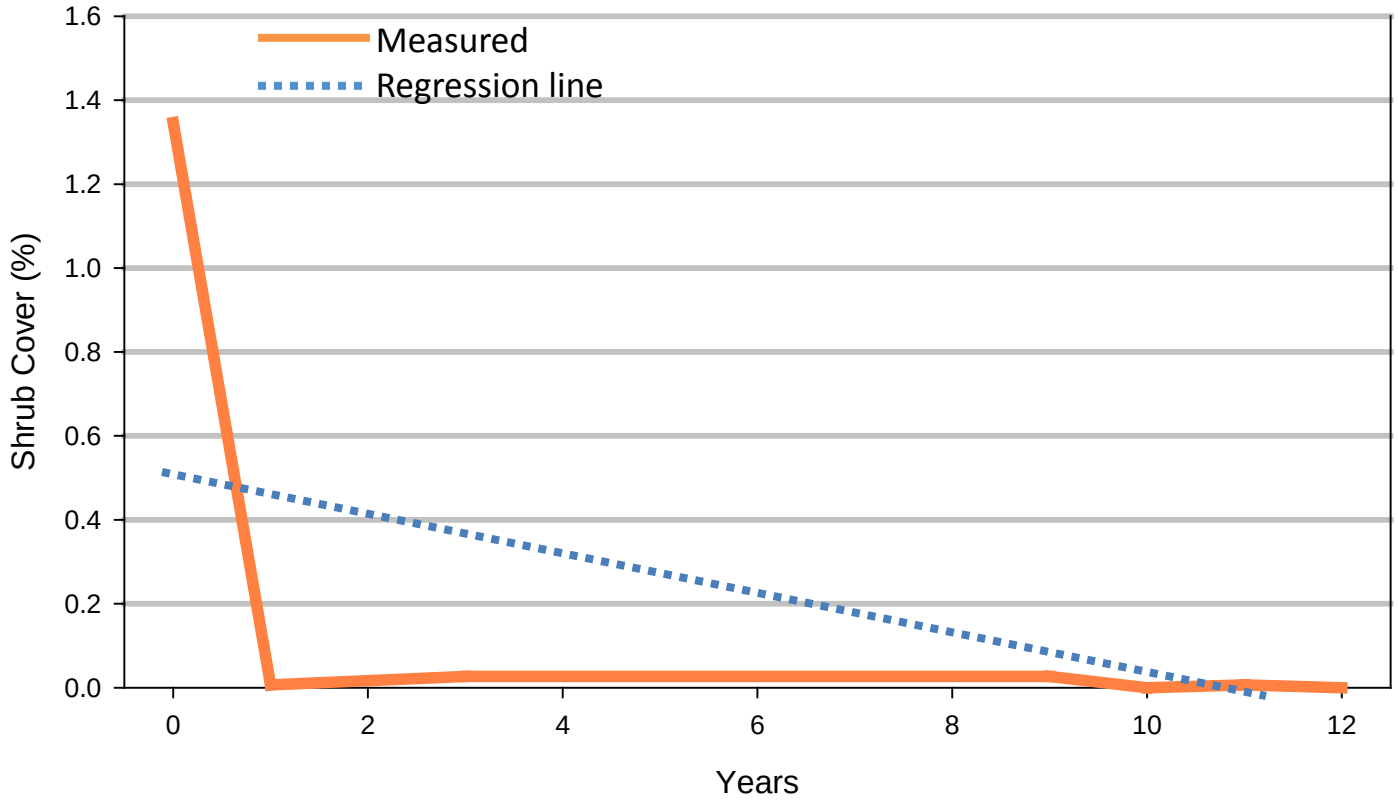
Mechanical + Burn: Mountain Laurel Cover (%)



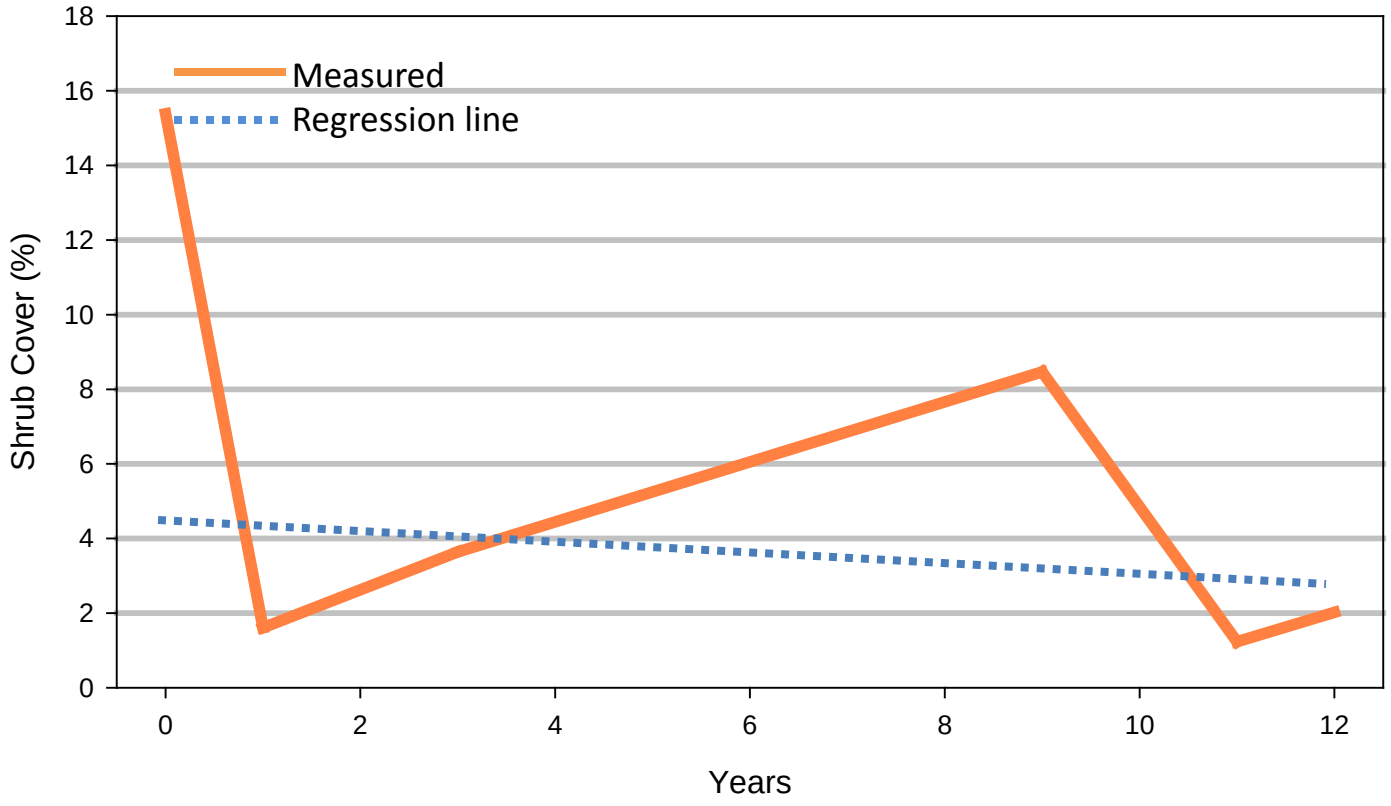
Mechanical + Burn: Other Species Cover (%)



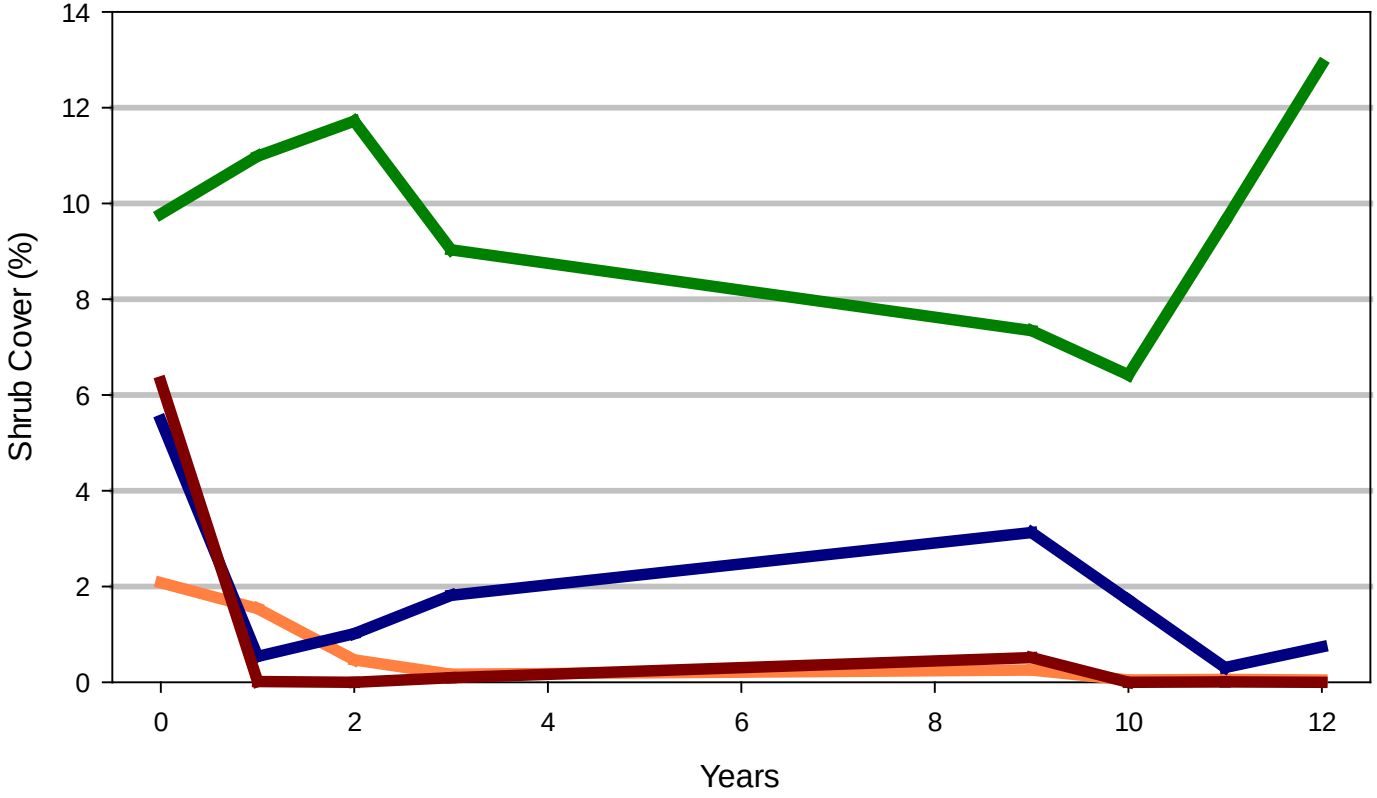
Mechanical + Burn: Rhododendron Cover (%)



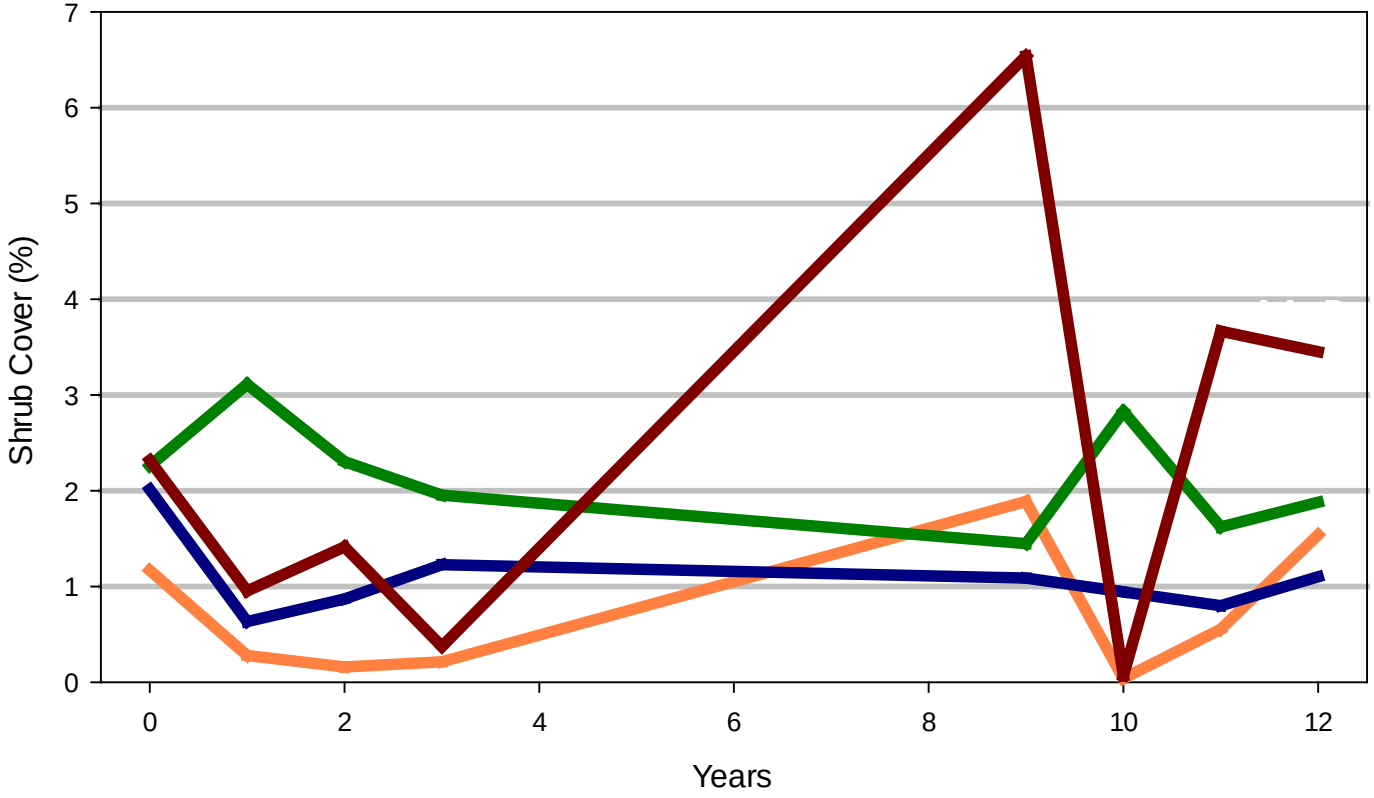
Mechanical + Burn: All Species Cover (%)



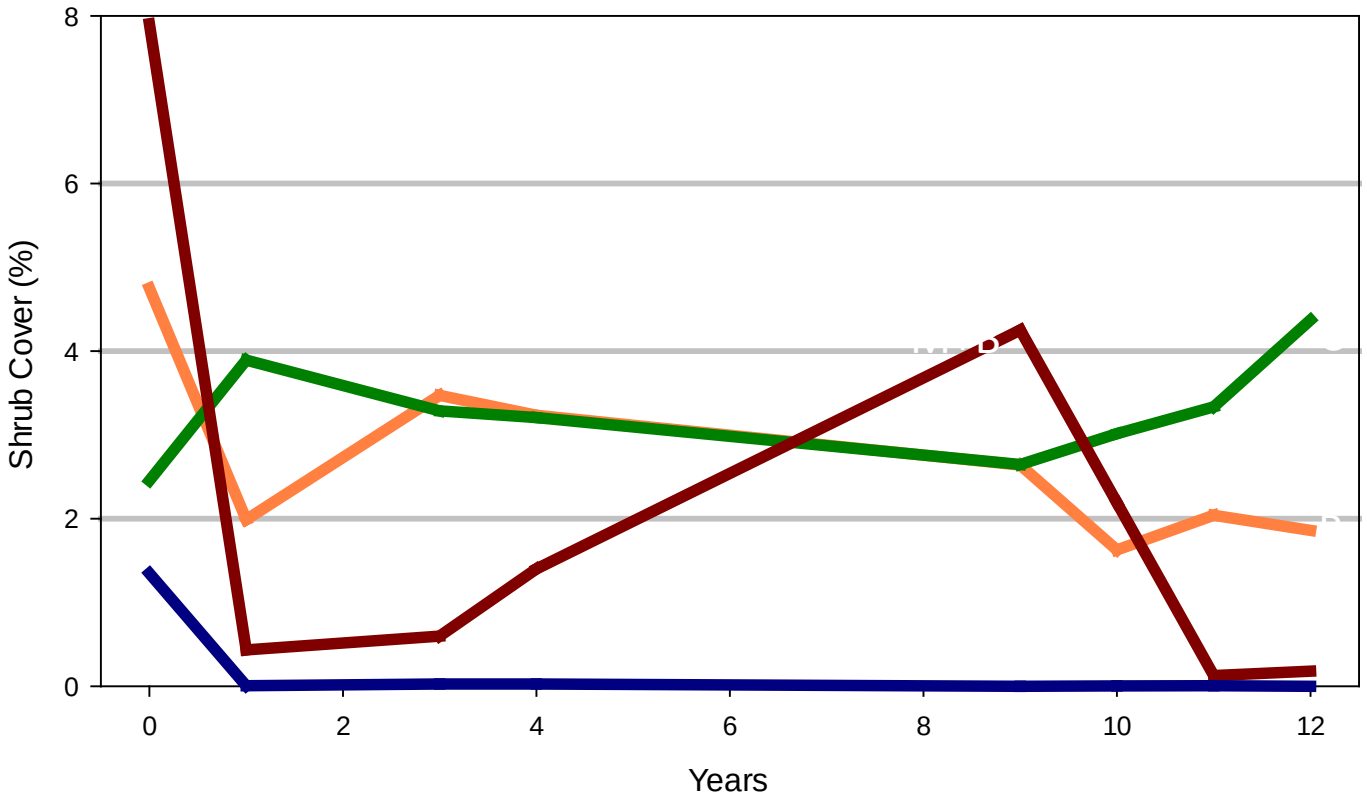
All Treatments: Mountain Laurel Cover (%)



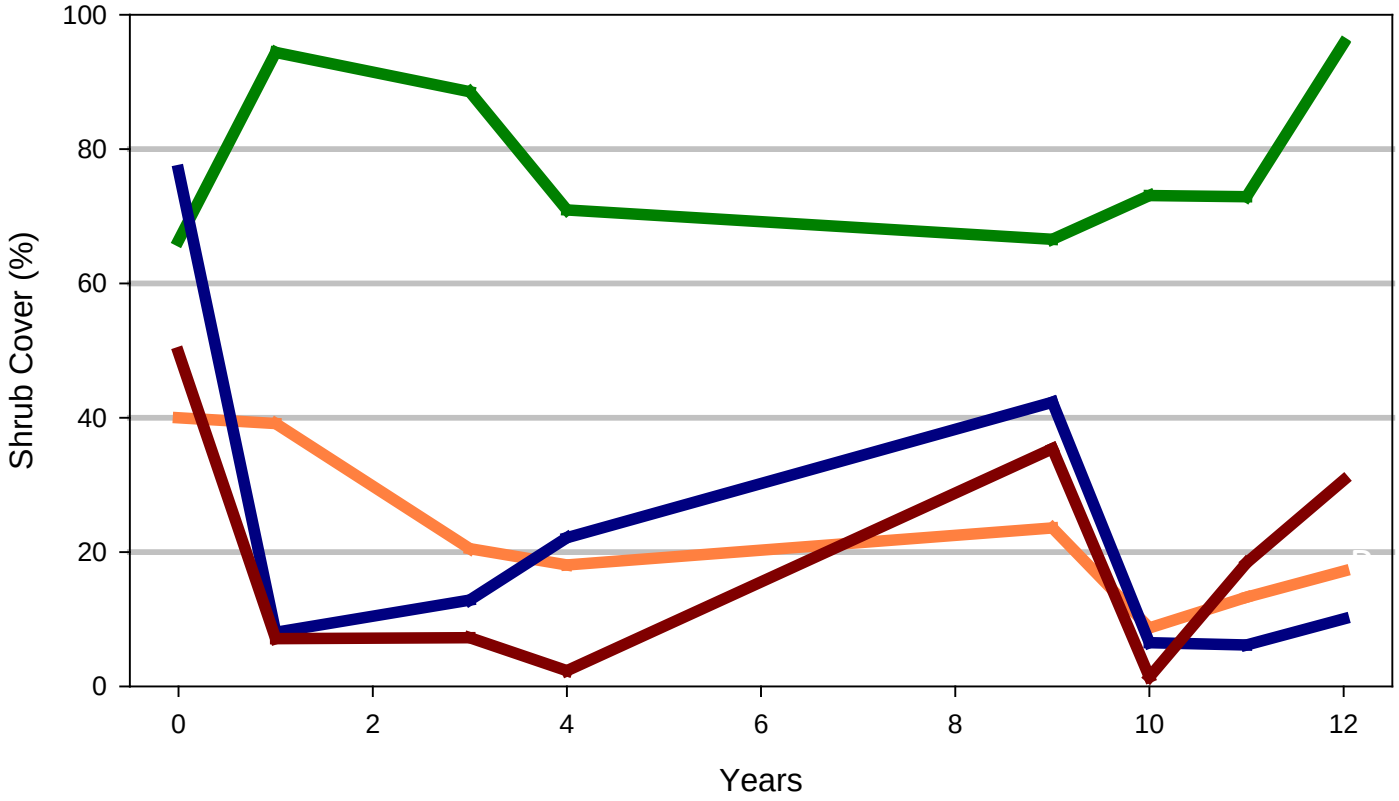
All Treatments: Other Species Cover (%)



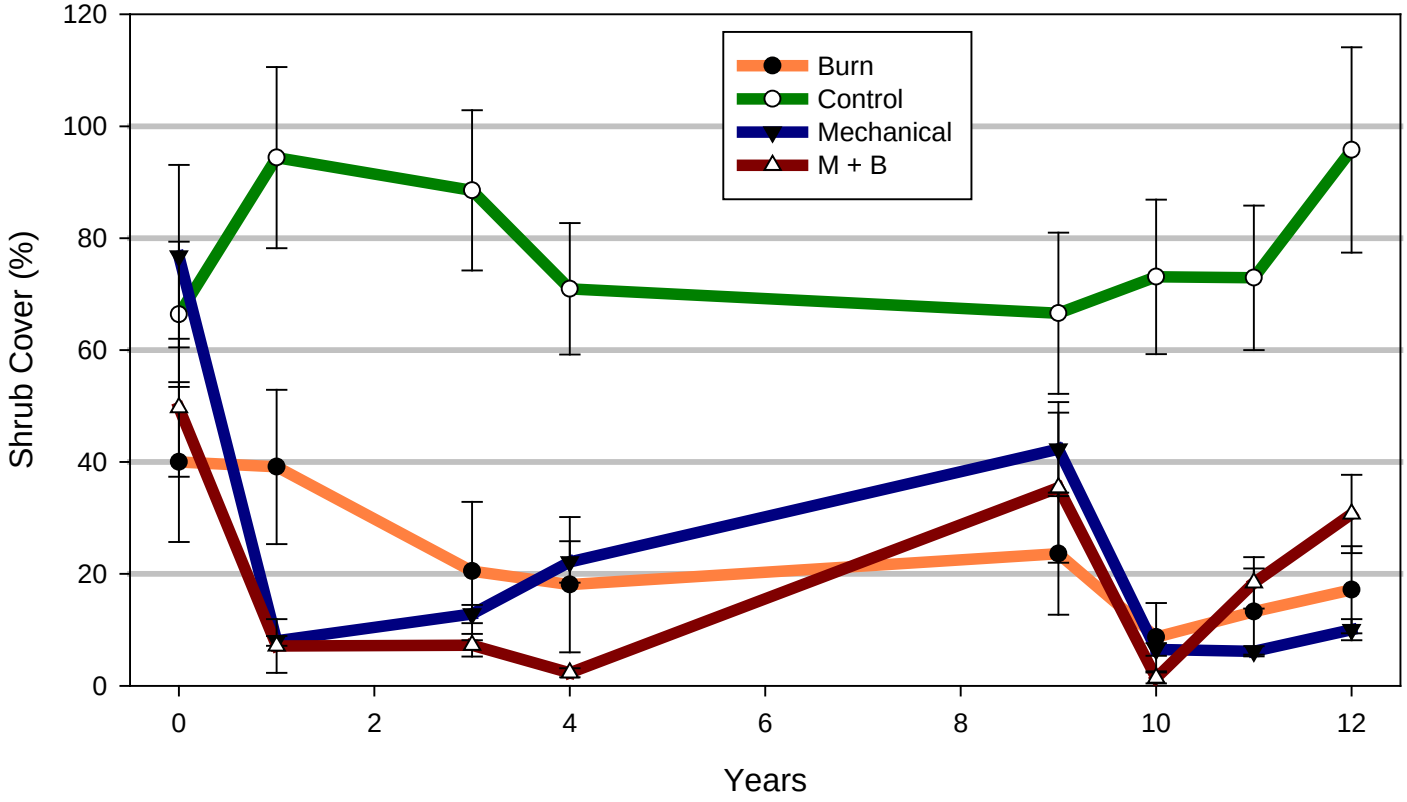
All Treatments: Rhododendron Cover (%)



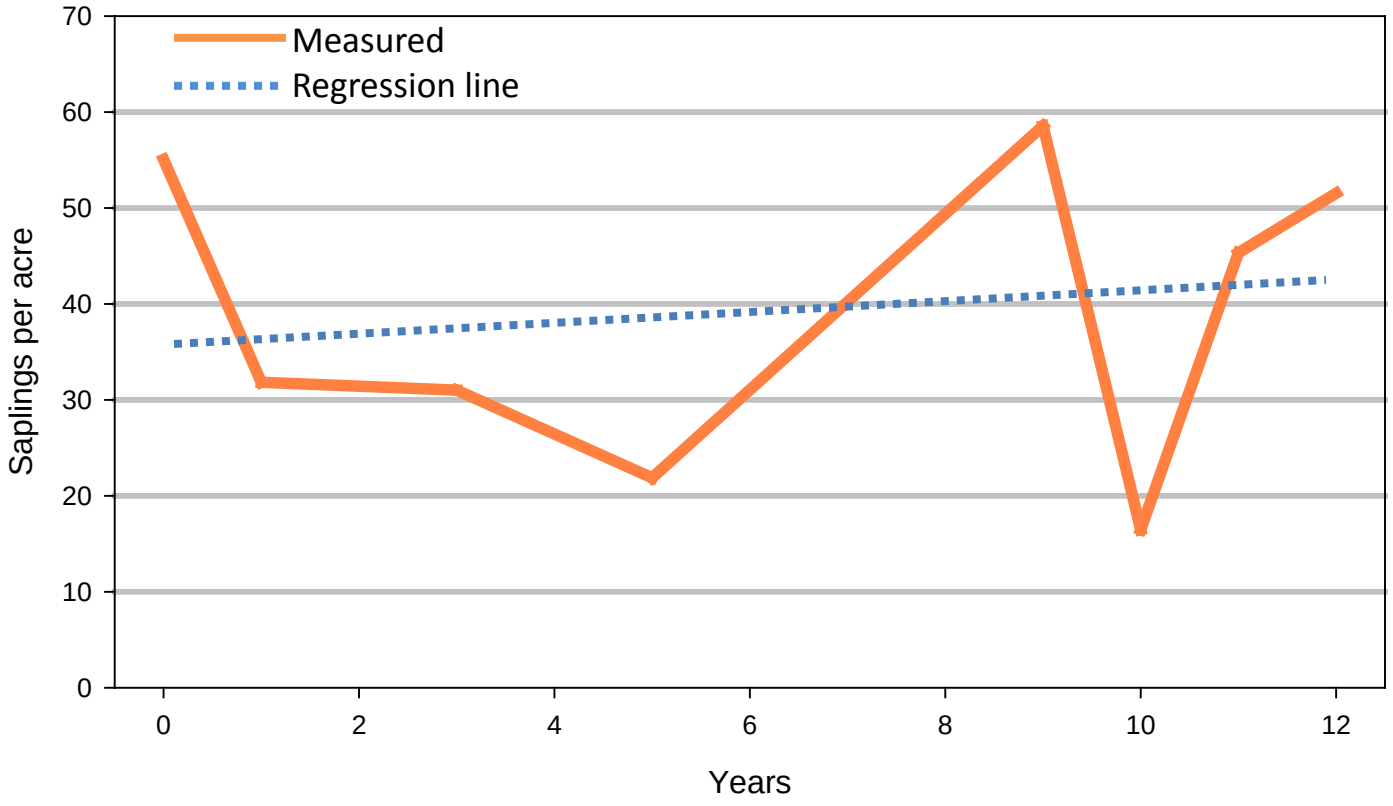
Shrub Layer
All Treatments: All Species Cover (%)



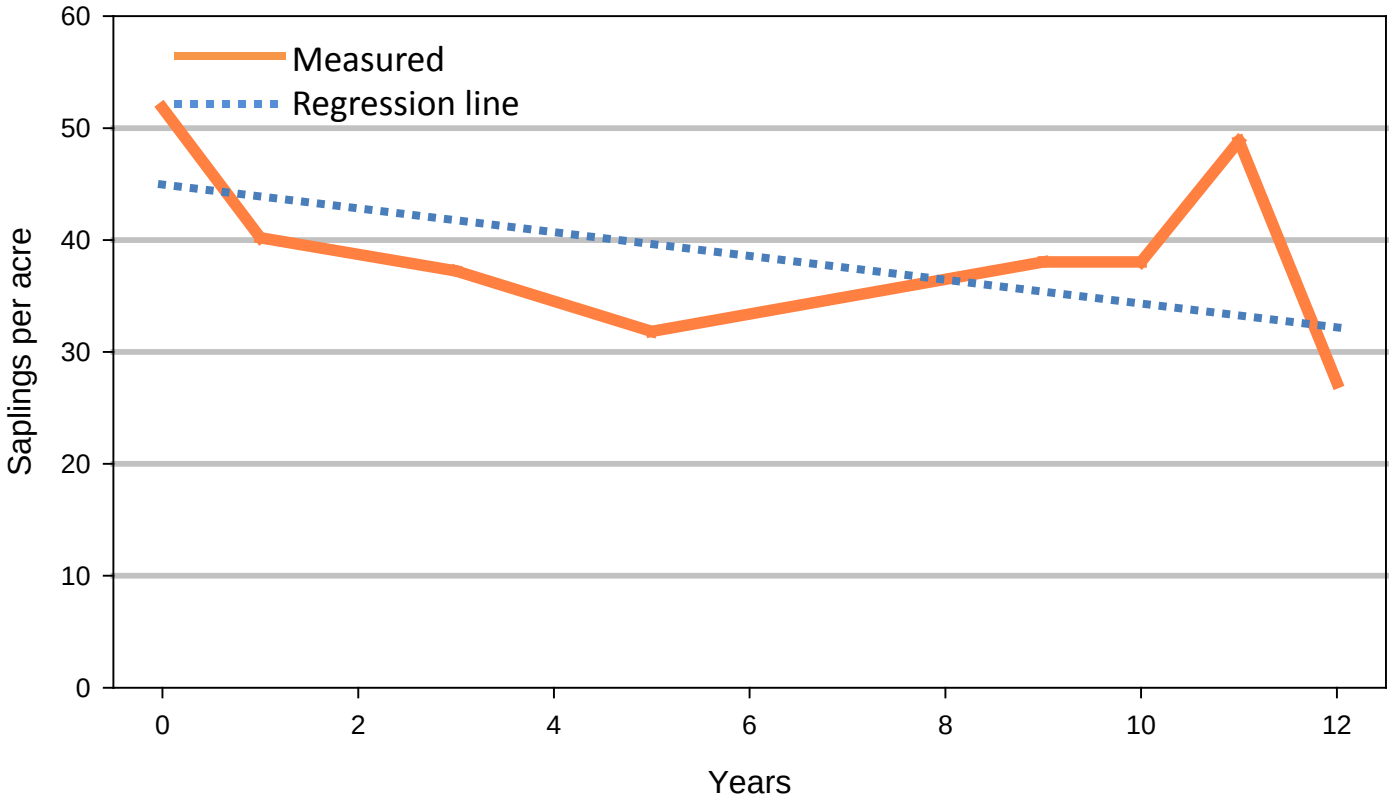
Shrub Layer
All Treatments: All Species Cover (%)



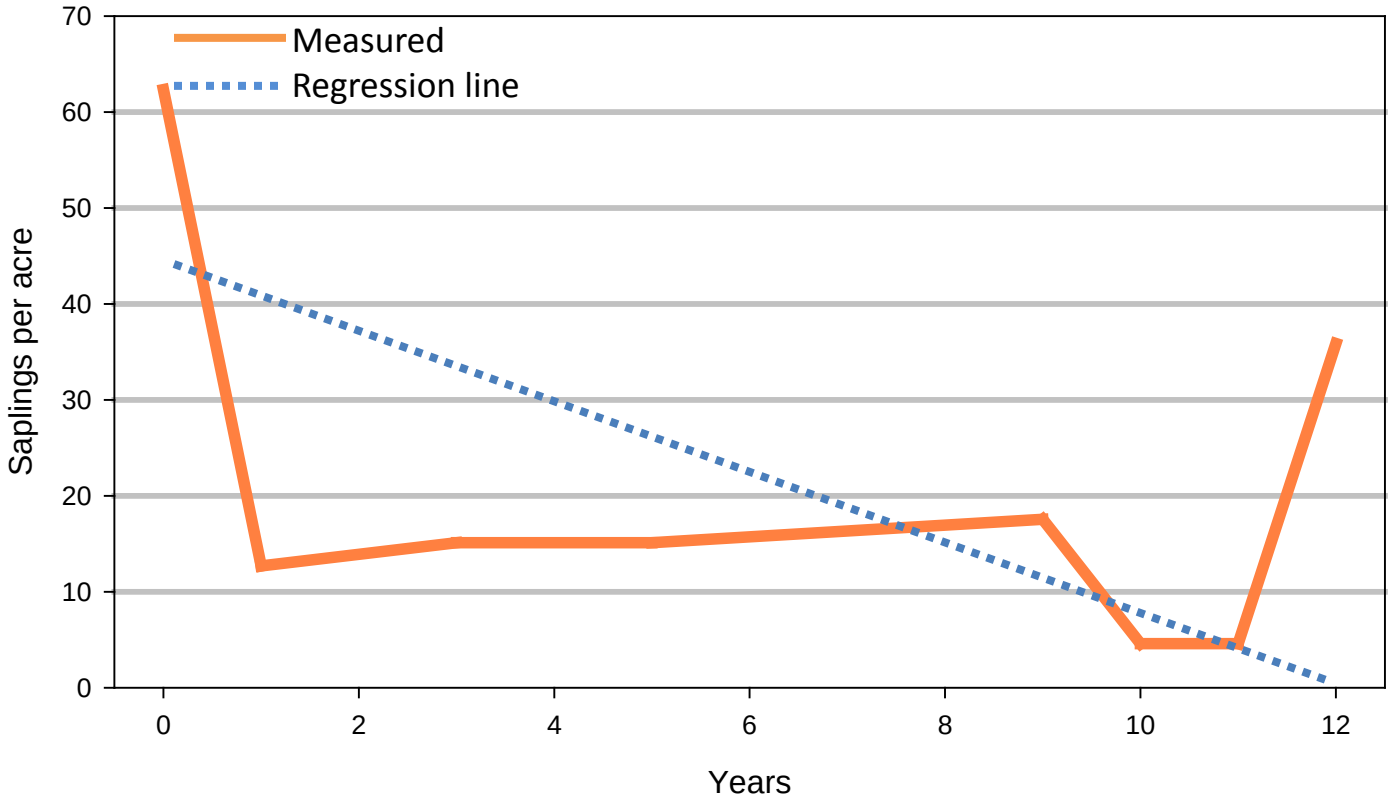
Burn Only: Blackgum saplings per acre



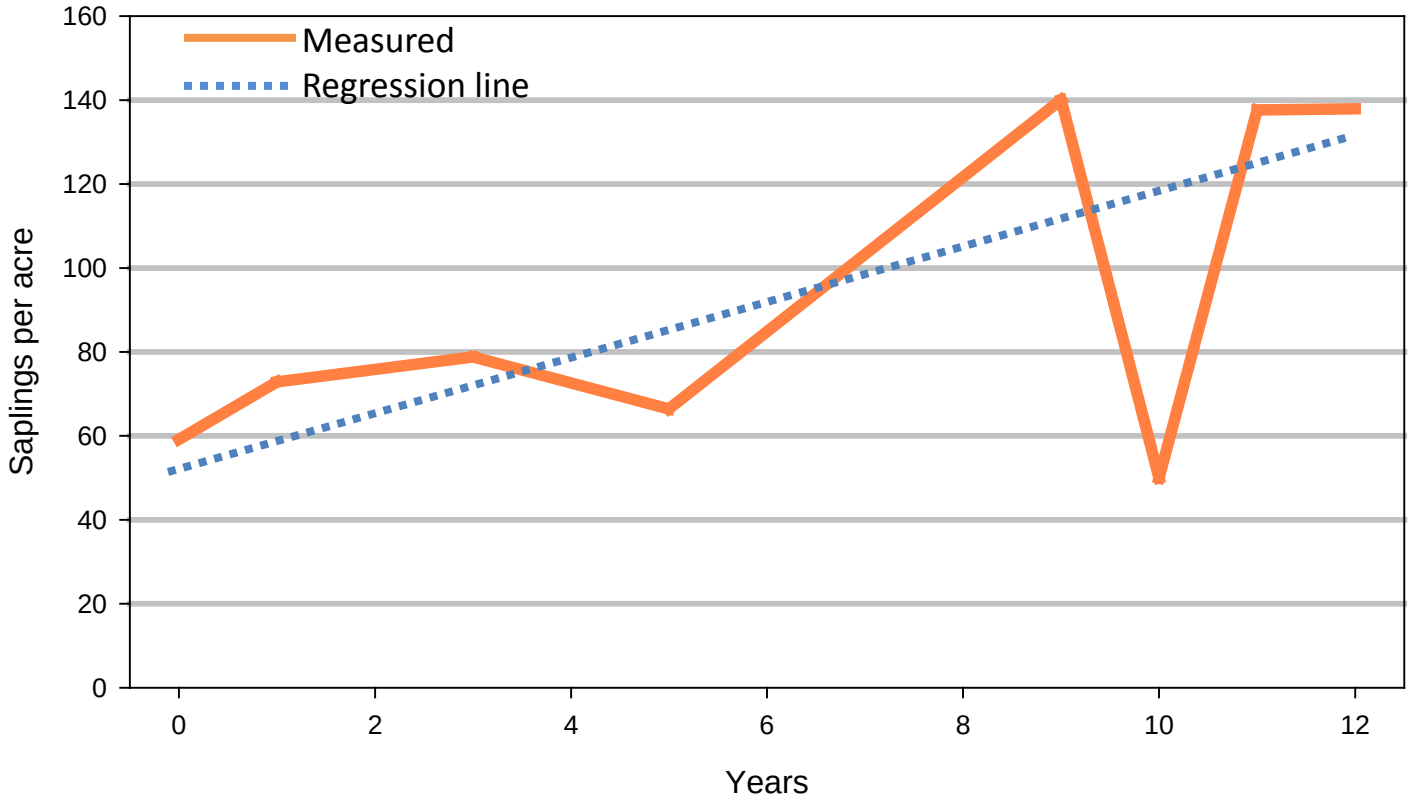
Control: Blackgum saplings per acre



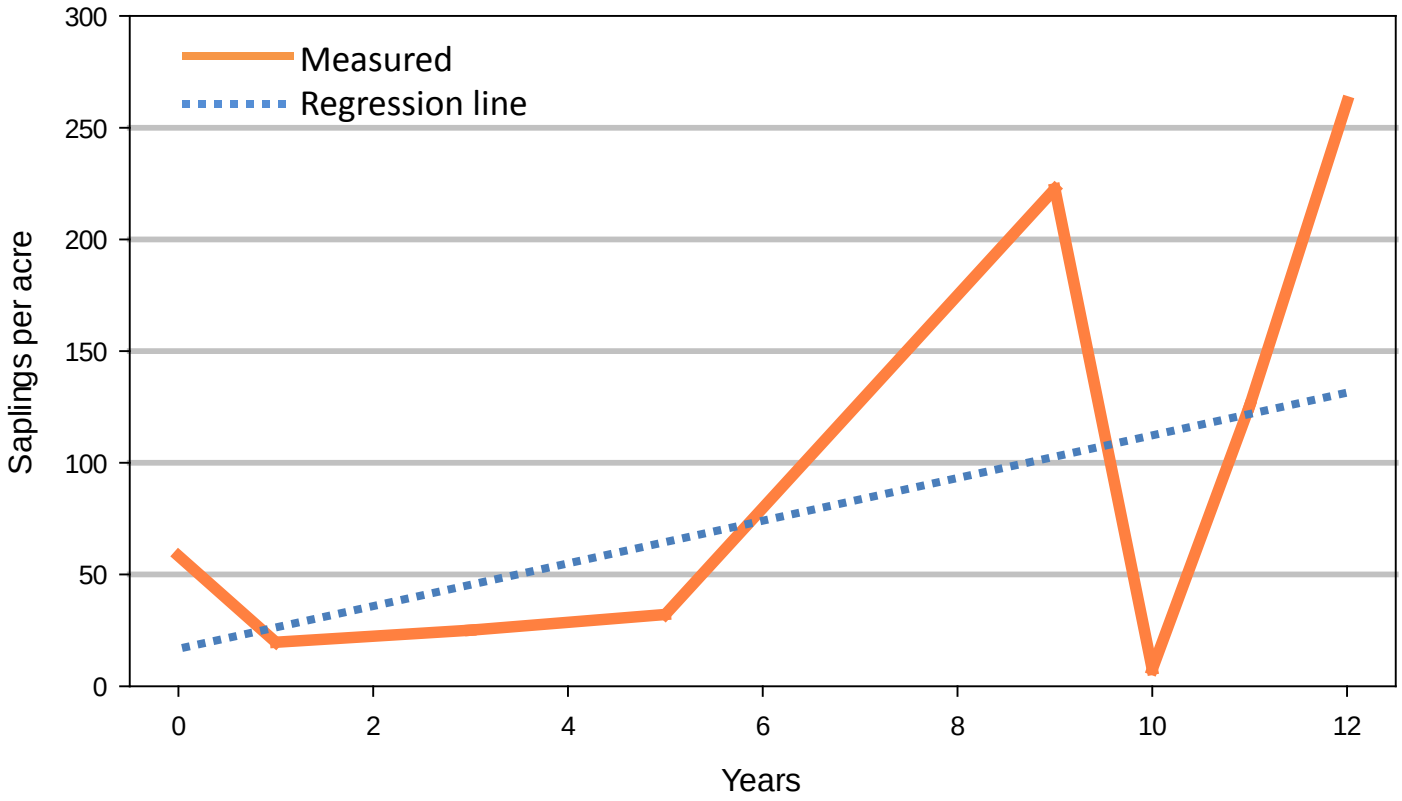
Mechanical: Blackgum saplings per acre



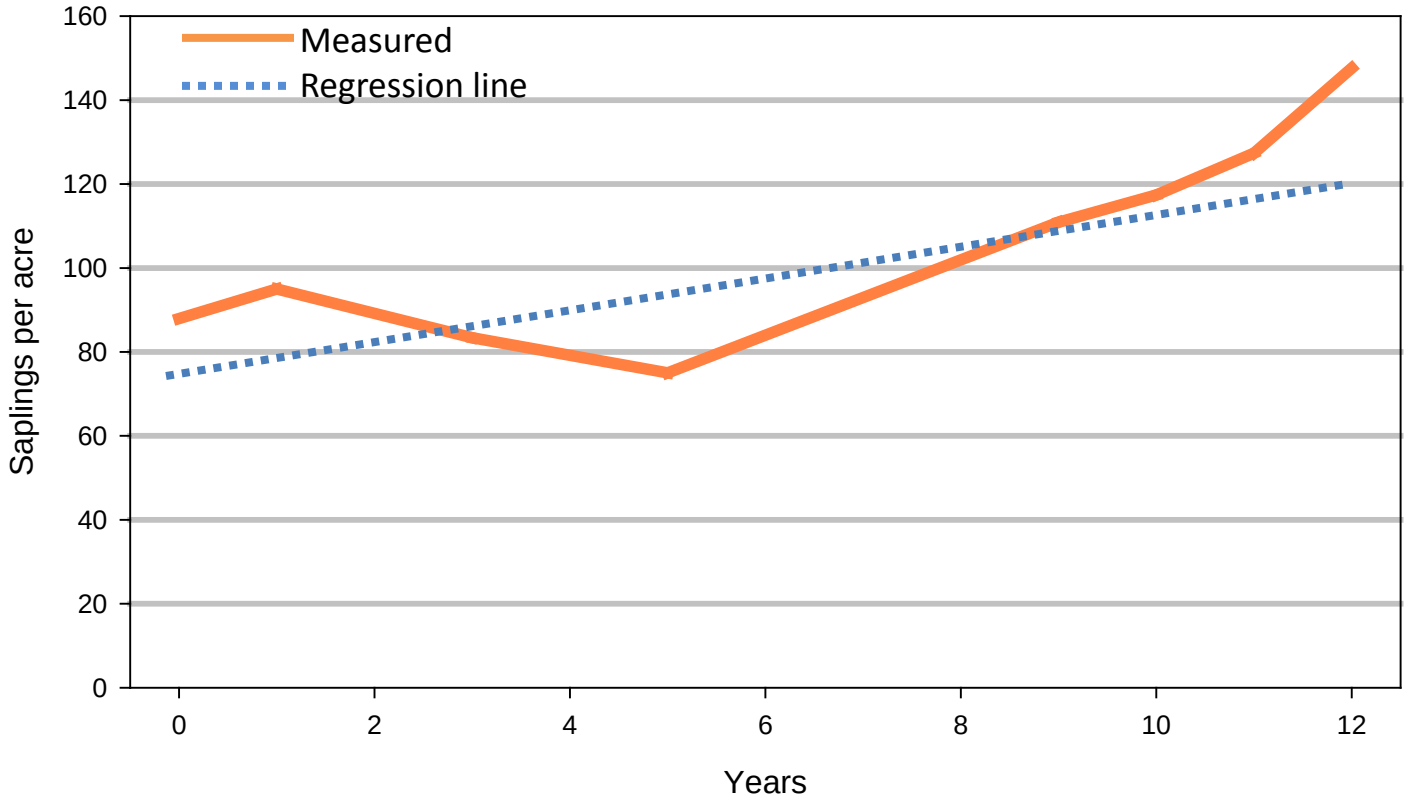
Mechanical + Burn: Blackgum saplings per acre



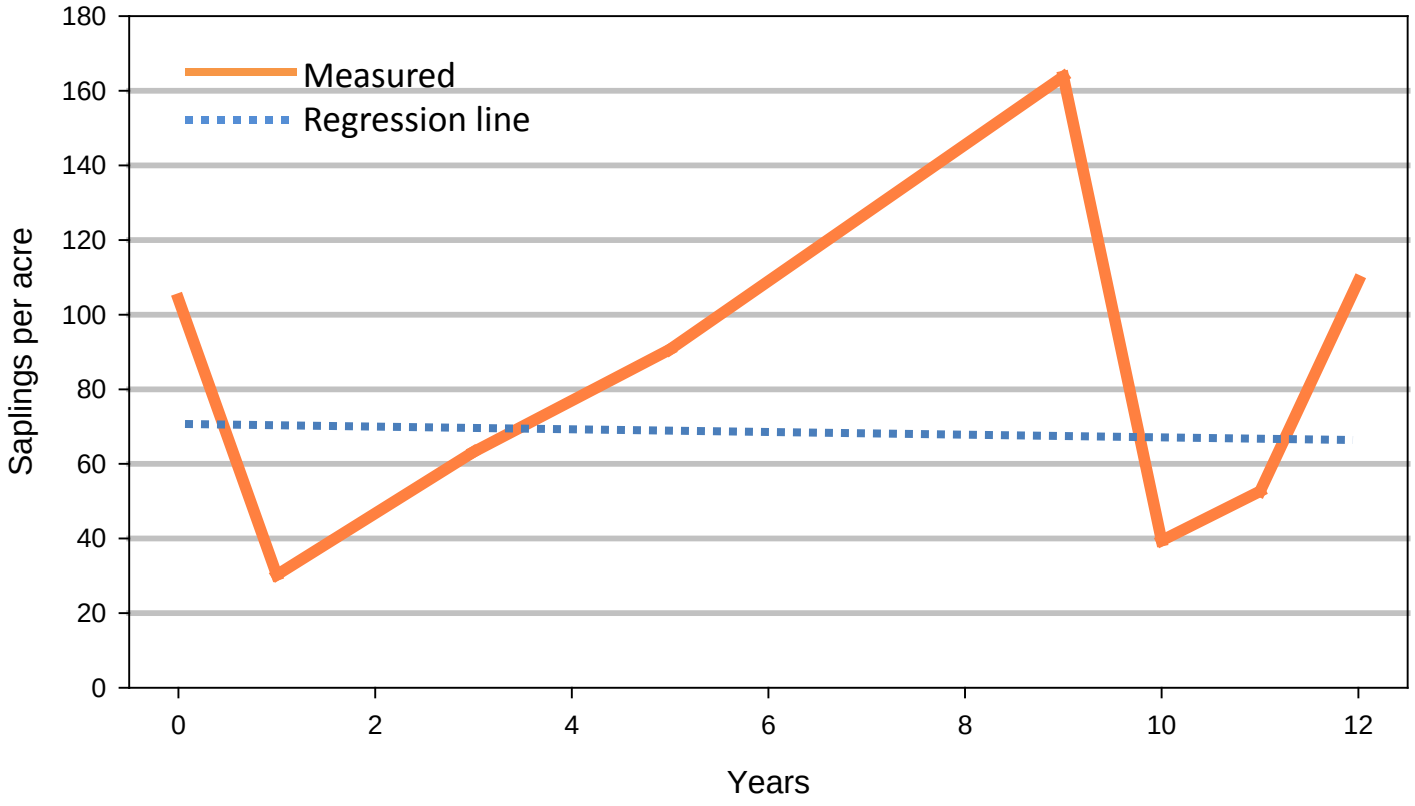
Burn Only: Oak saplings per acre



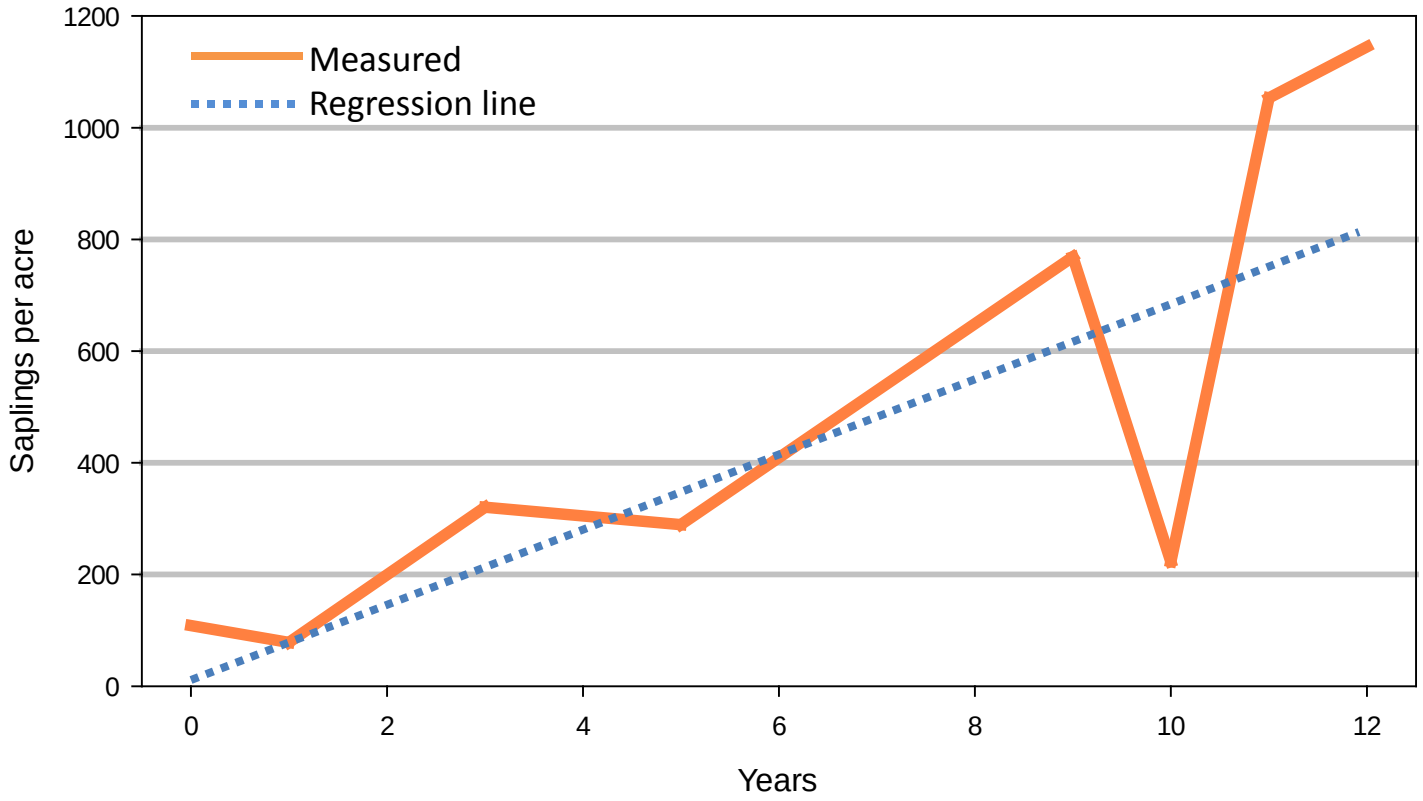
Control: Oak saplings per acre



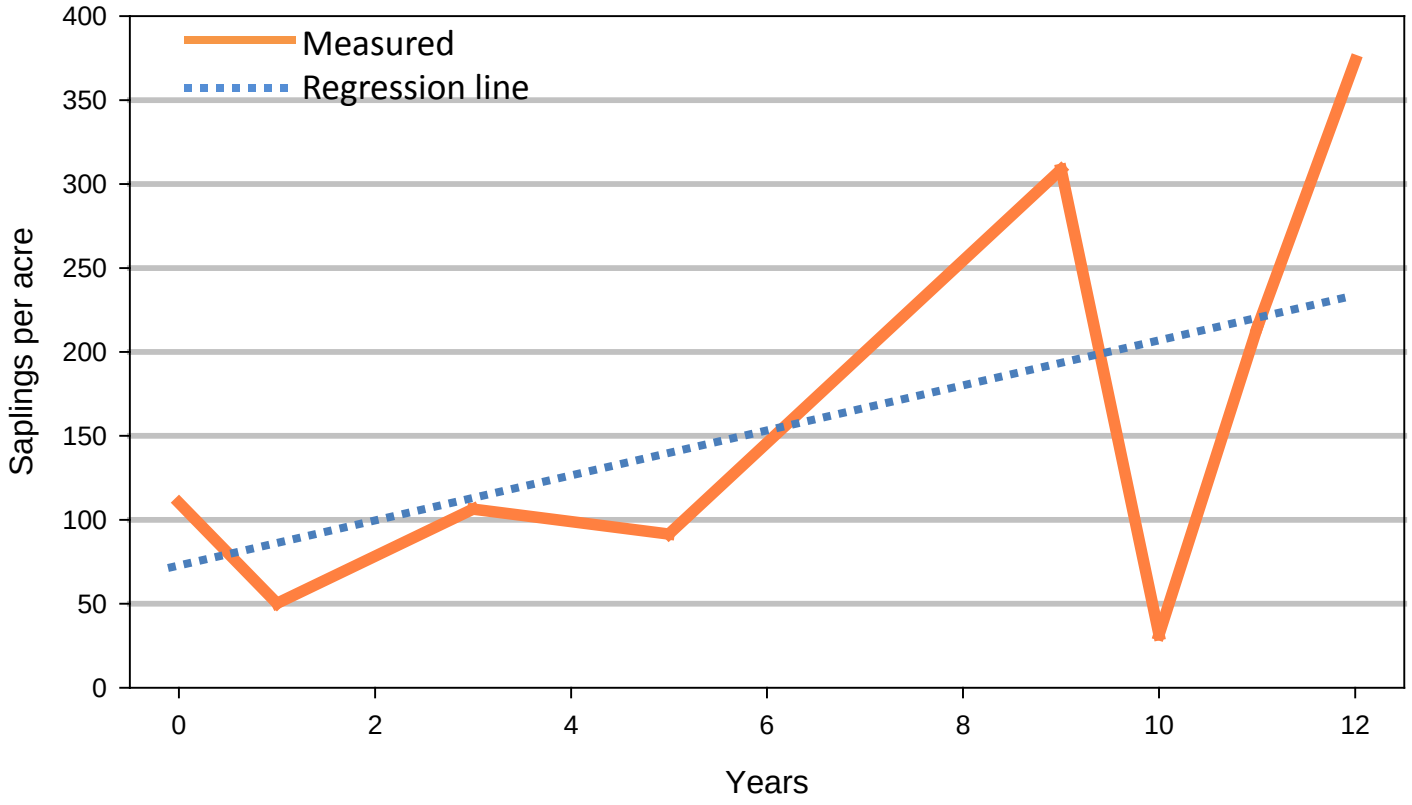
Mechanical: Oak saplings per acre



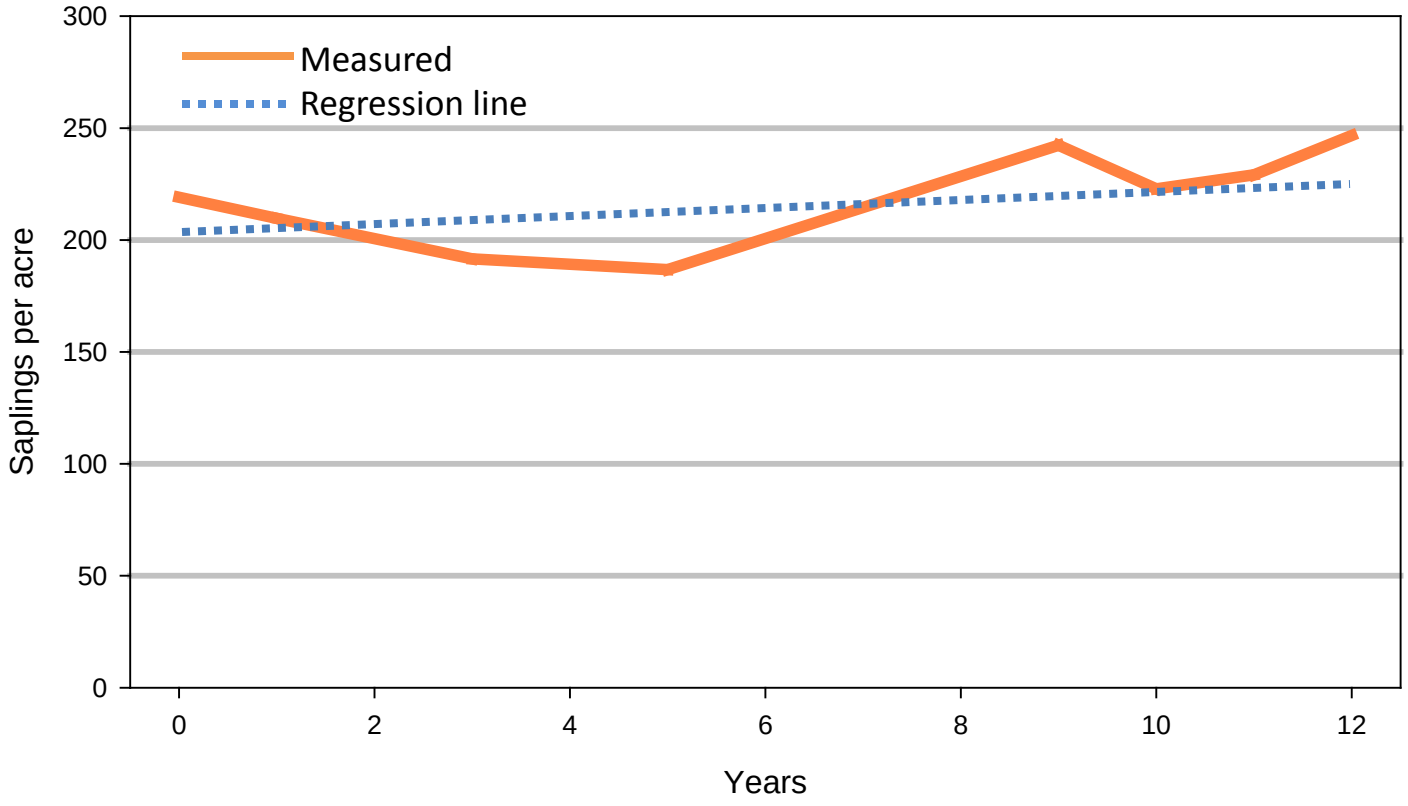
Mechanical + Burn: Oak saplings per acre



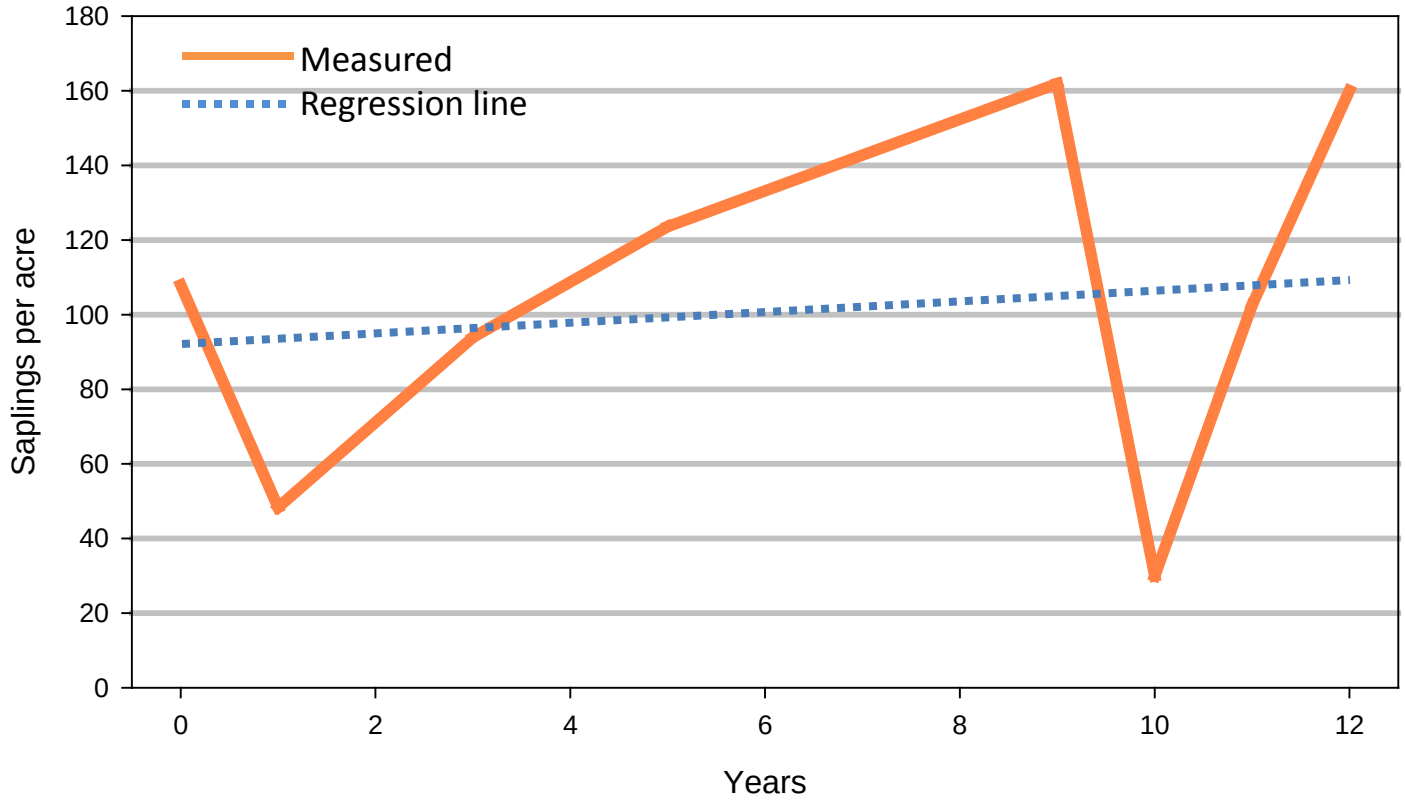
Burn Only: Other species saplings per acre



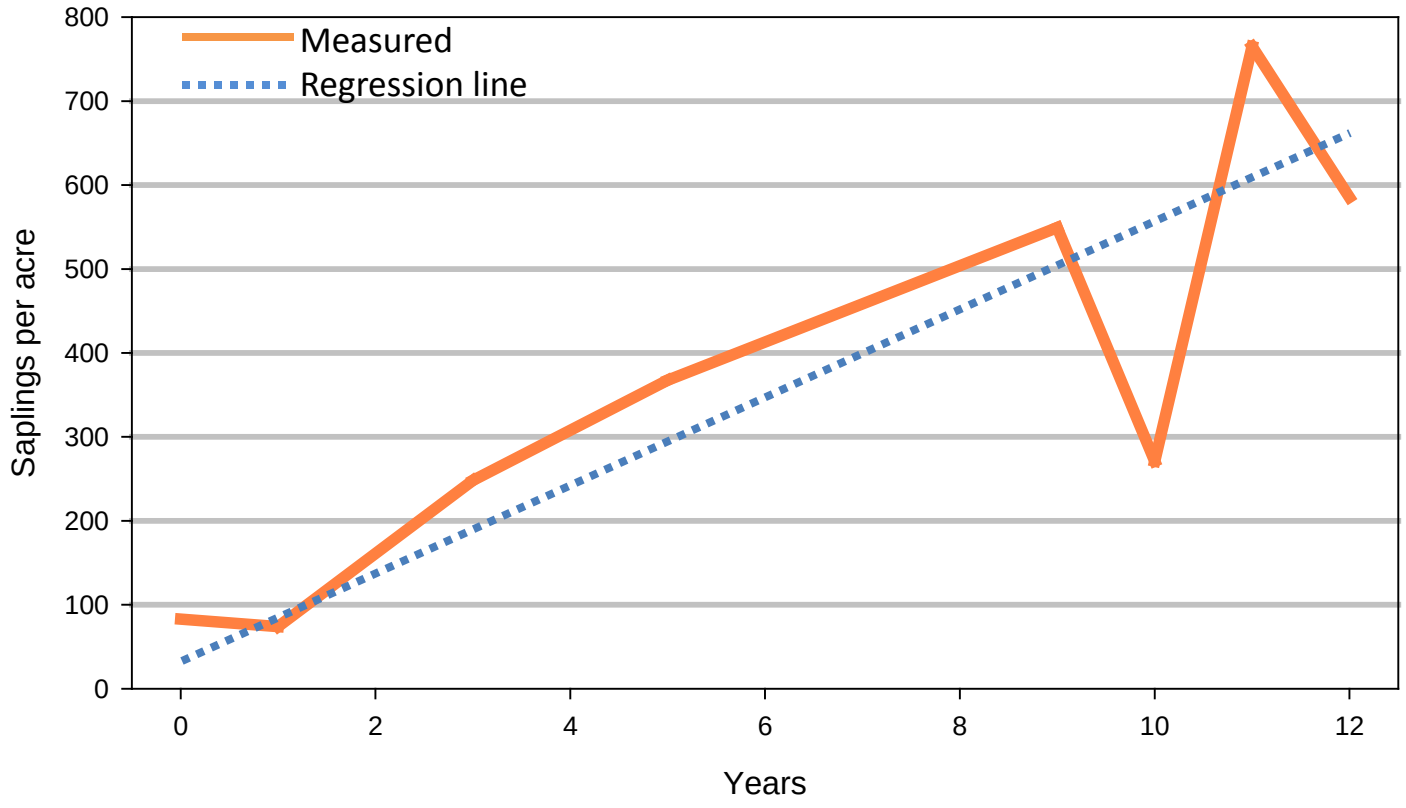
Control: Other species saplings per acre



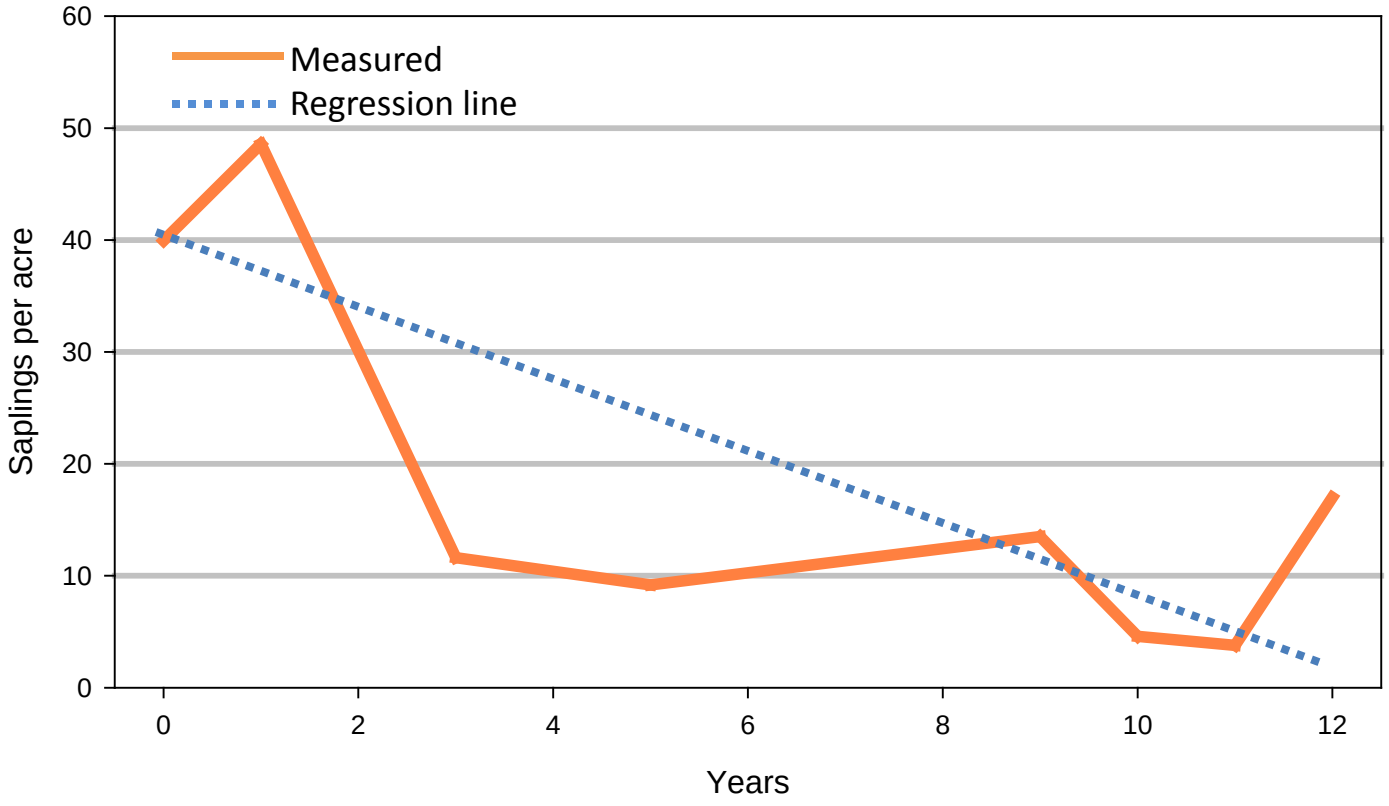
Mechanical: Other species saplings per acre



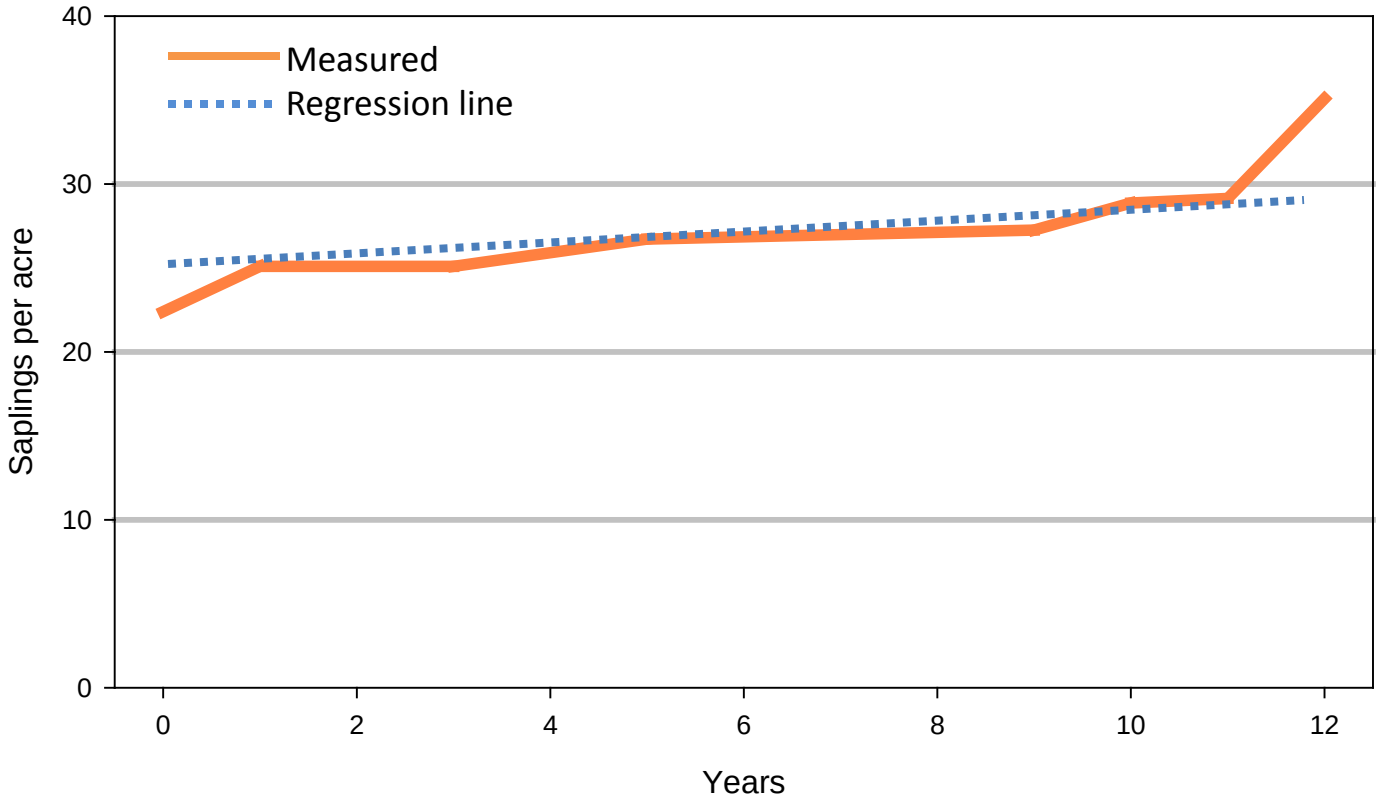
Mechanical + Burn: Other species saplings per acre



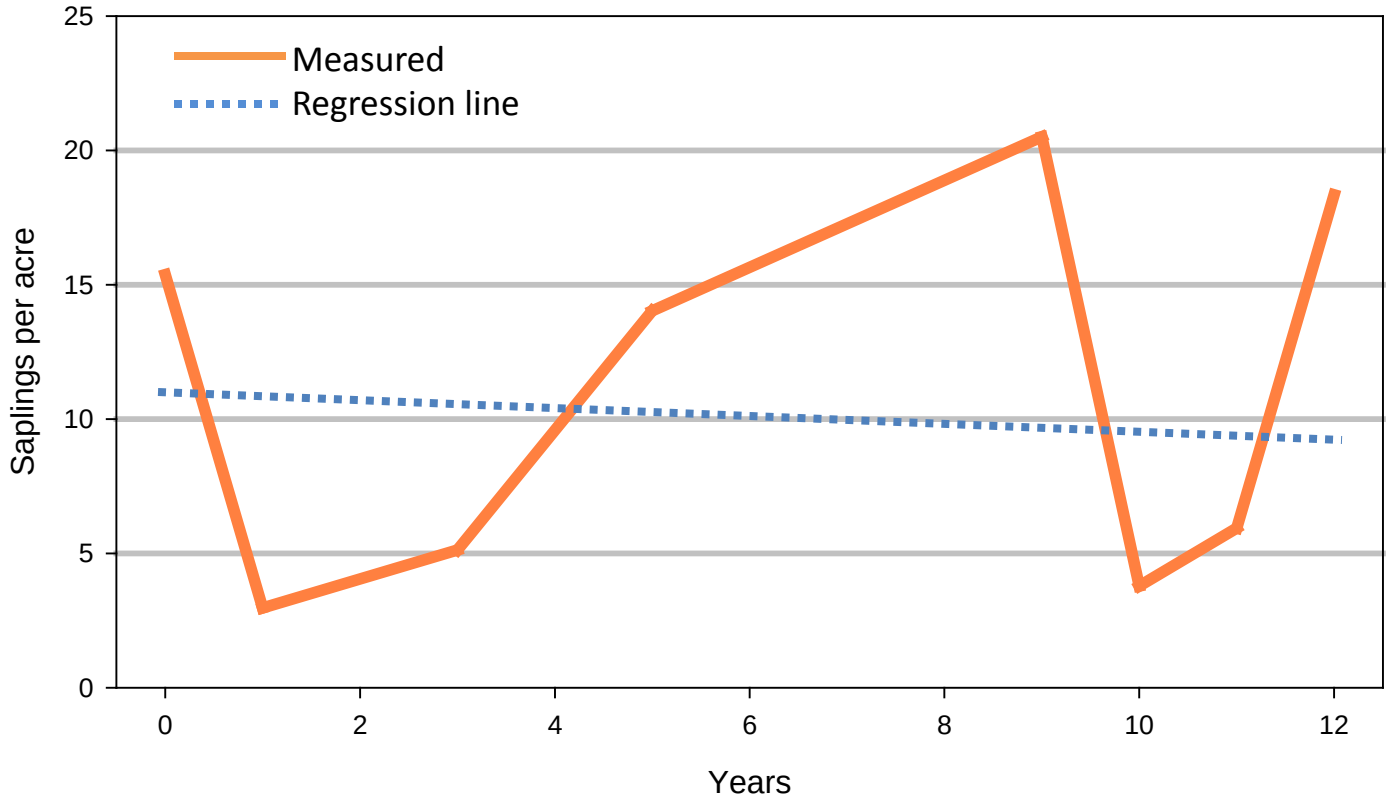
Burn Only: Pine saplings per acre



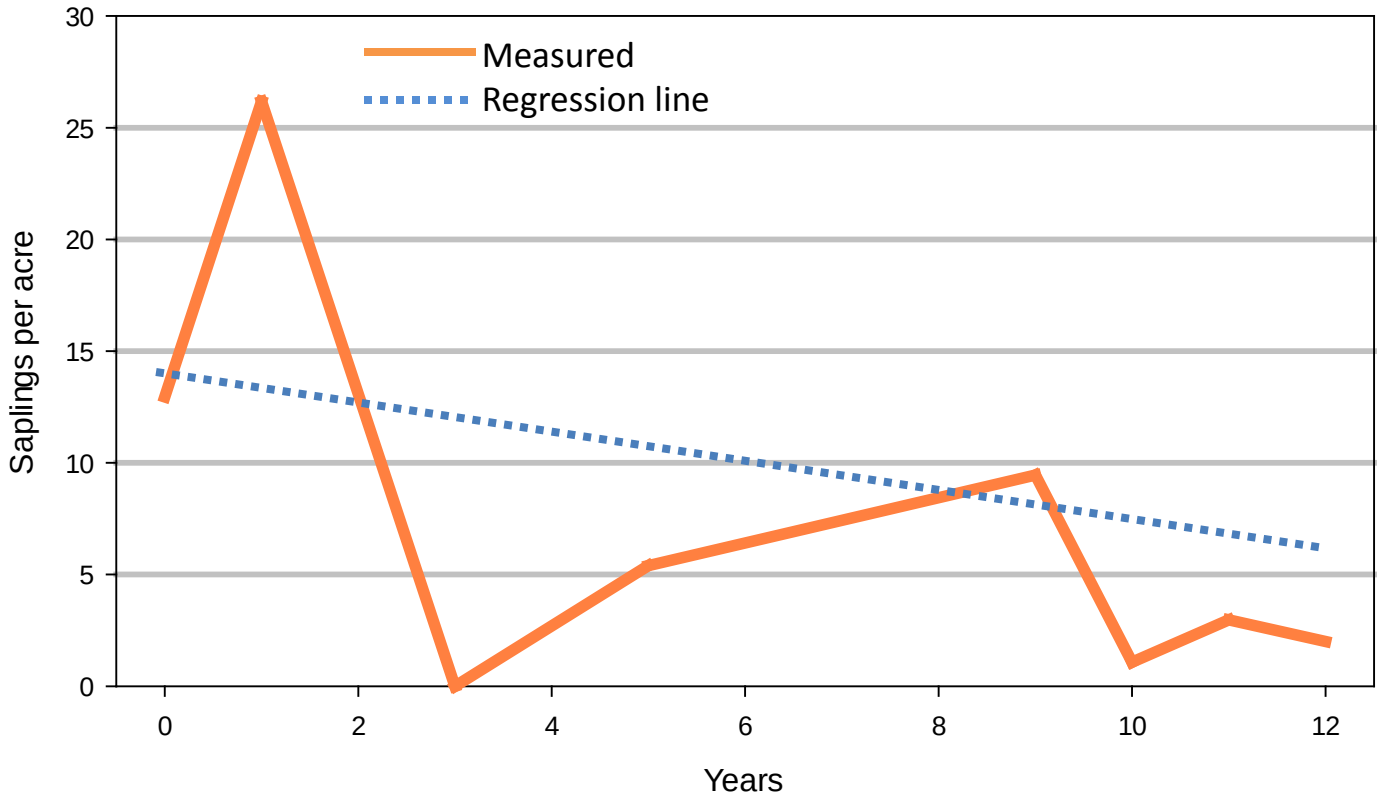
Control: Pine saplings per acre



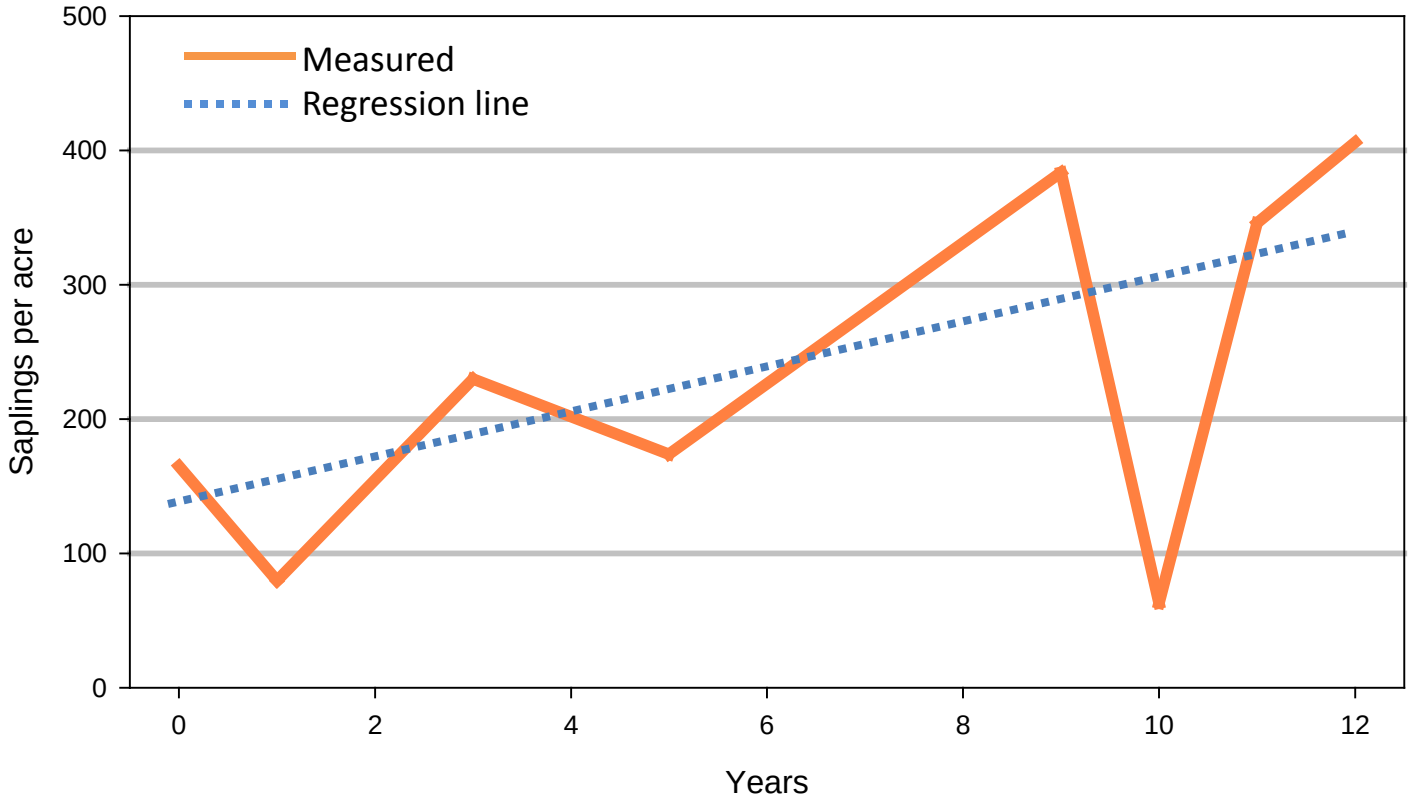
Mechanical: Pine saplings per acre



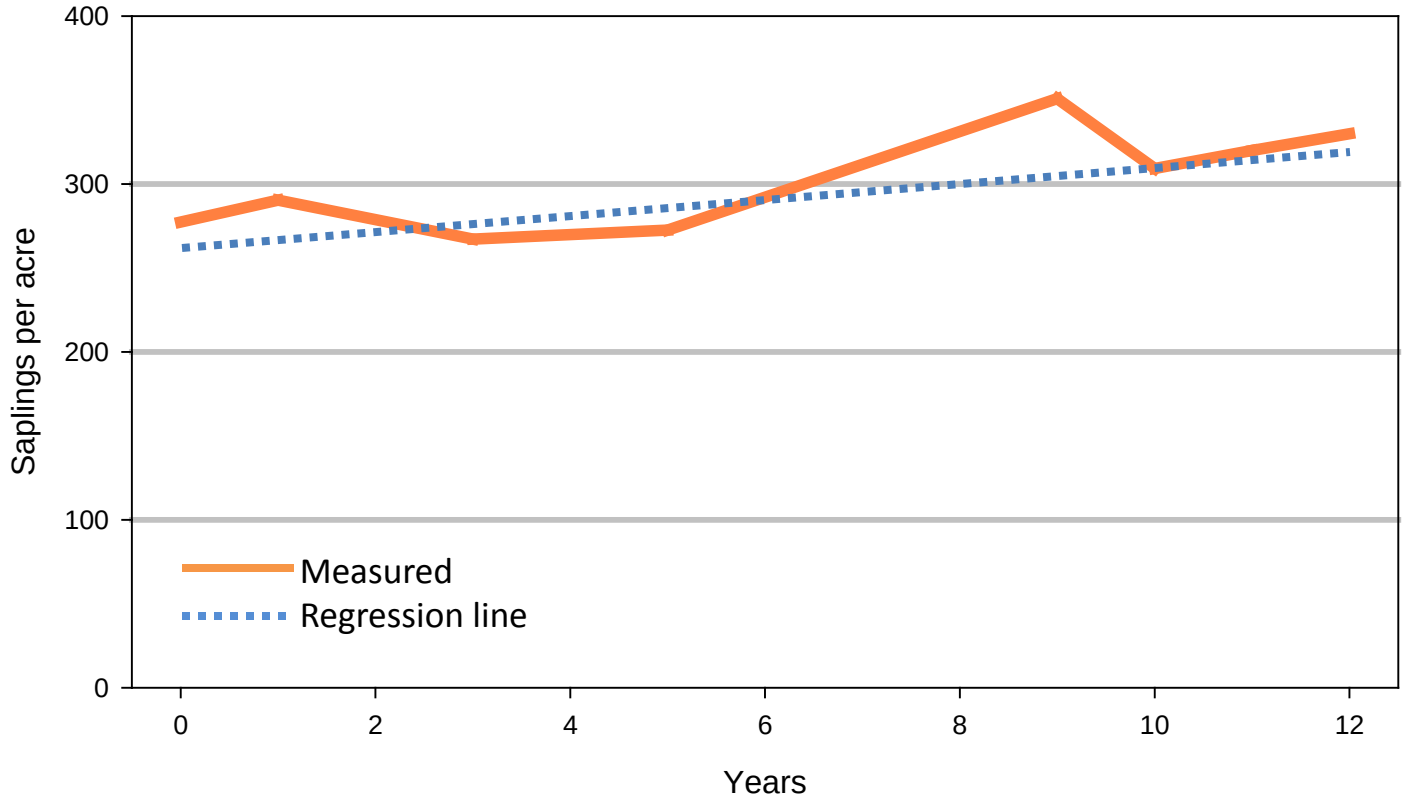
Mechanical + Burn: Pine saplings per acre



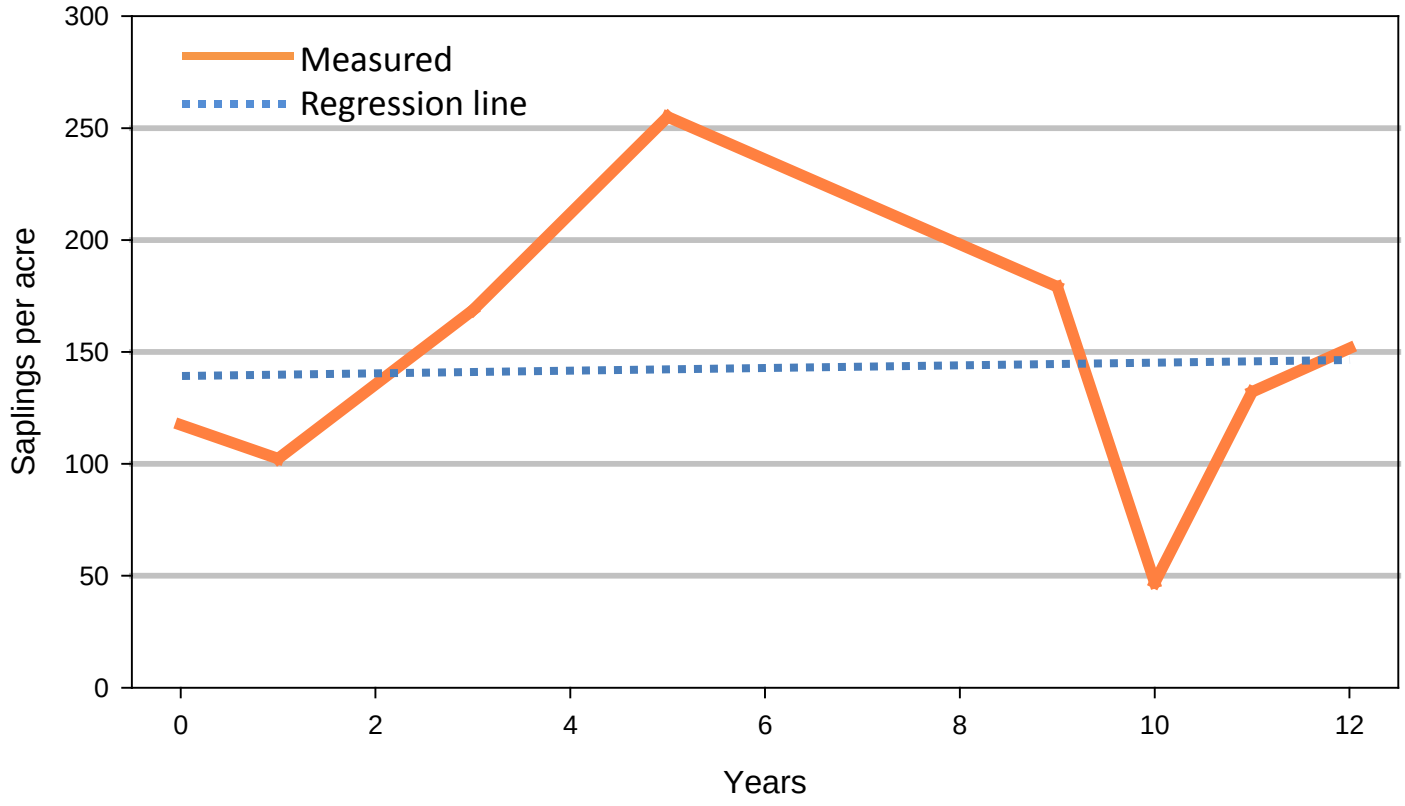
Burn Only: Red Maple saplings per acre



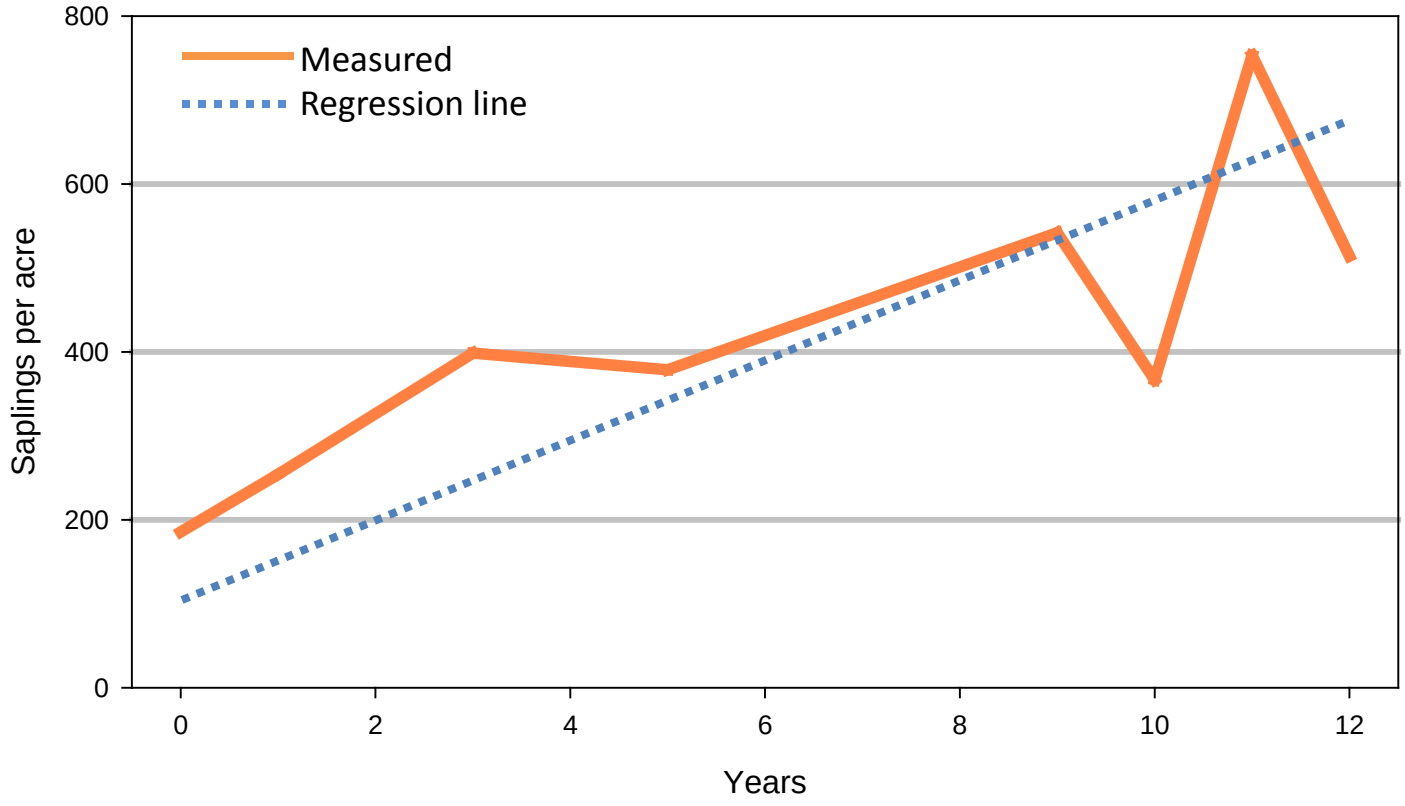
Control: Red Maple saplings per acre



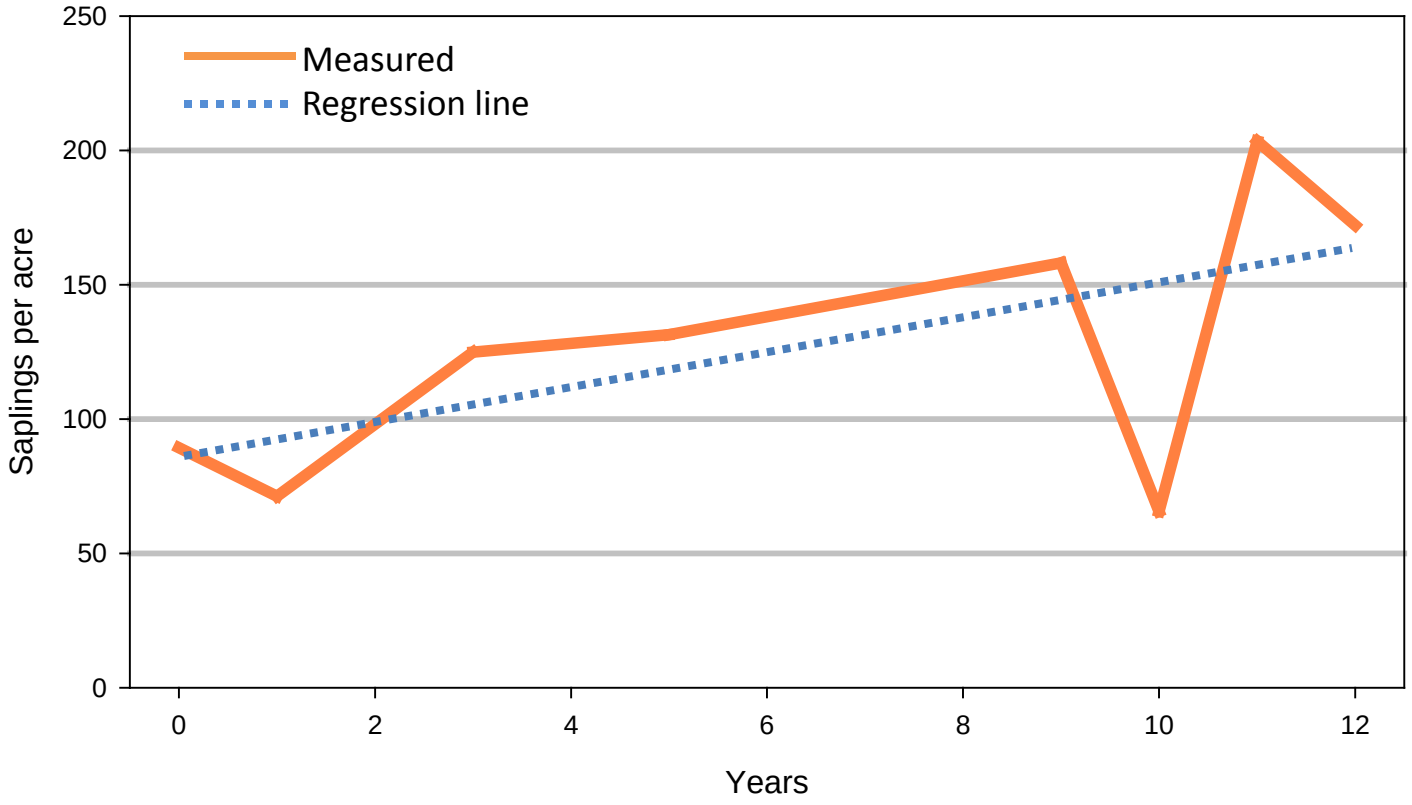
Mechanical: Red Maple saplings per acre



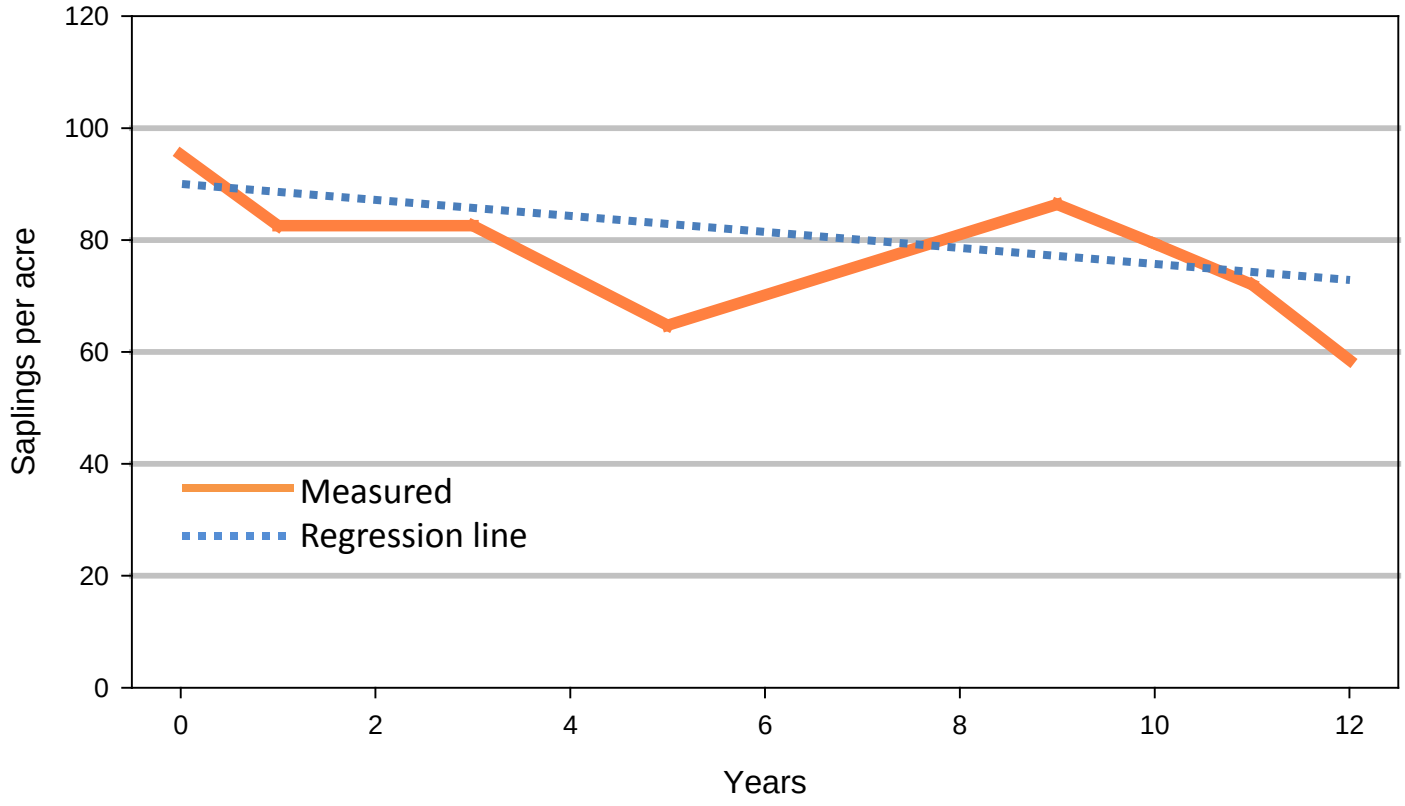
Mechanical + Burn: Red Maple saplings per acre



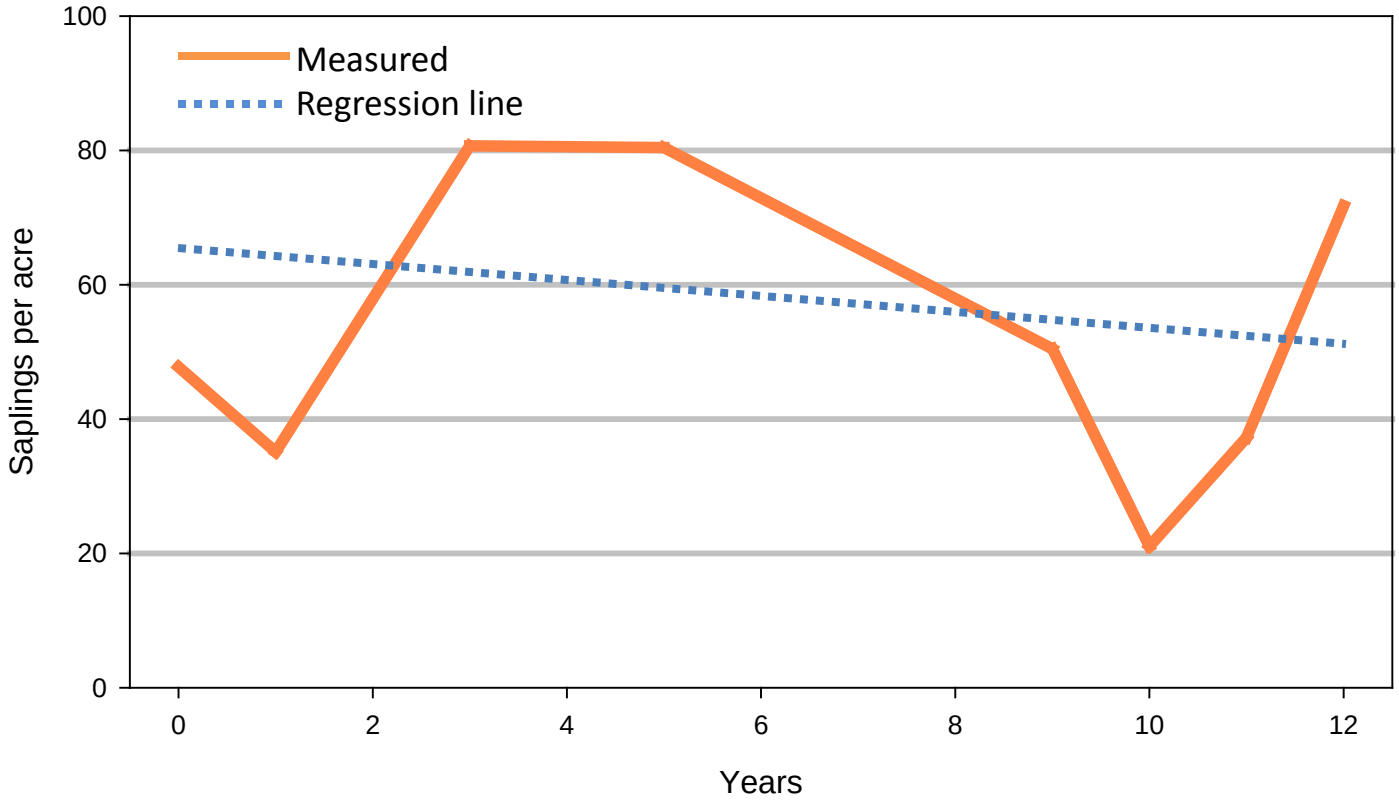
Burn Only: Sourwood saplings per acre



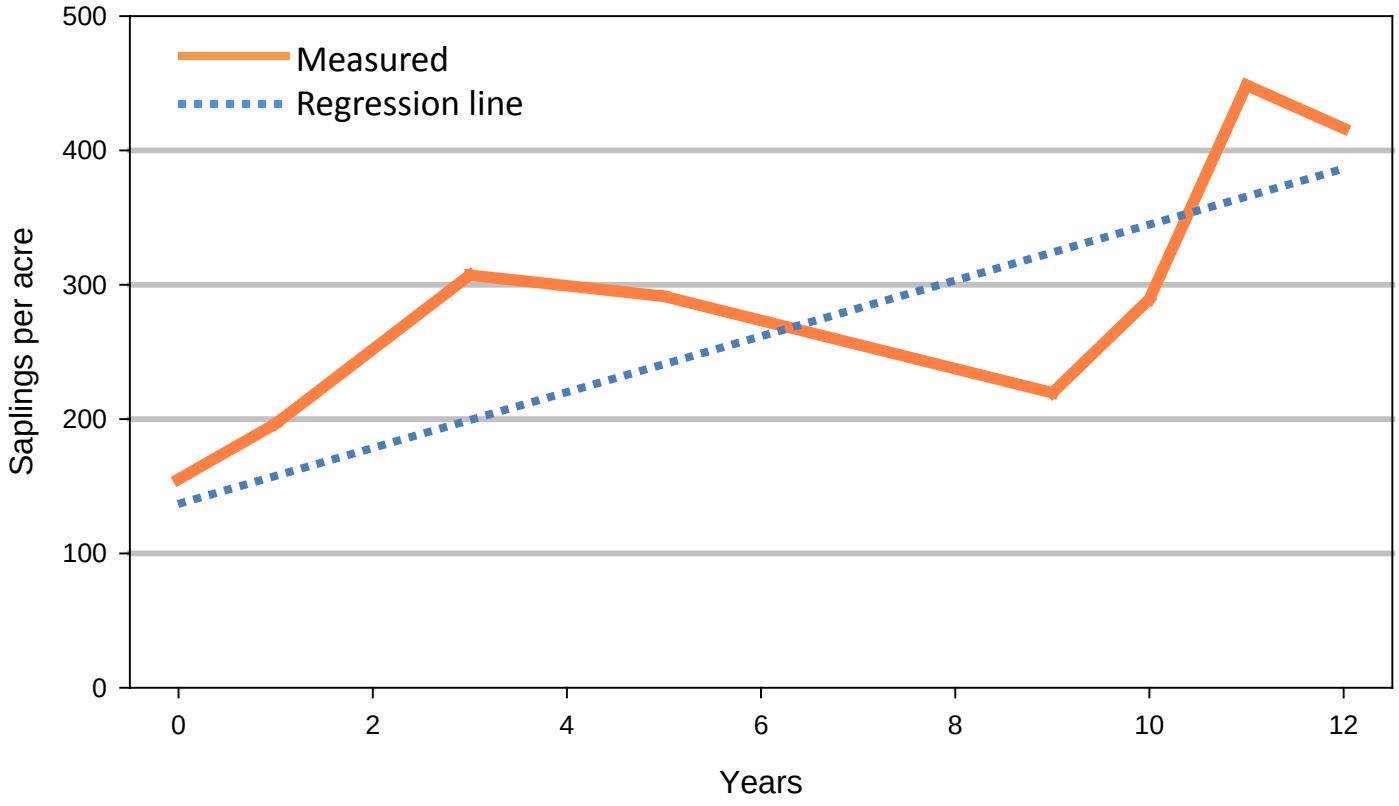
Control: Sourwood saplings per acre



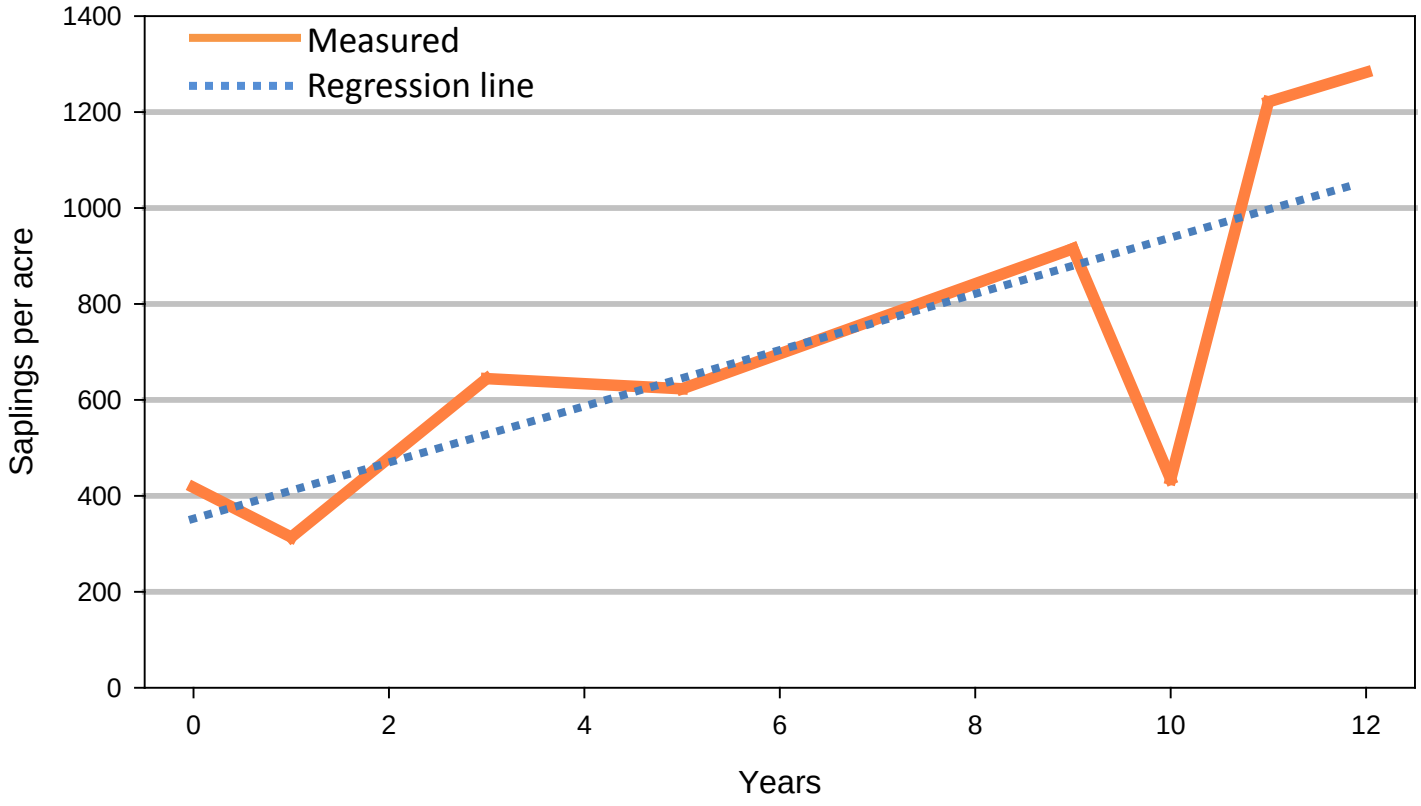
Mechanical: Sourwood saplings per acre



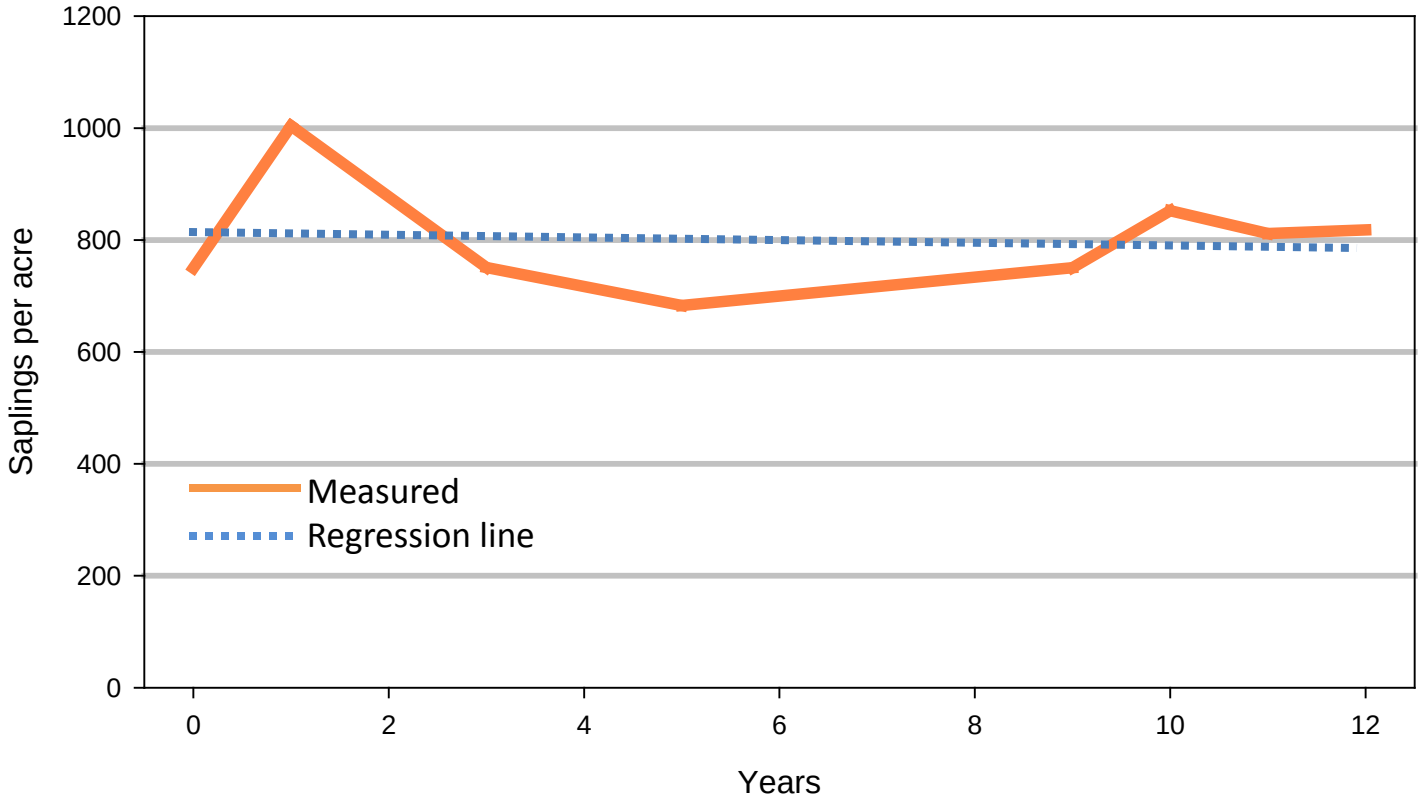
Mechanical + Burn: Sourwood saplings per acre



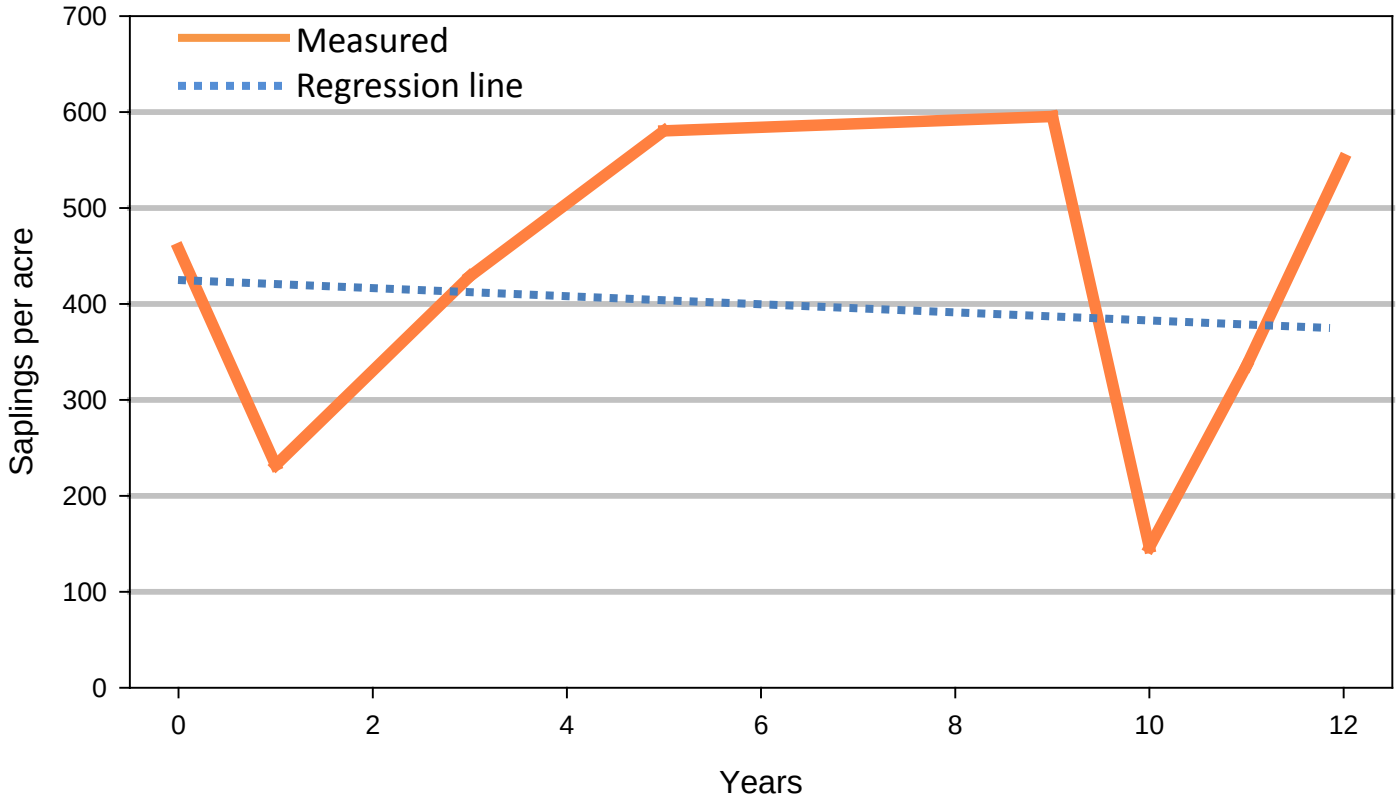
Burn Only: All Species saplings per acre



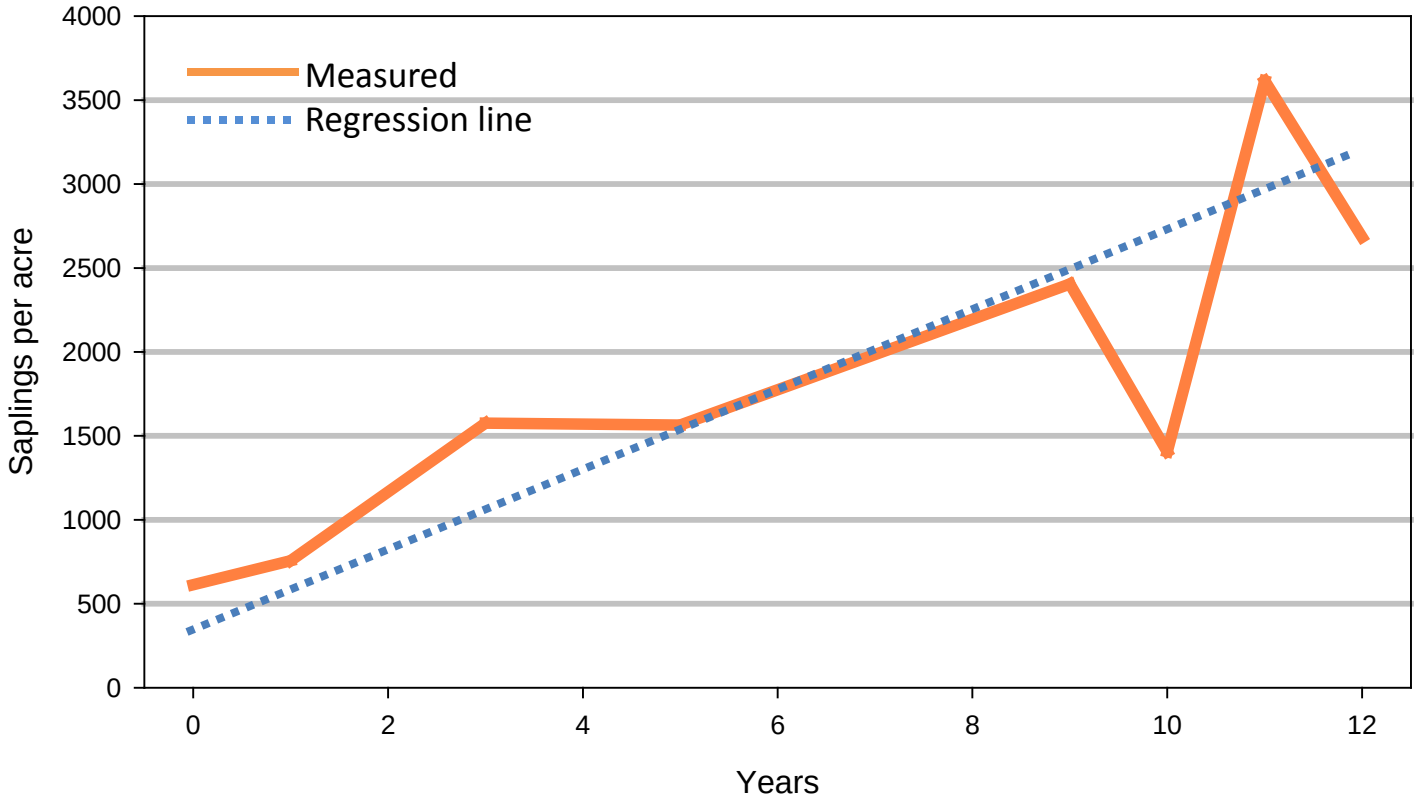
Control: All Species saplings per acre



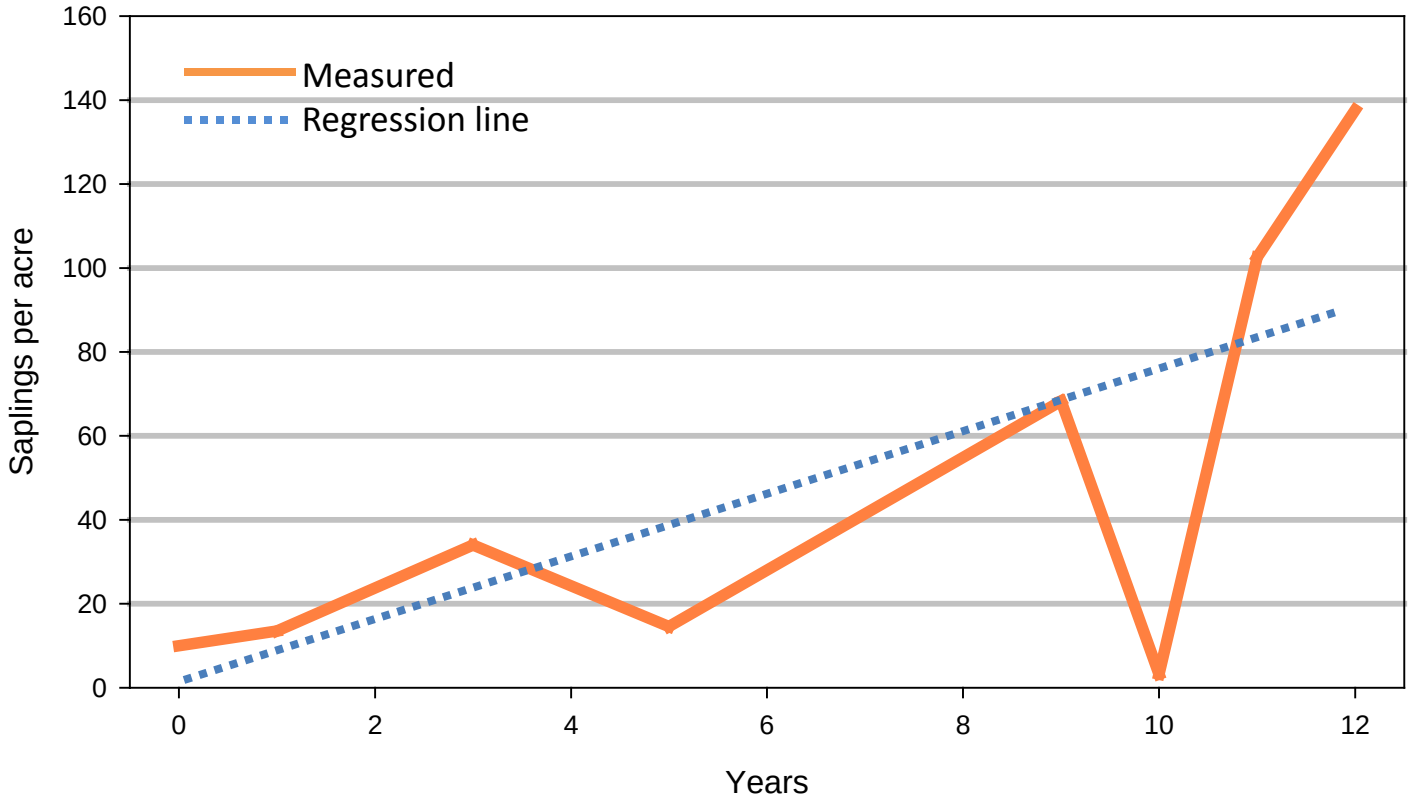
Mechanical: All Species saplings per acre



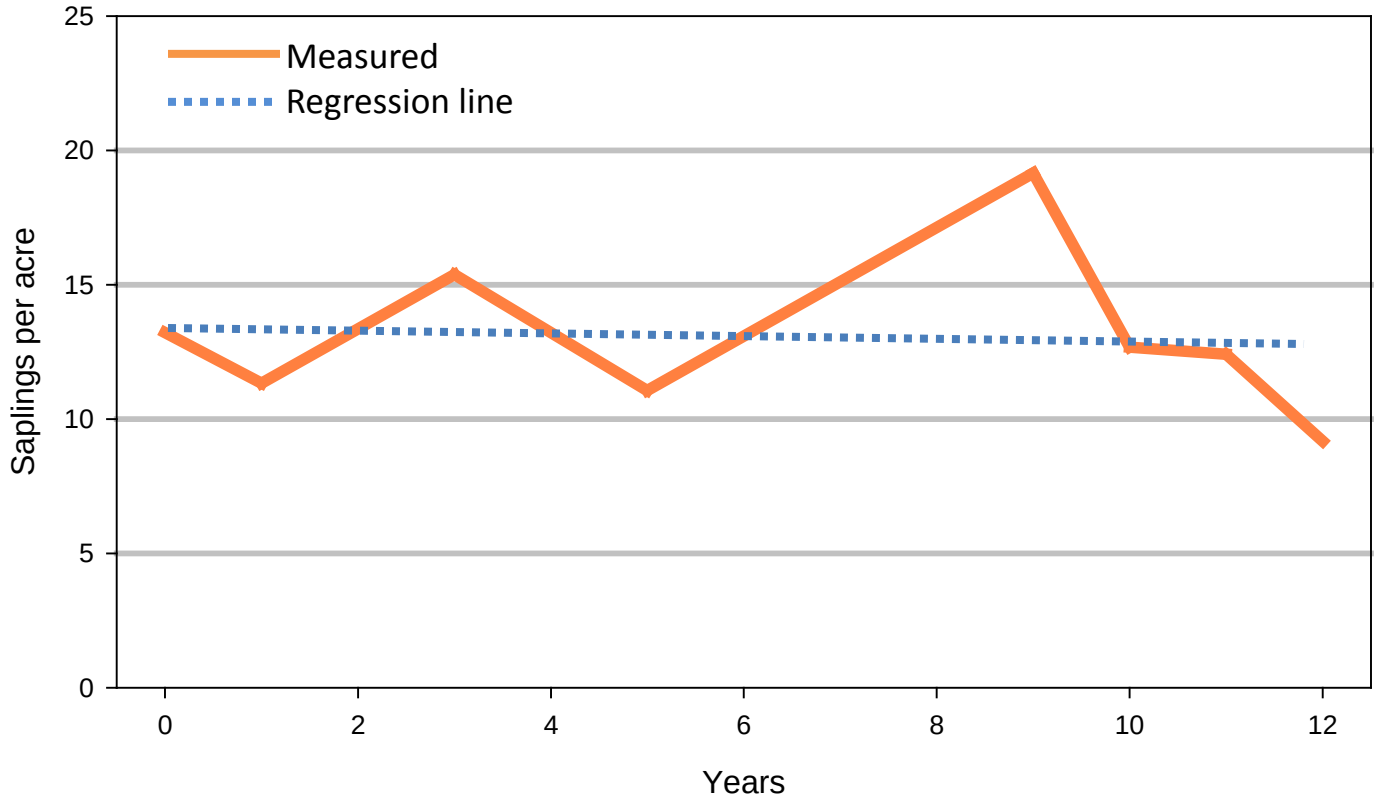
Mechanical + Burn: All Species saplings per acre



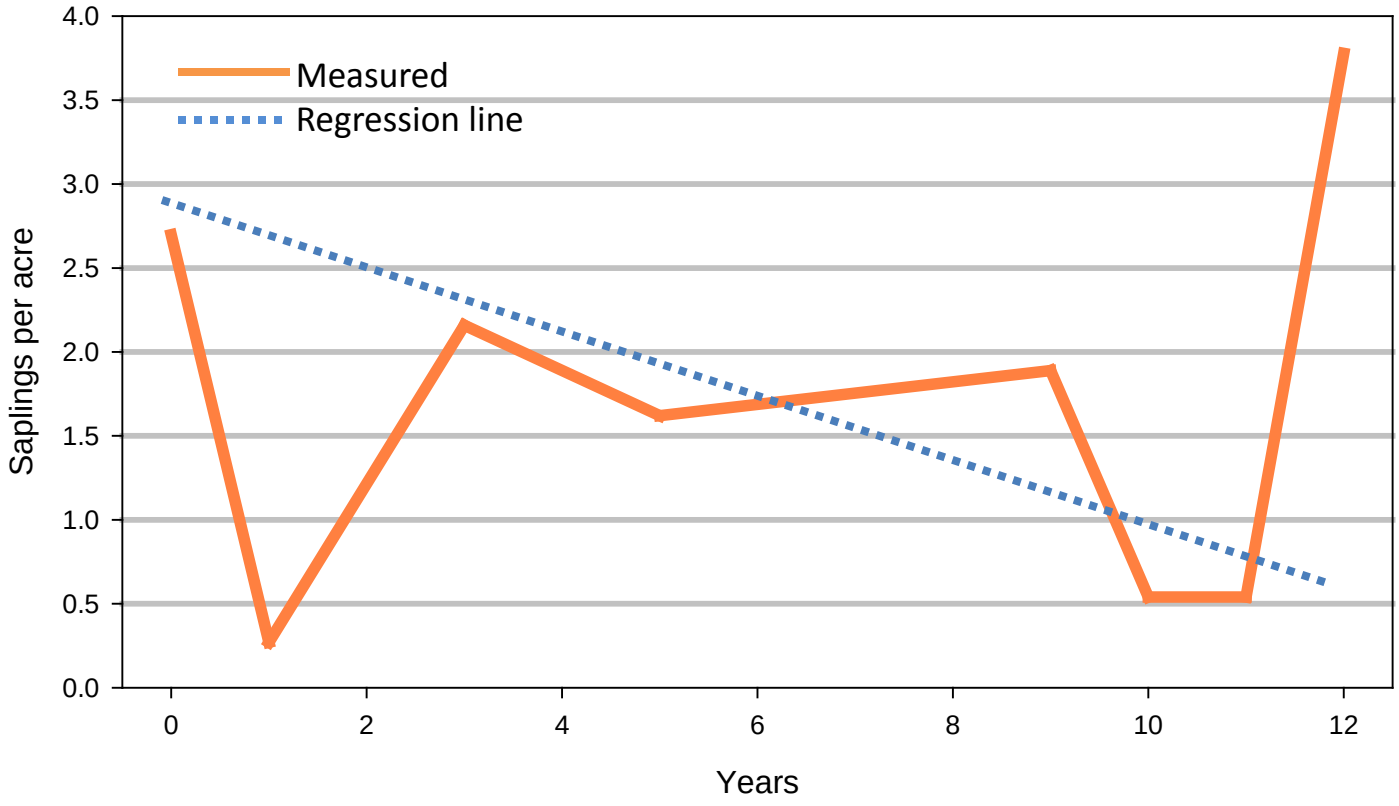
Burn Only: Yellow-poplar saplings per acre



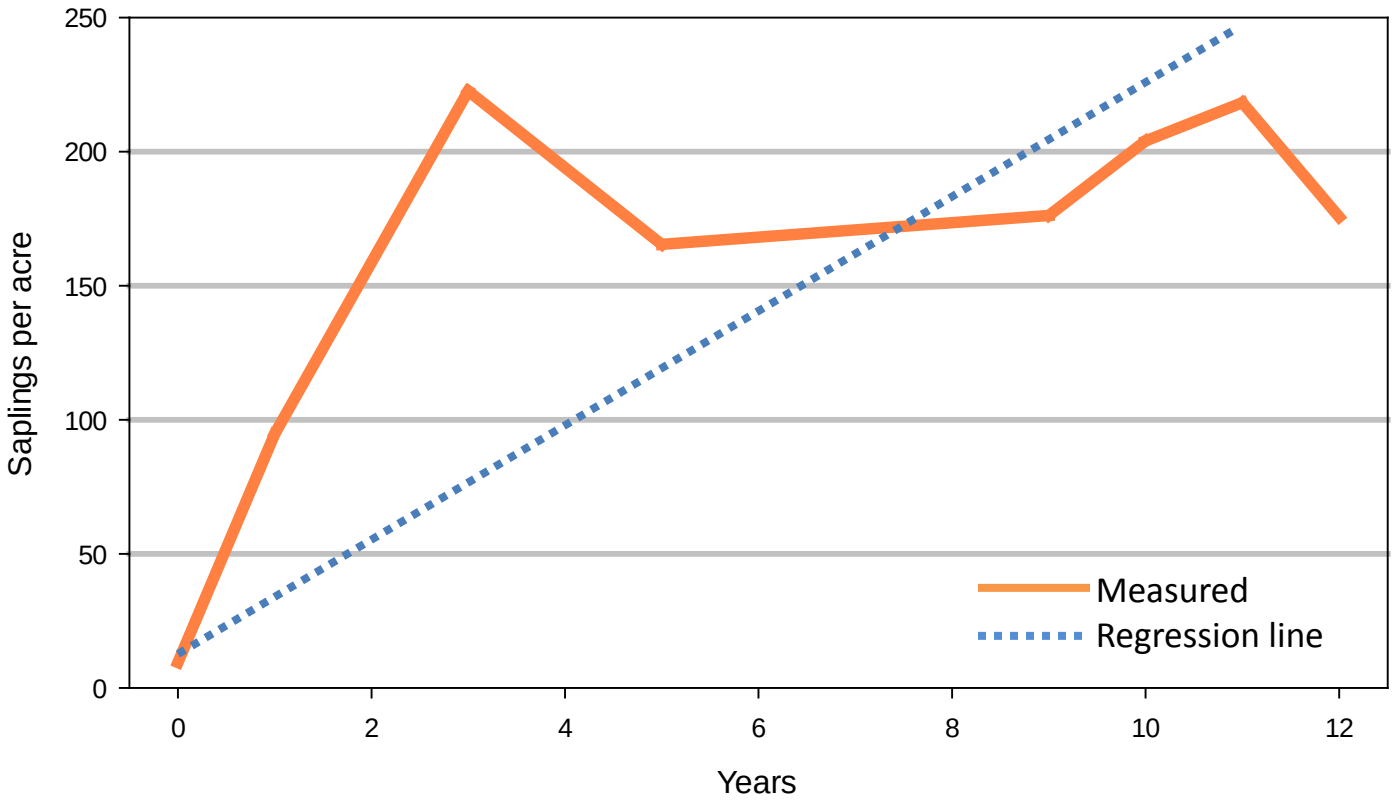
Control: Yellow-poplar saplings per acre



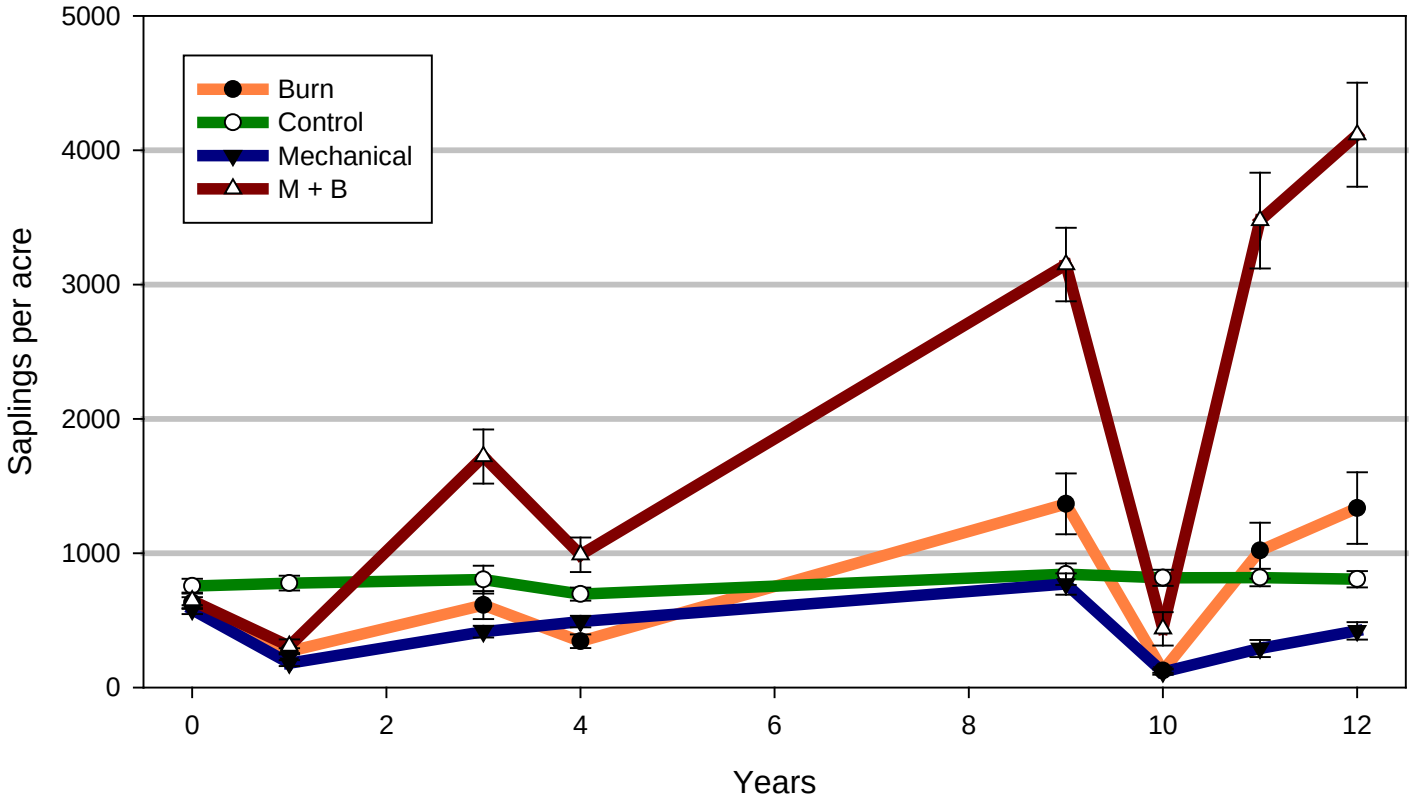
Mechanical: Yellow-poplar saplings per acre



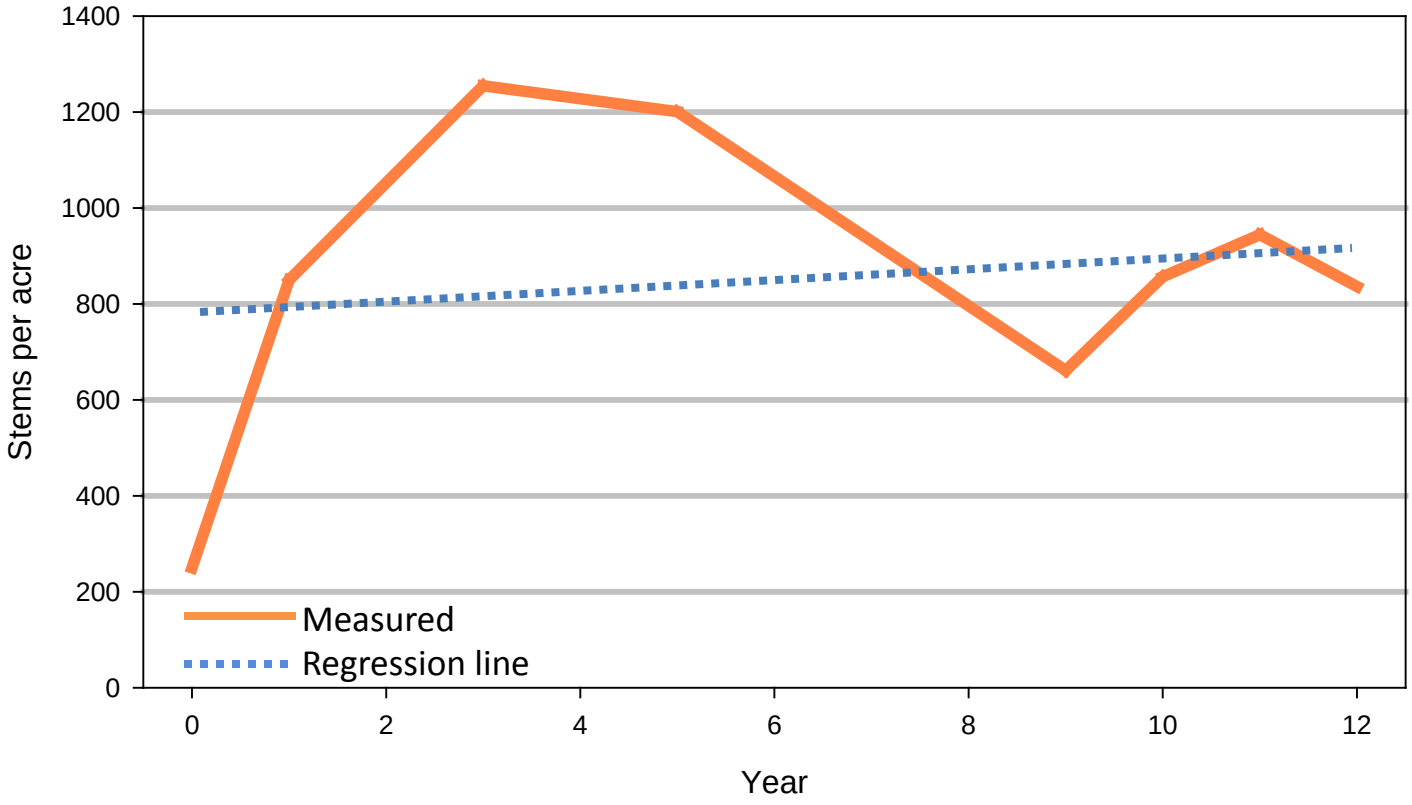
Mechanical + Burn: Yellow-poplar saplings per acre



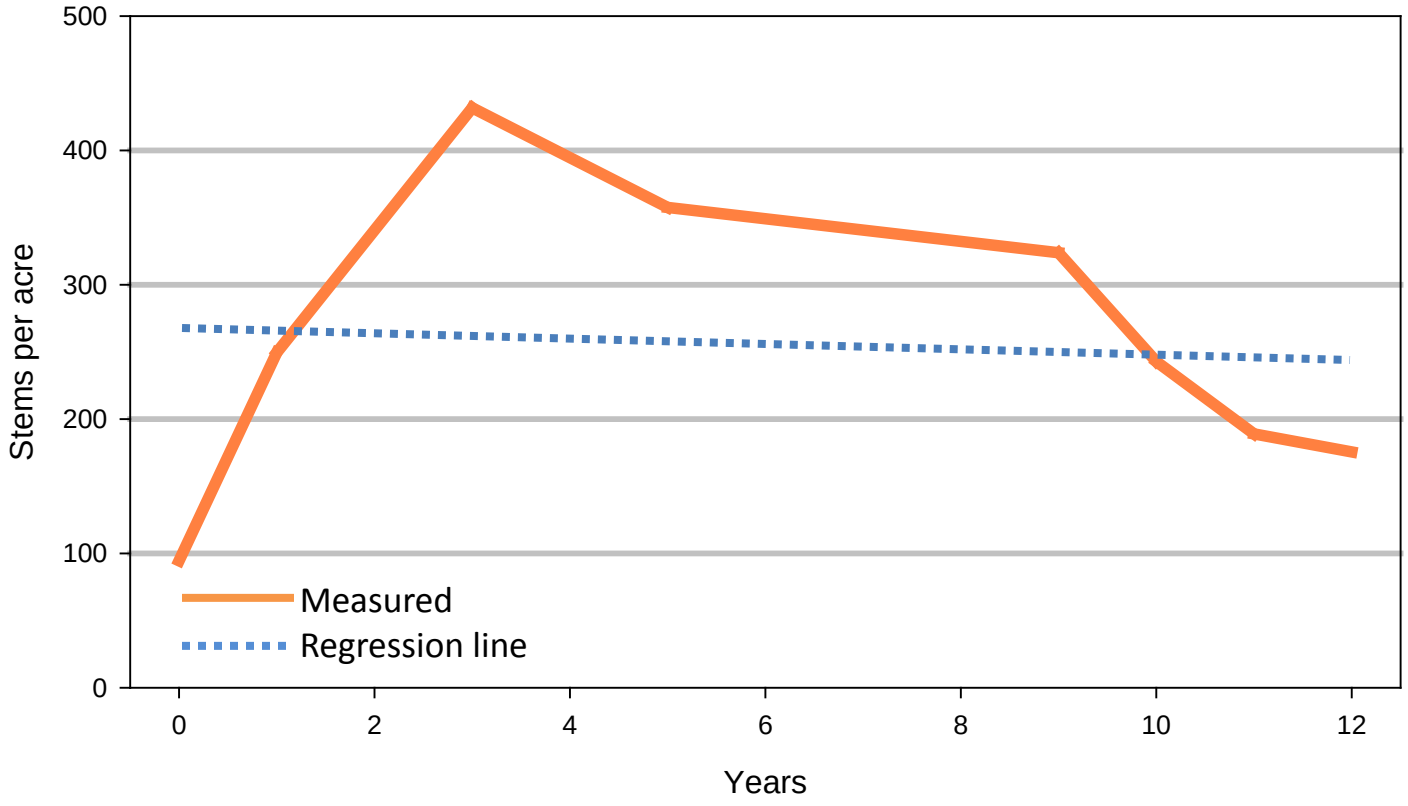
Sapling Density – All Species All Treatments



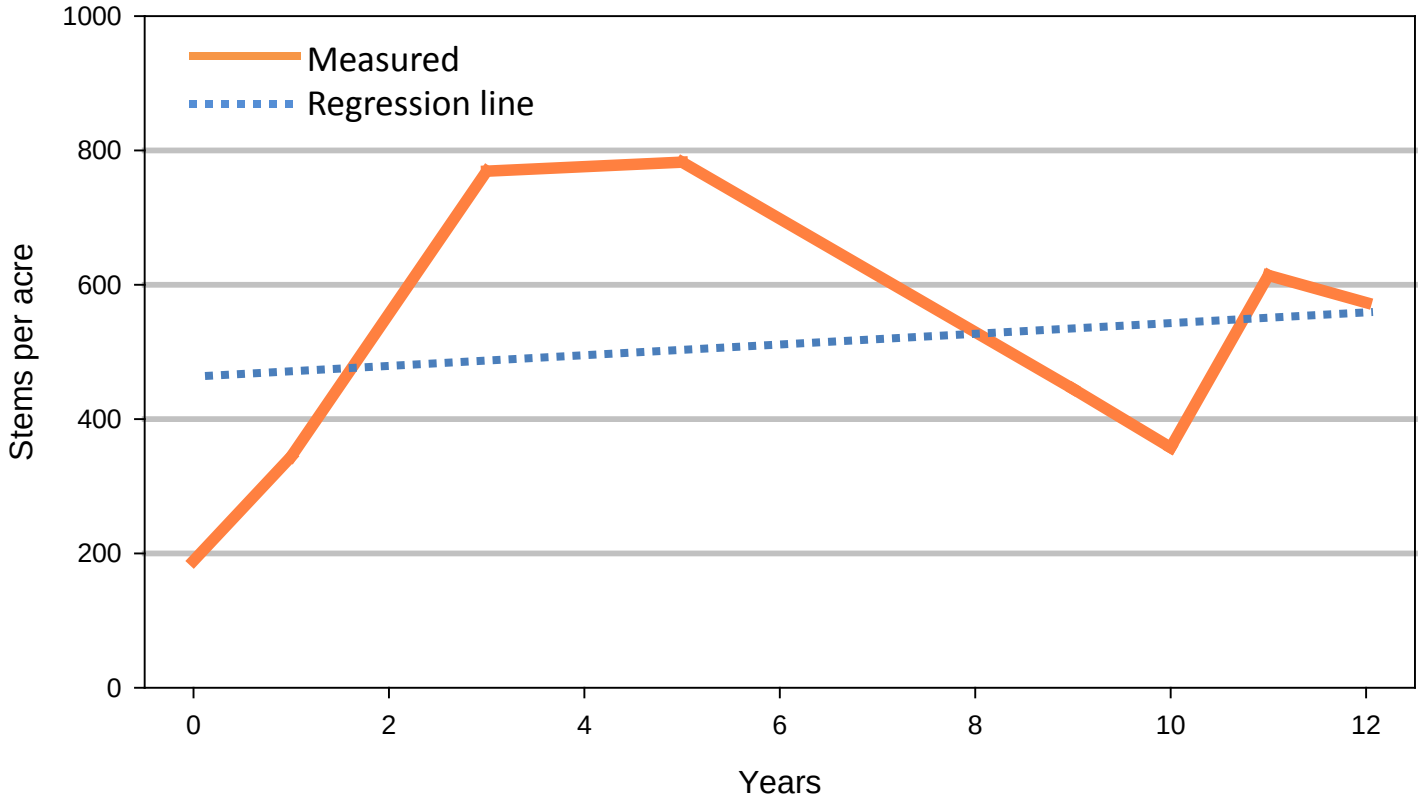
Burn Only: Blackgum regeneration



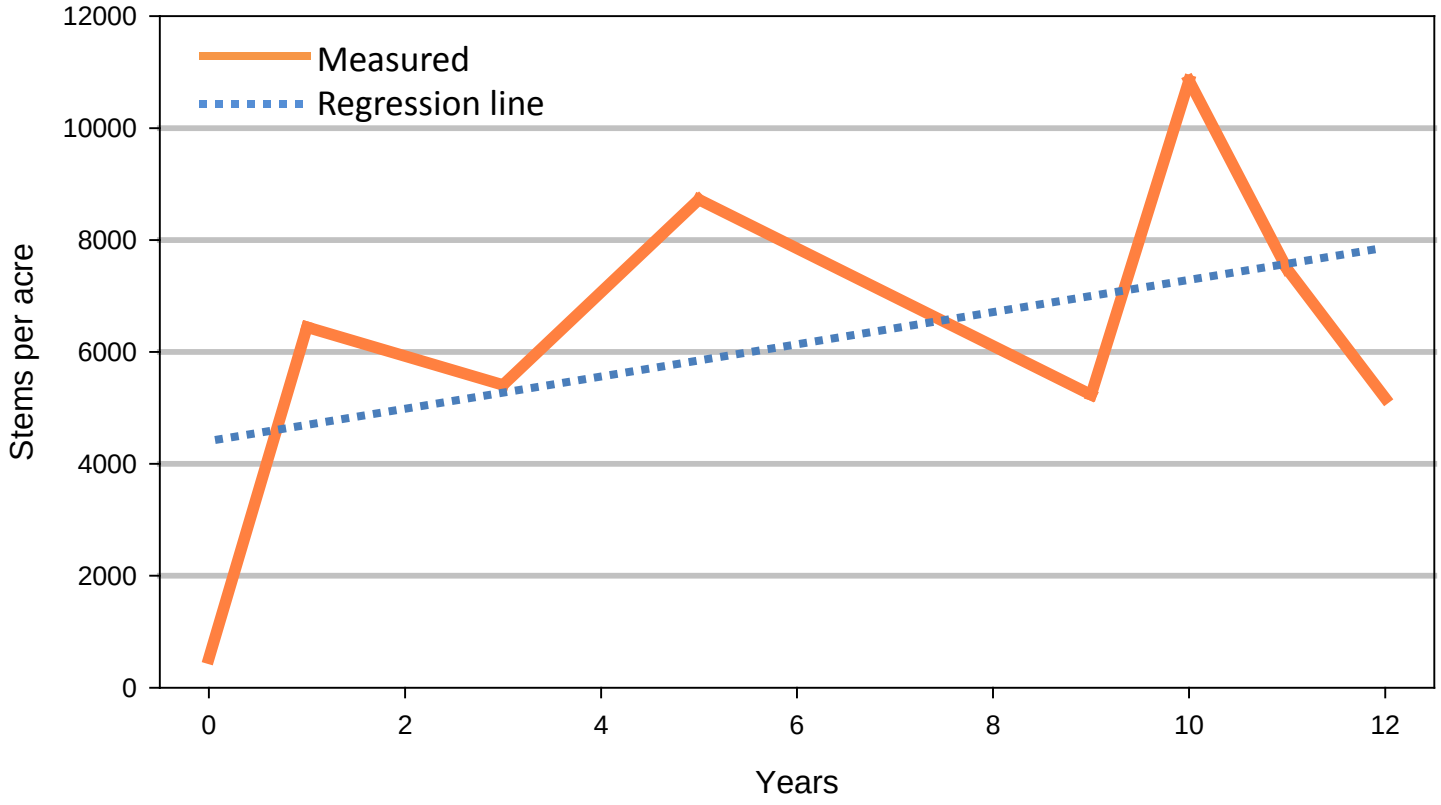
Control: Blackgum regeneration



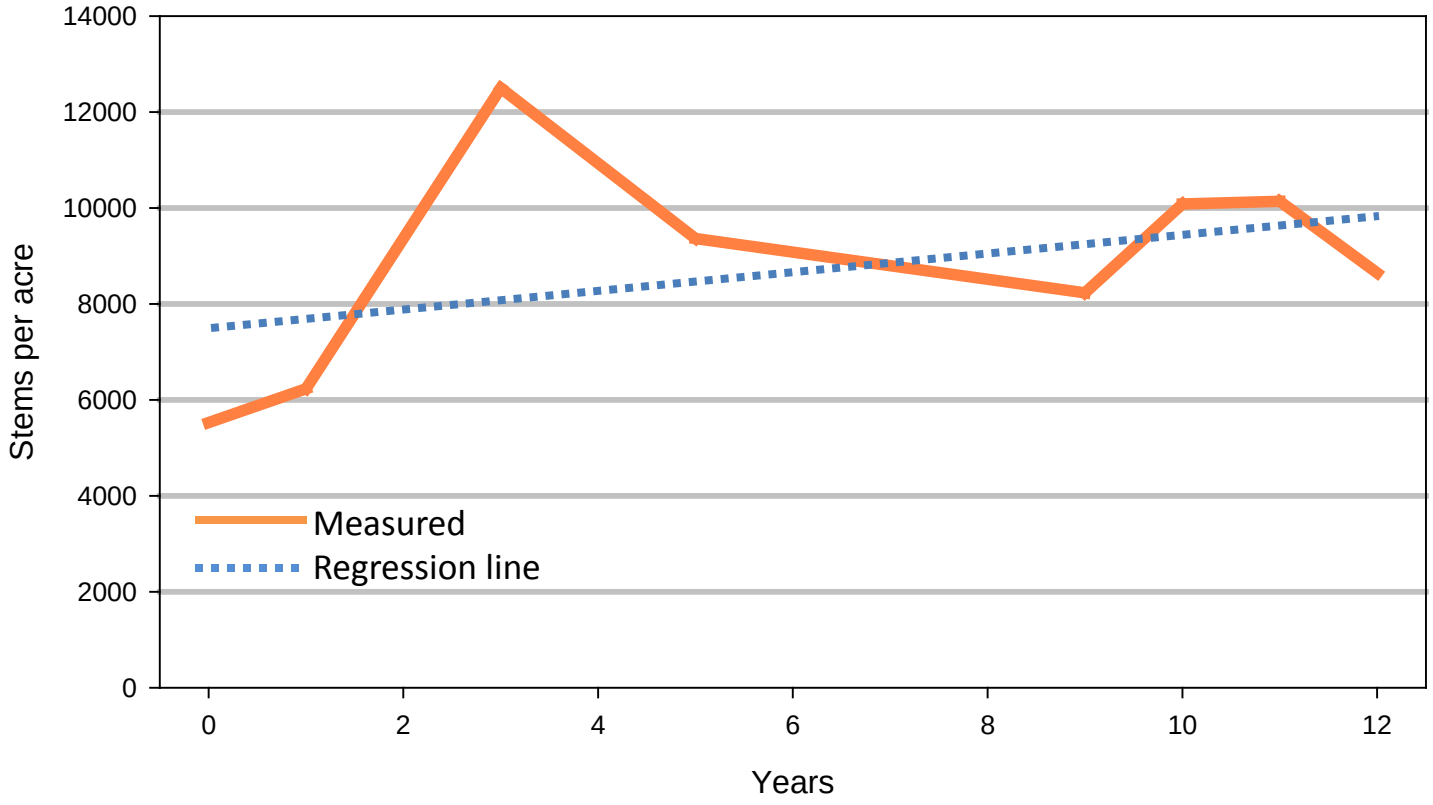
Mechanical: Blackgum regeneration



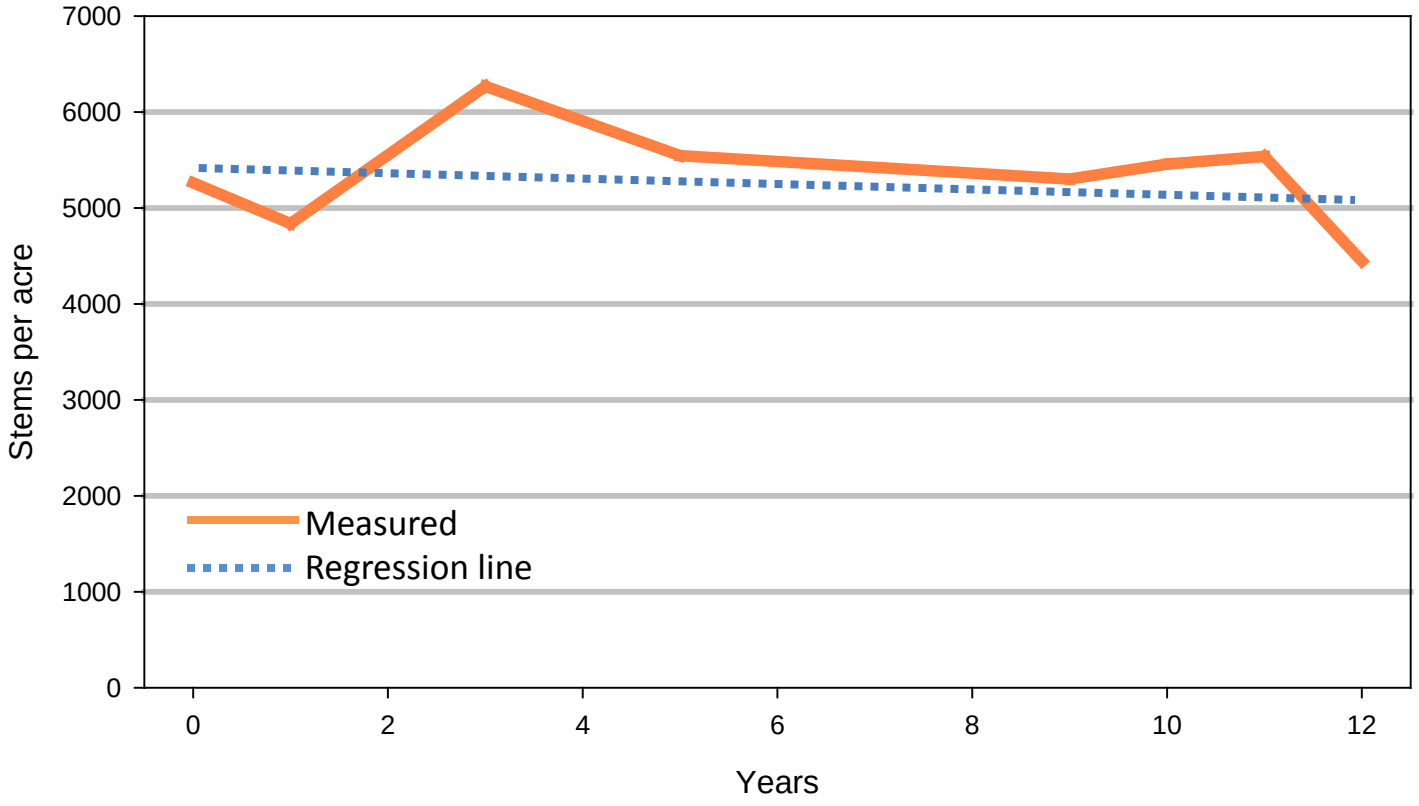
Mechanical + Burn: Blackgum regeneration



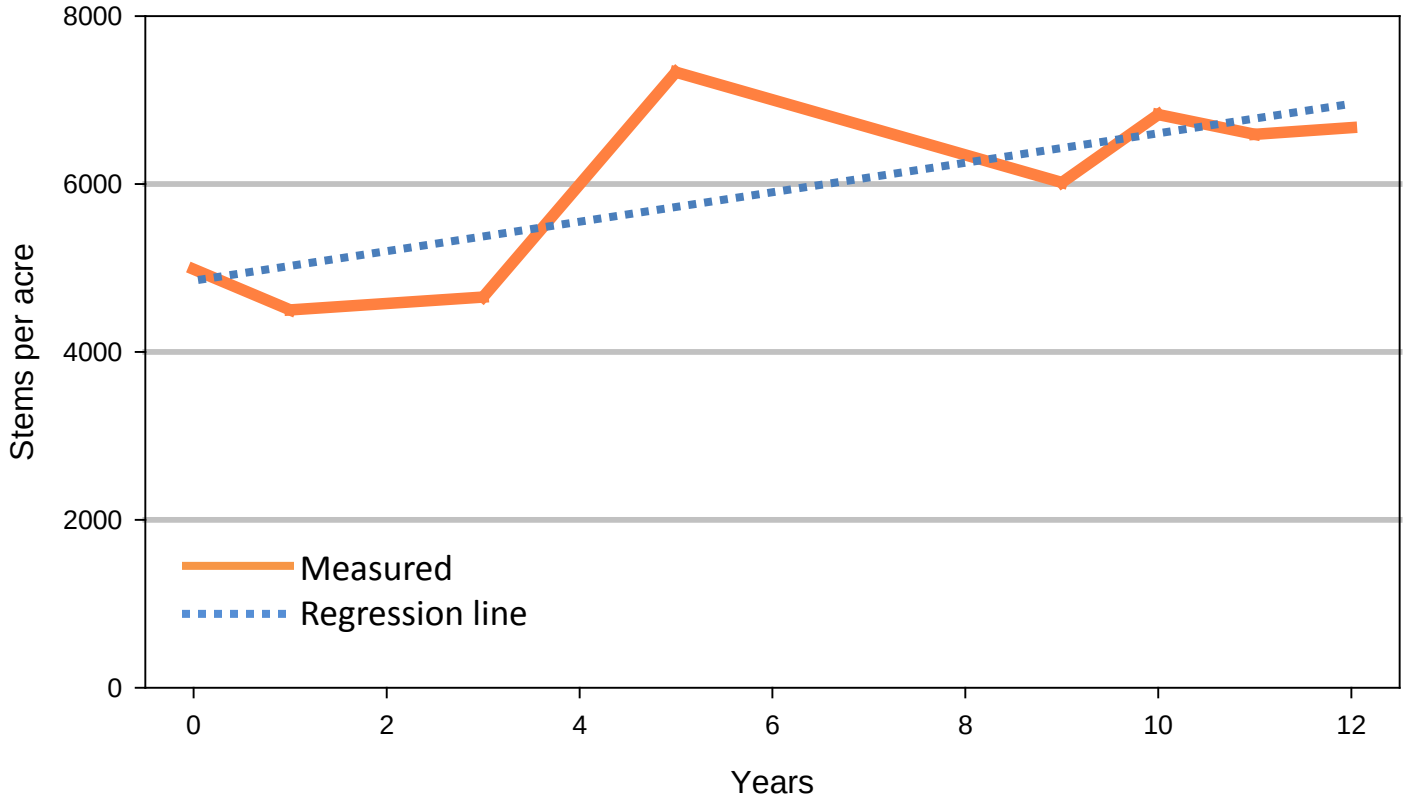
Burn Only: Oak regeneration



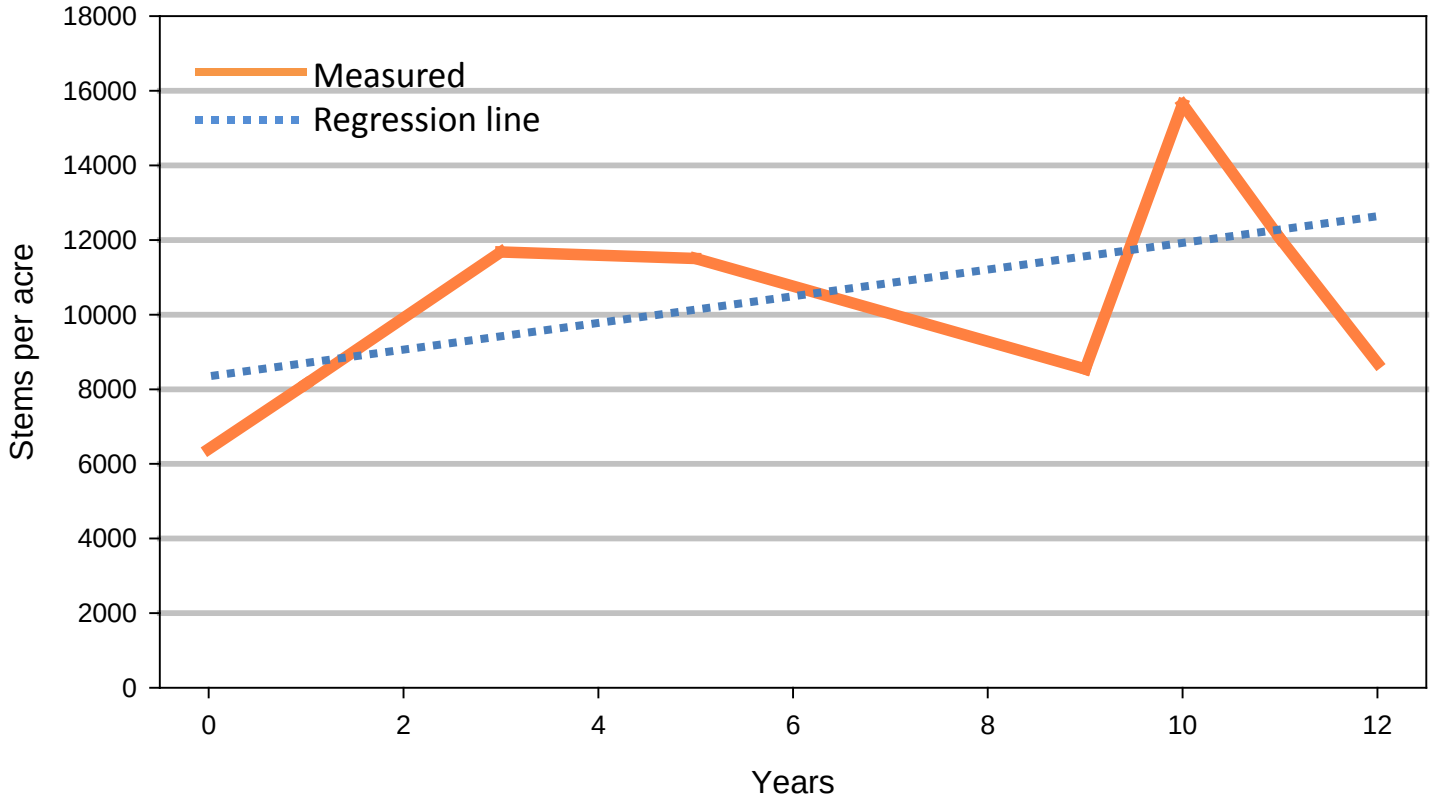
Control: Oak regeneration



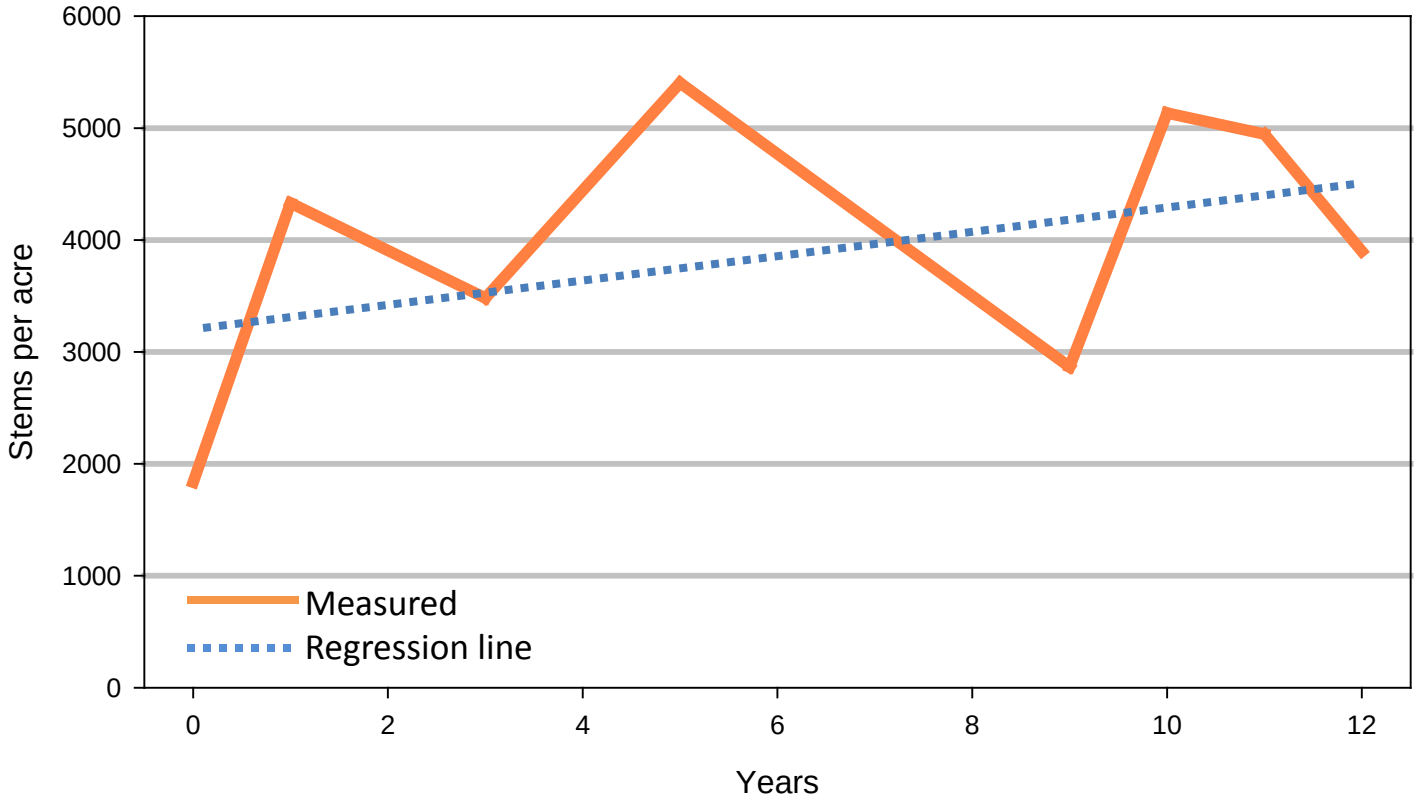
Mechanical: Oak regeneration



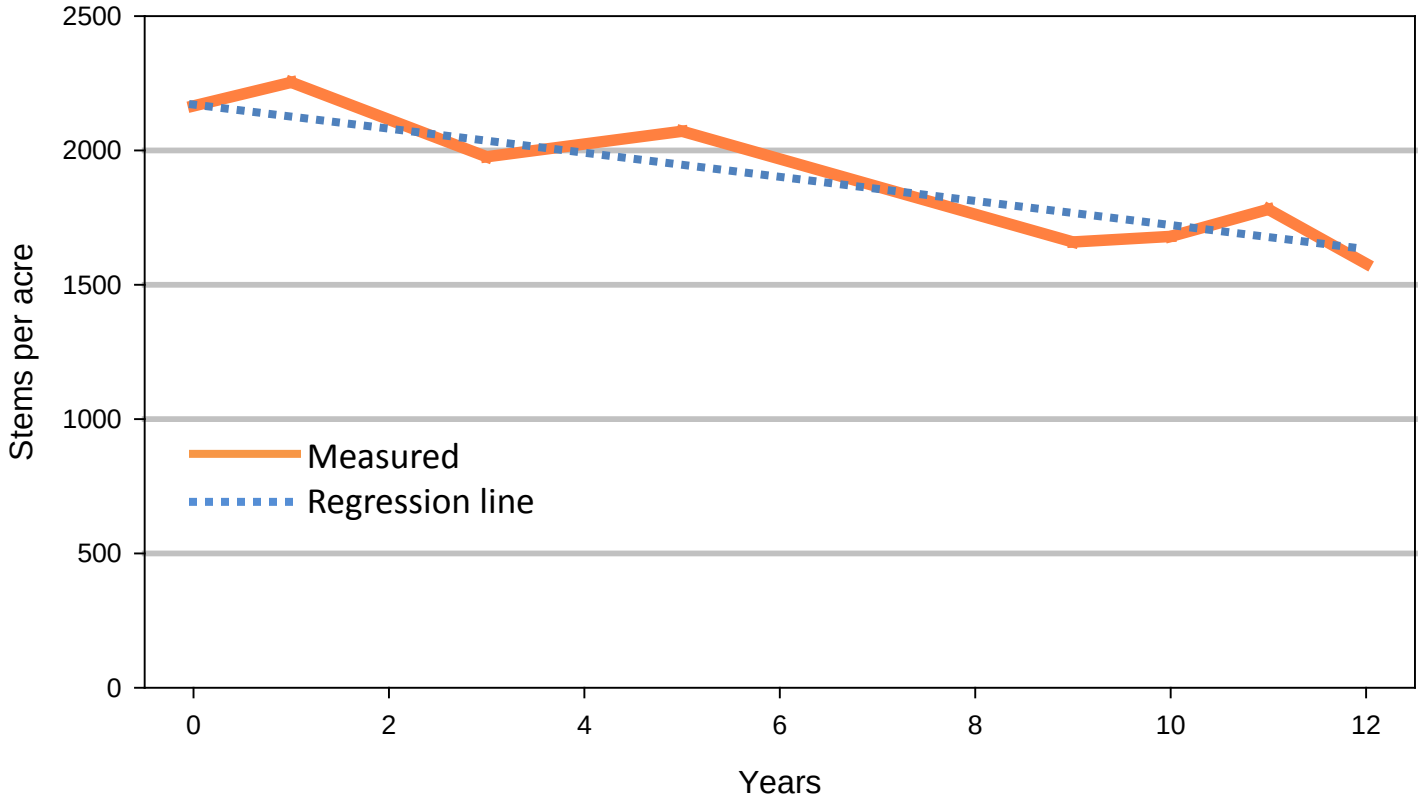
Mechanical + Burn: Oak regeneration



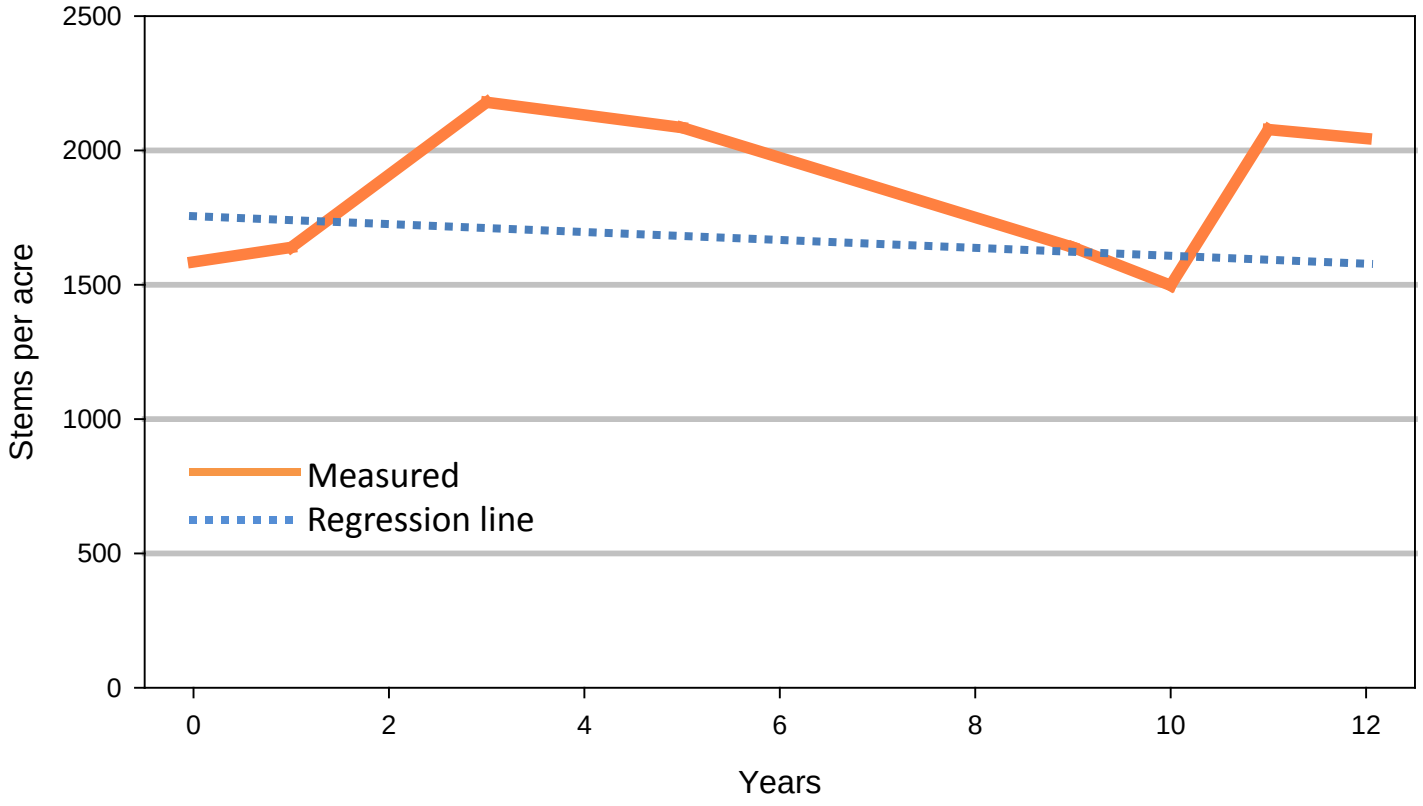
Burn Only: Other Species regeneration



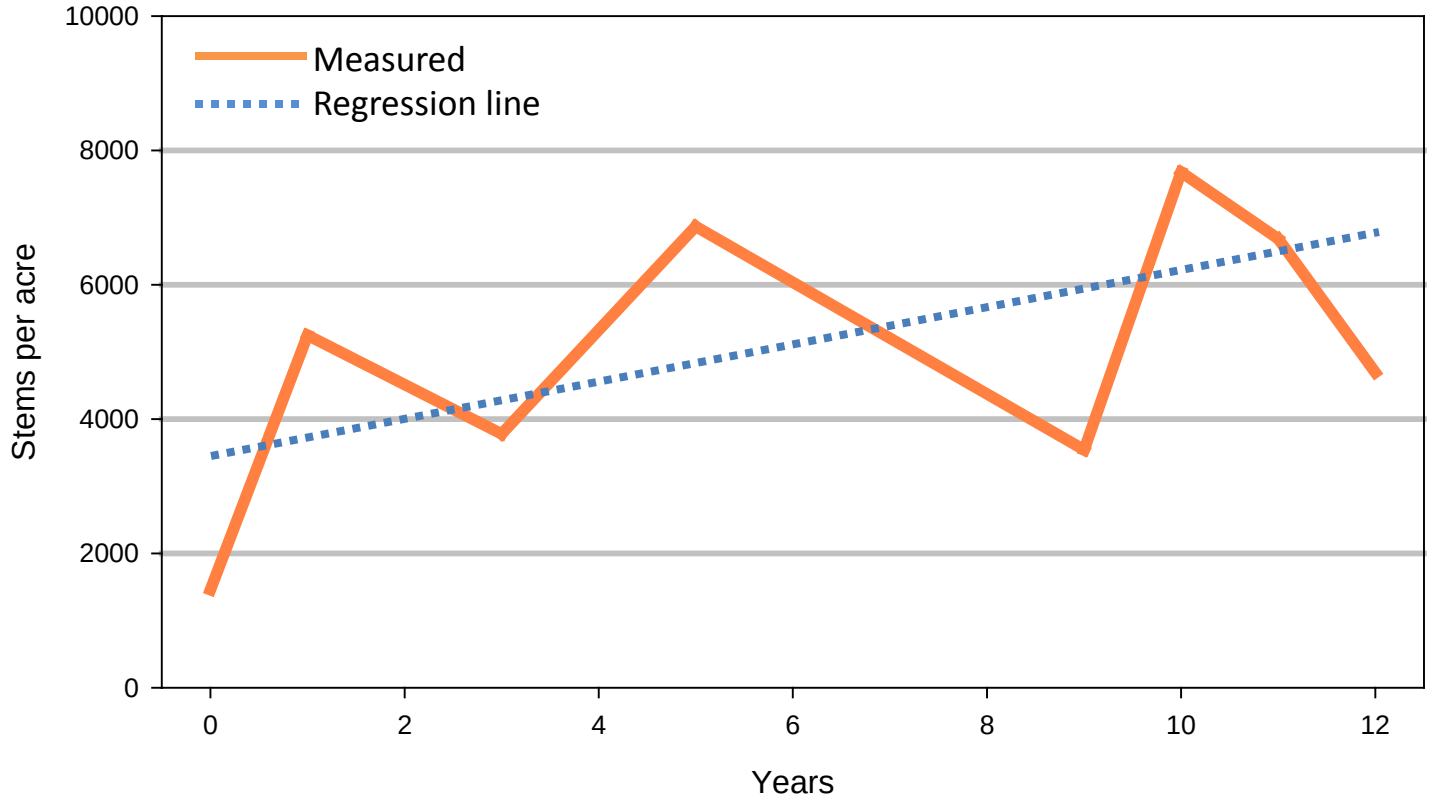
Control: Other Species regeneration



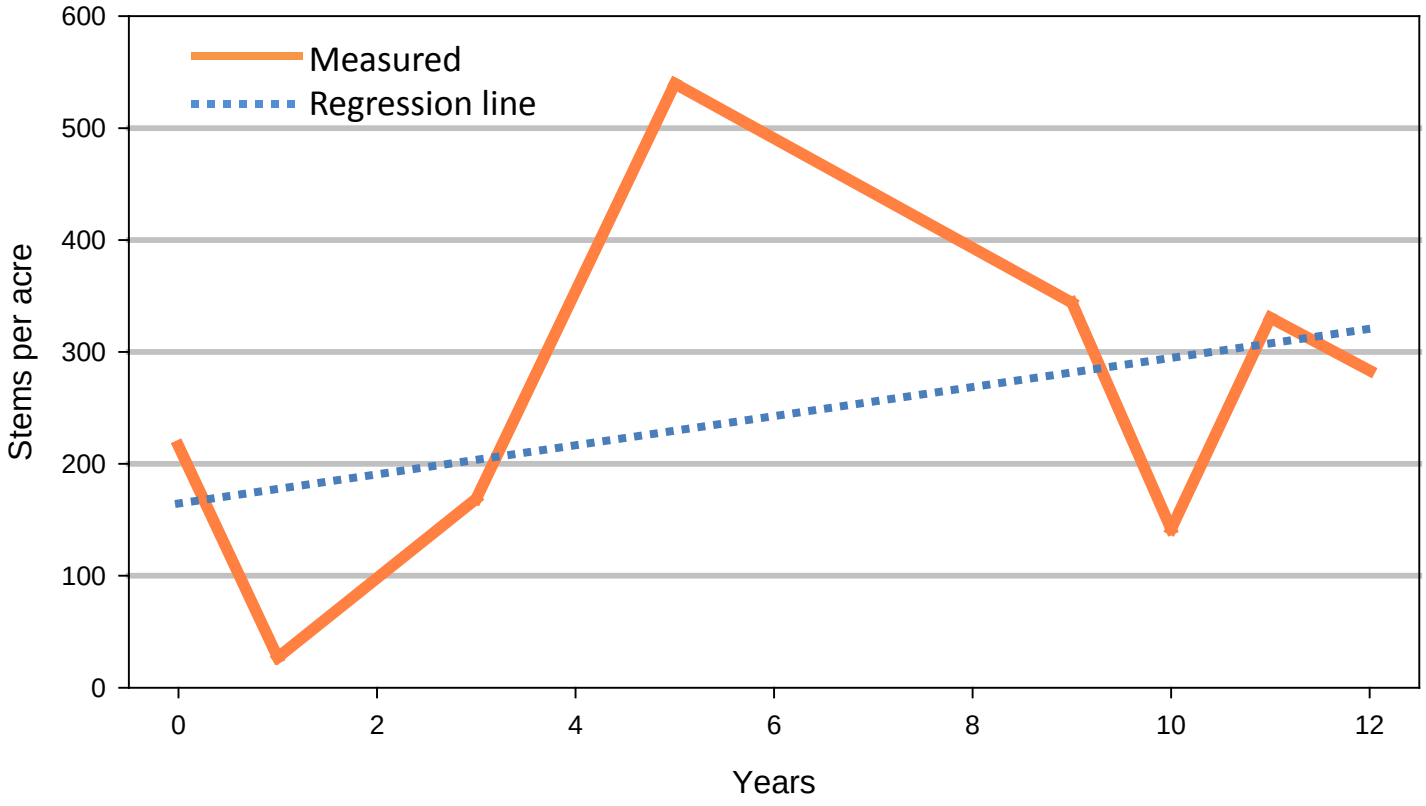
Mechanical: Other Species regeneration



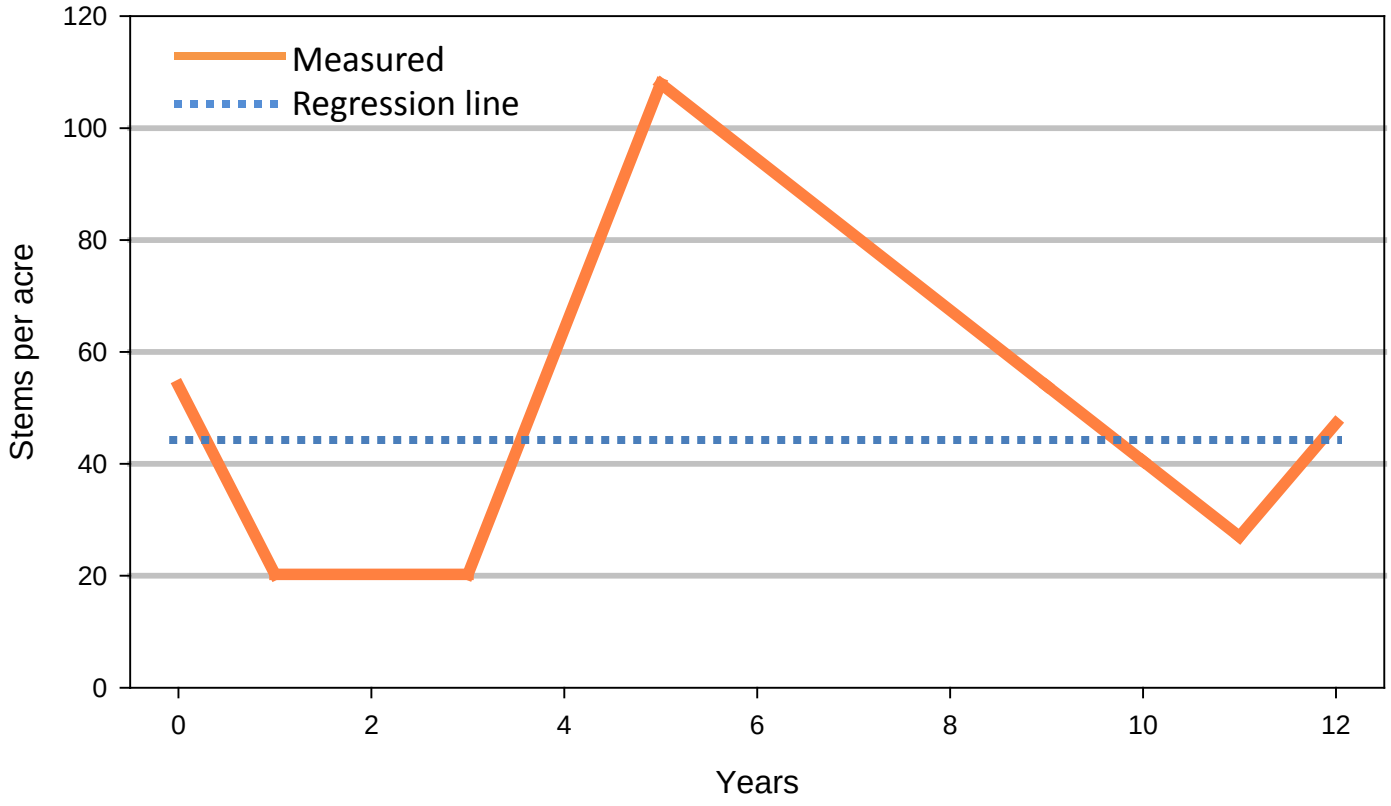
Mechanical + Burn: Other Species regeneration



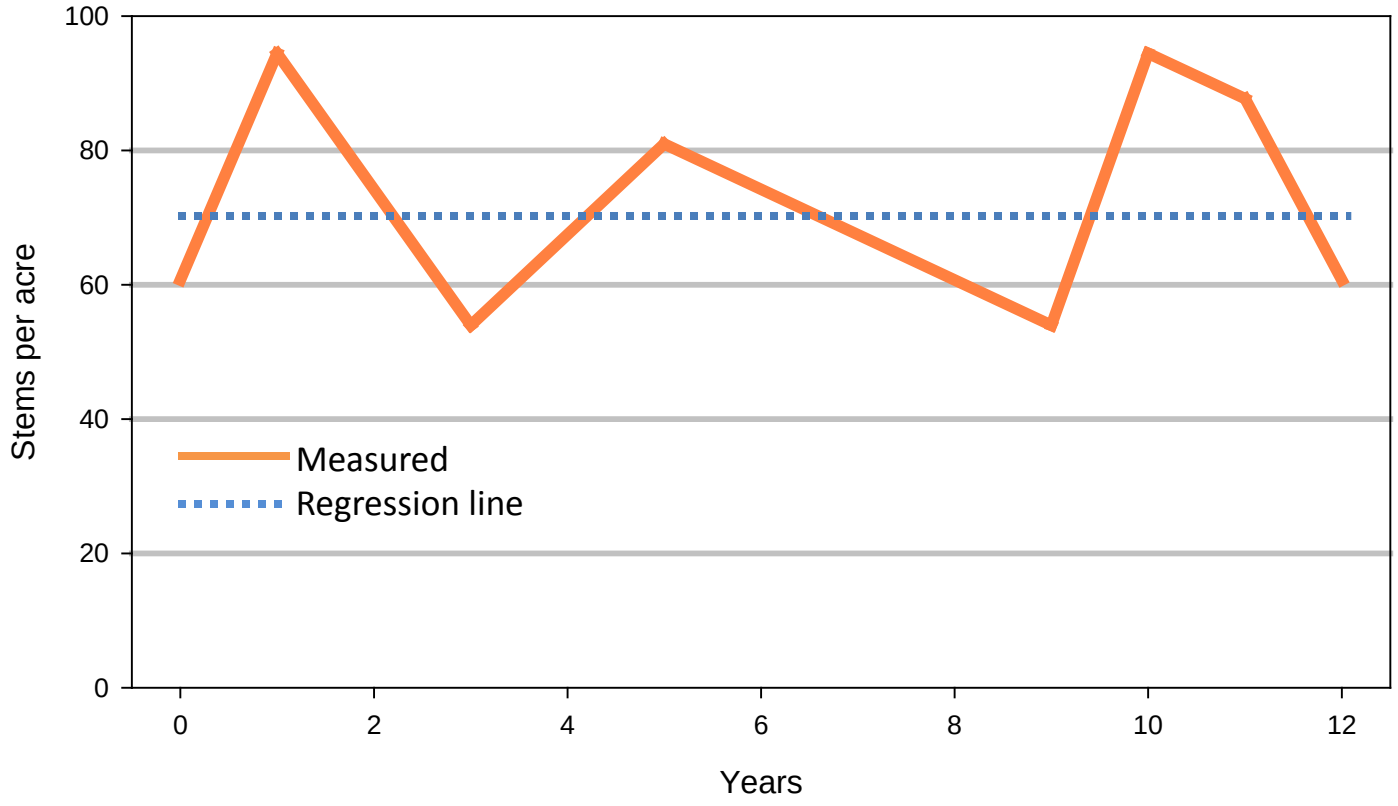
Burn Only: Pine regeneration



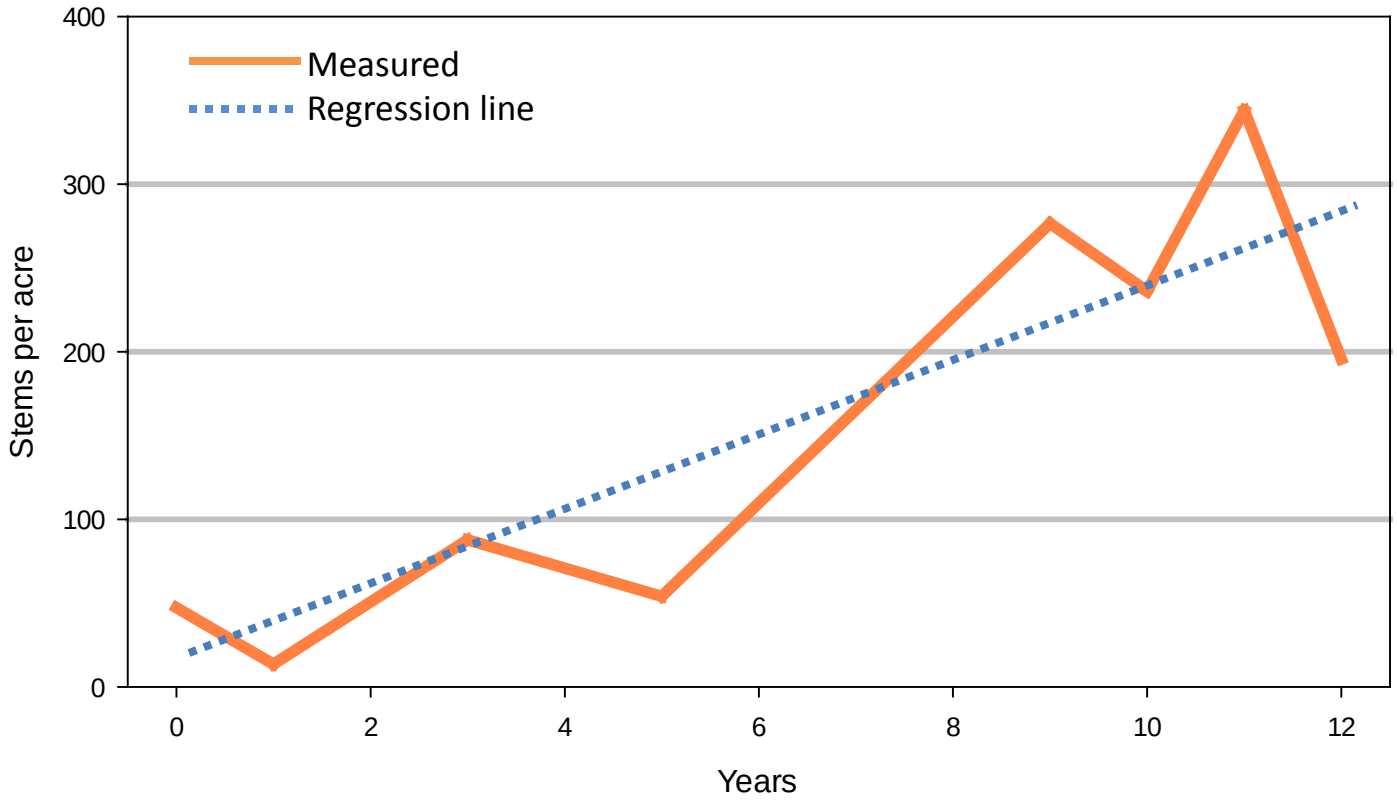
Control: Pine regeneration



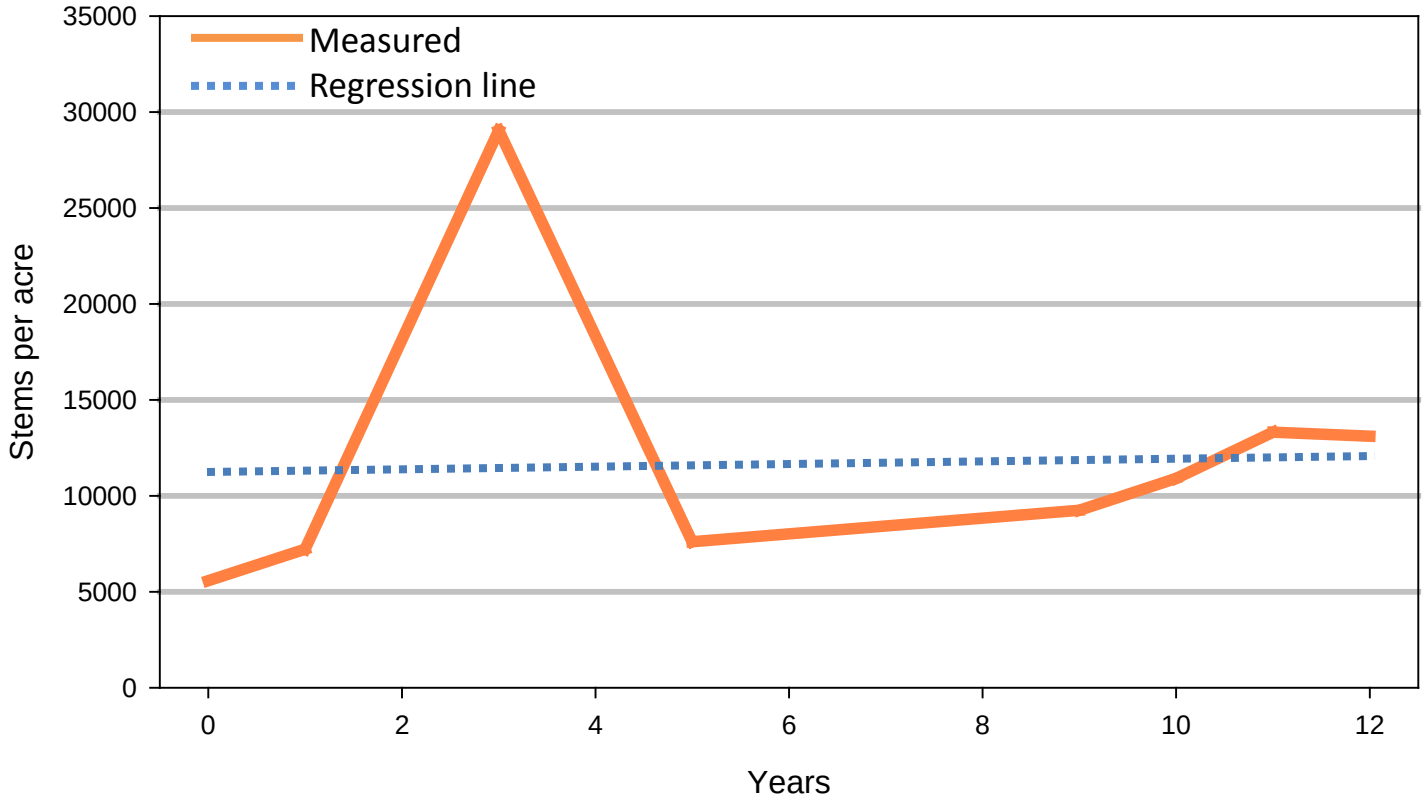
Mechanical: Pine regeneration



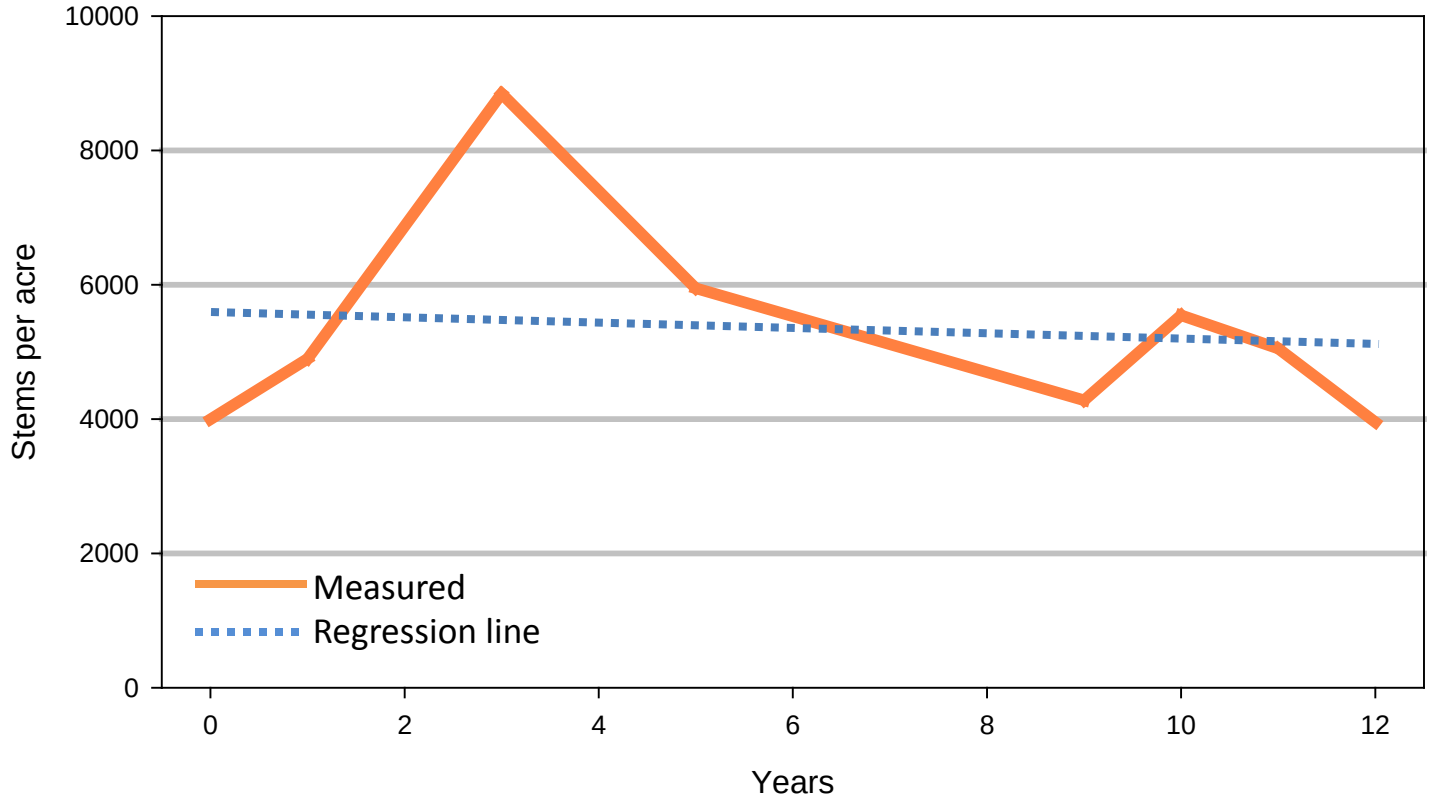
Mechanical + Burn: Pine regeneration



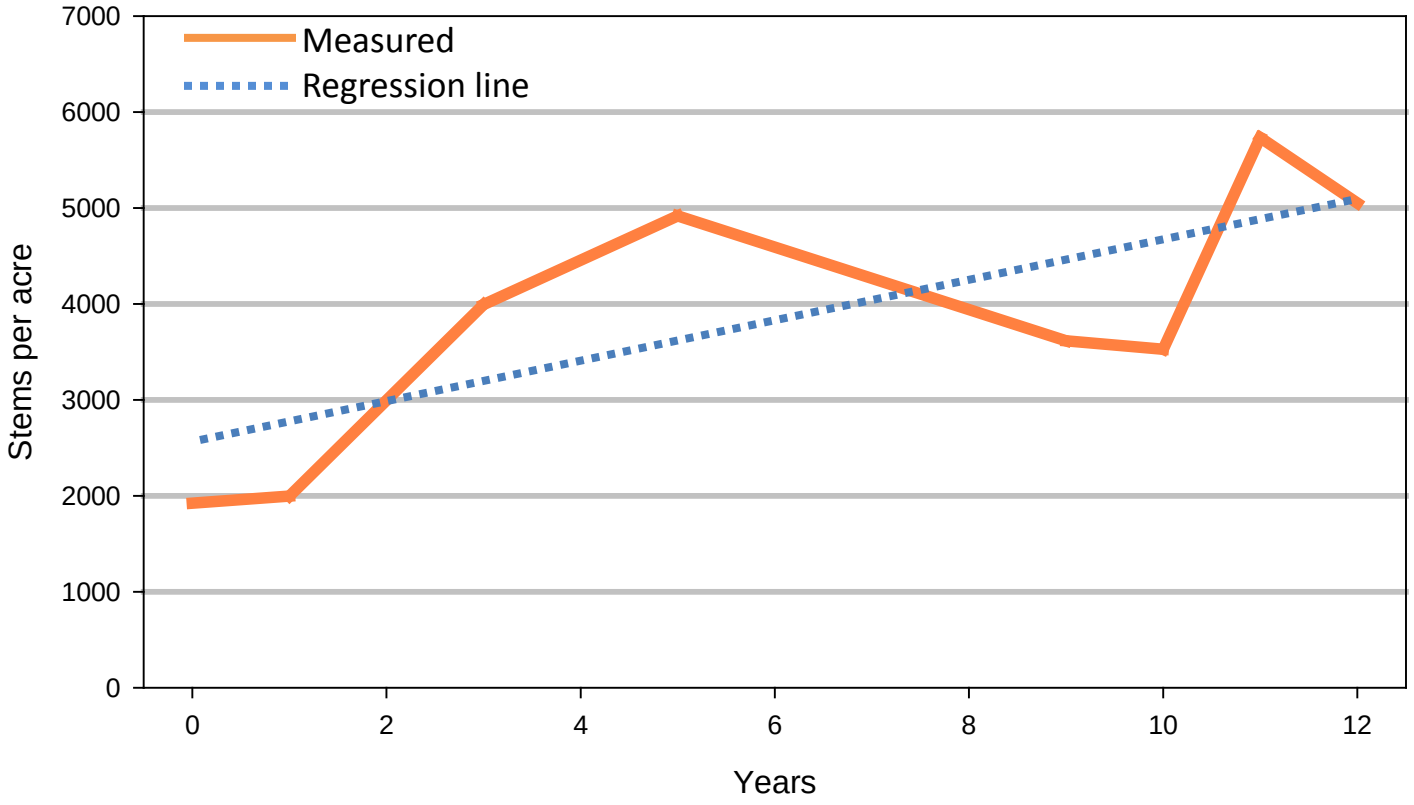
Burn Only: Red Maple regeneration



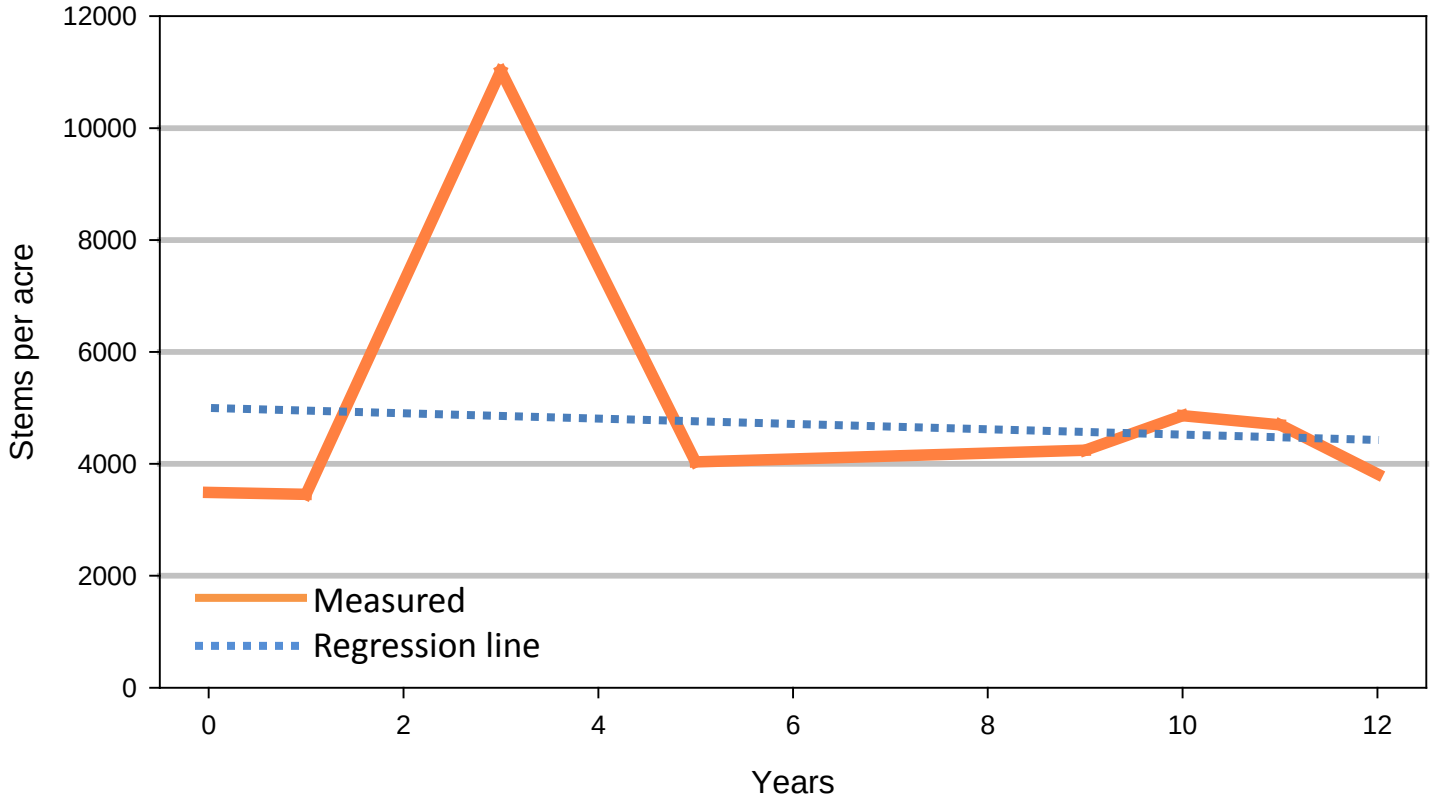
Control: Red Maple regeneration



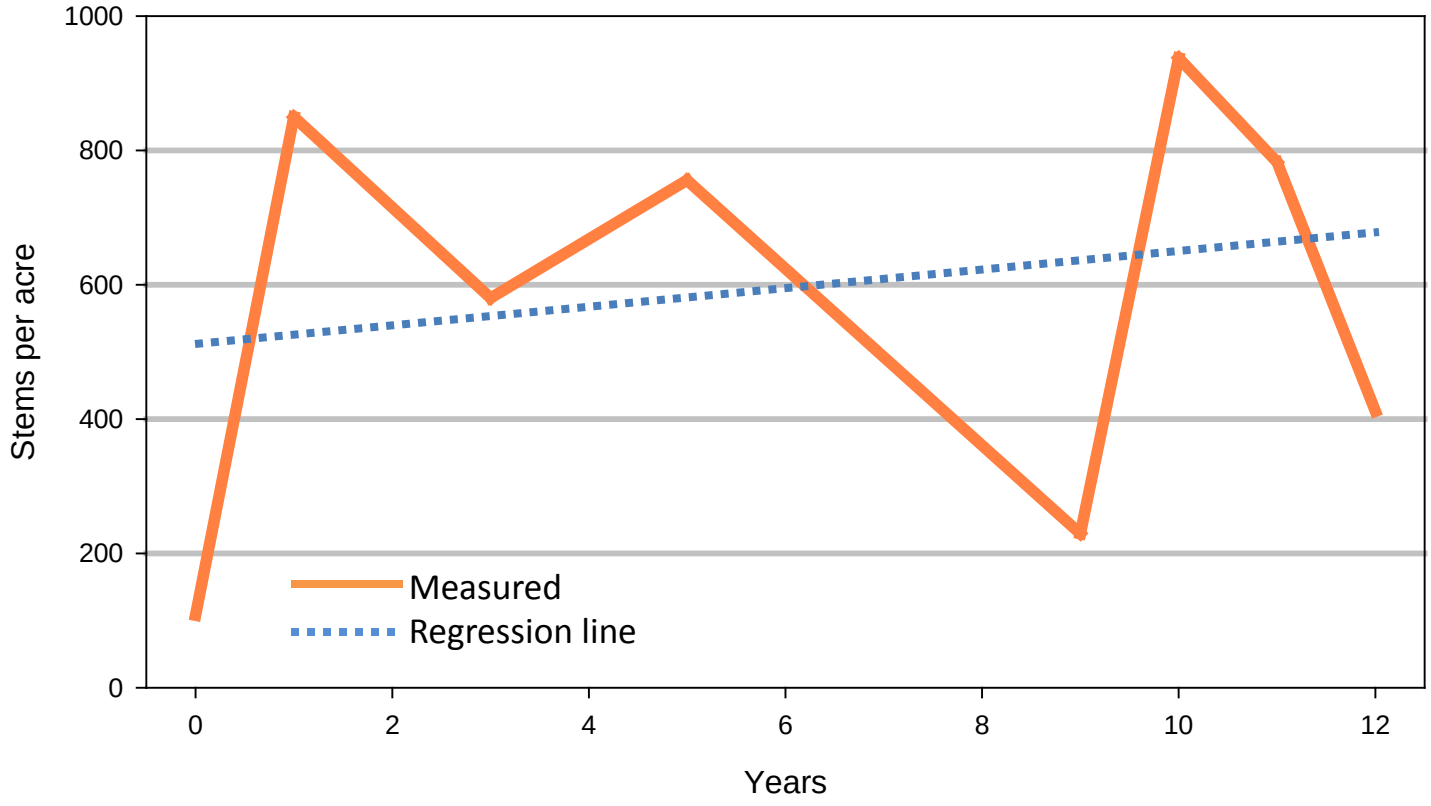
Mechanical: Red Maple regeneration



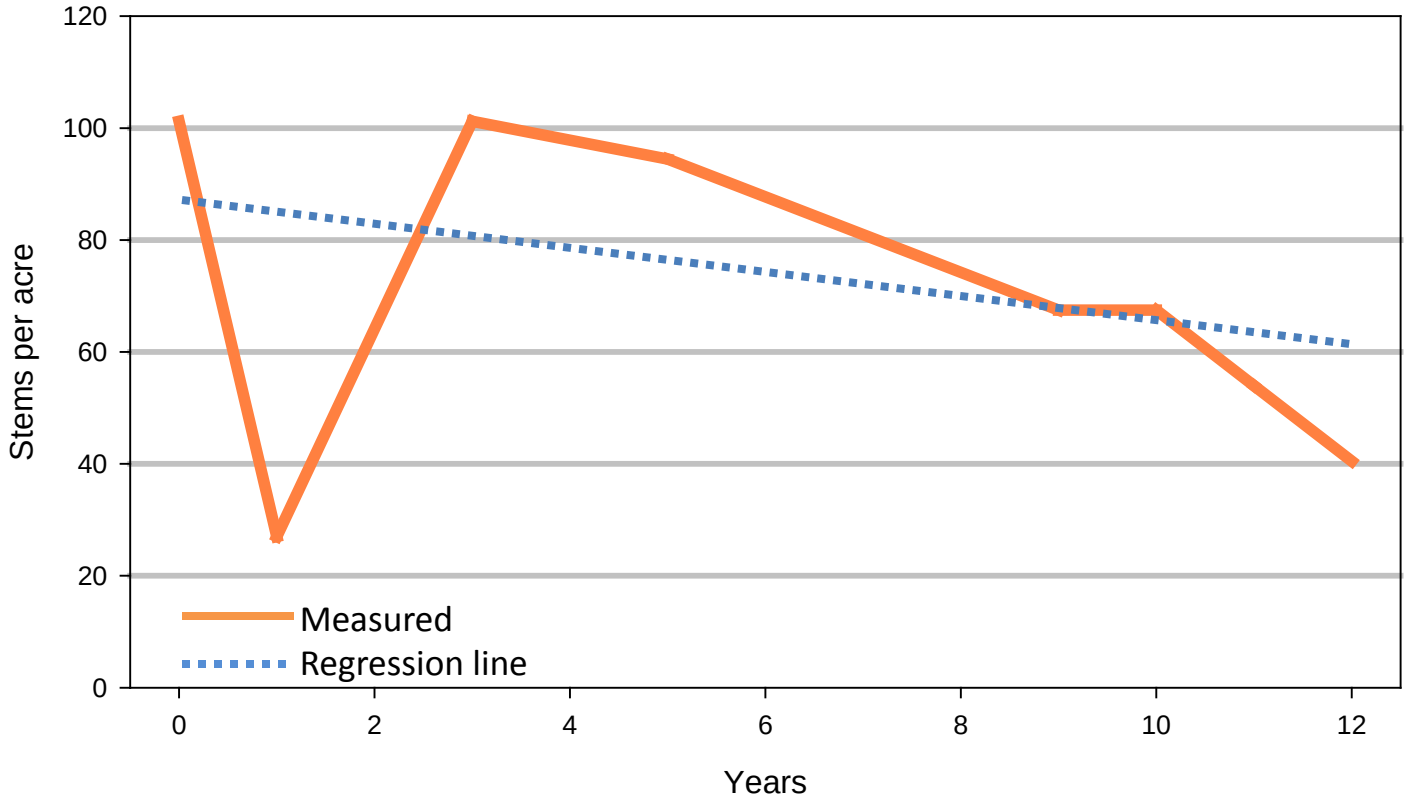
Mechanical + Burn: Red Maple regeneration



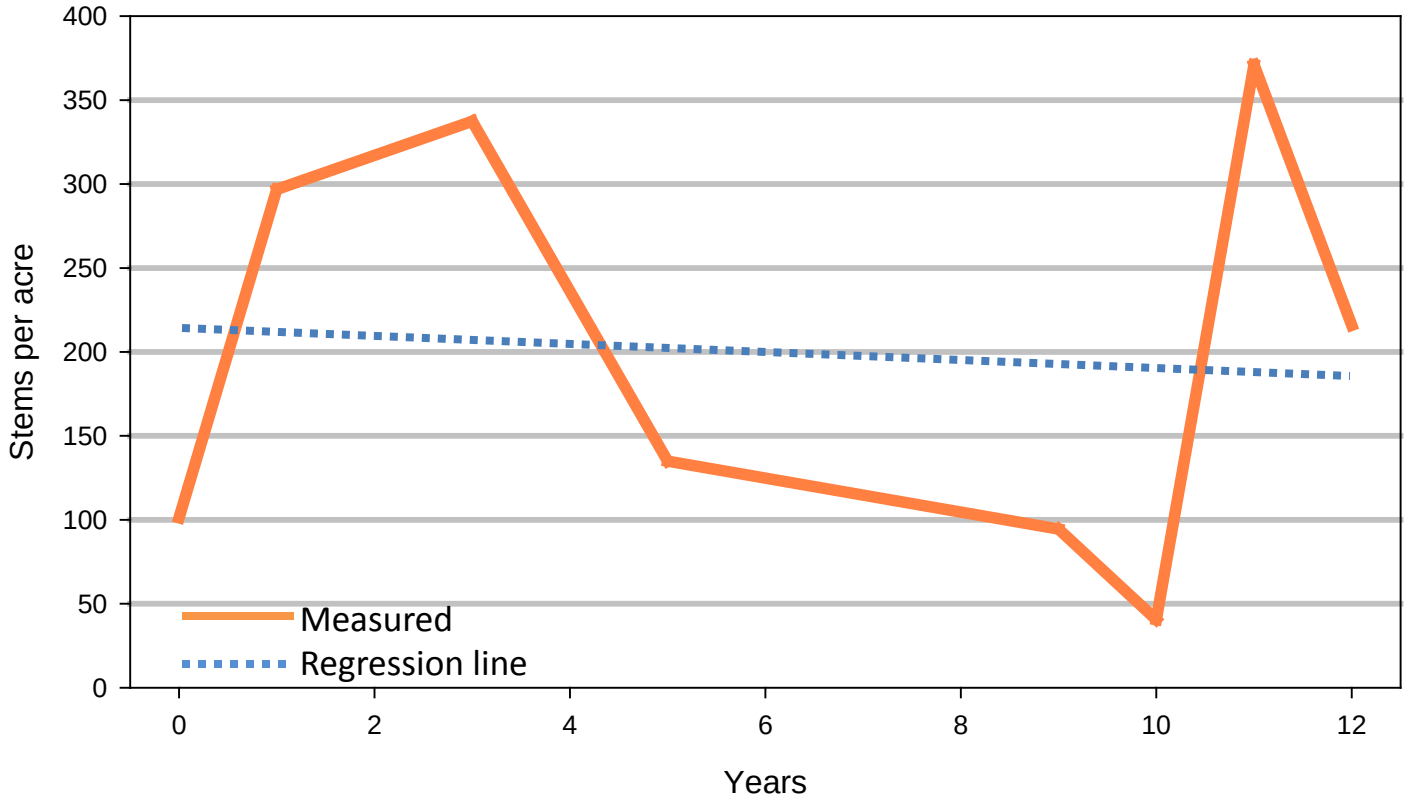
Burn Only: Sourwood regeneration



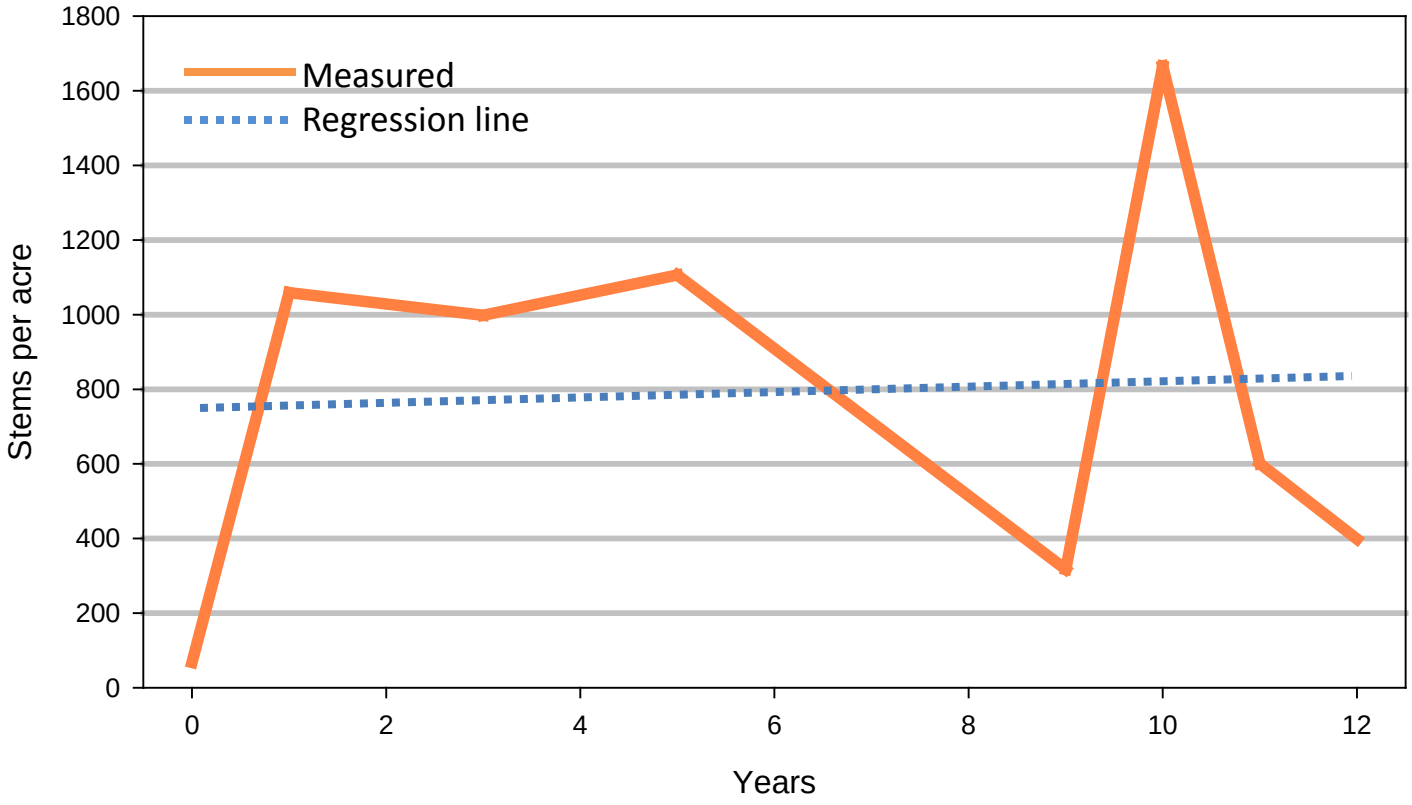
Control: Sourwood regeneration



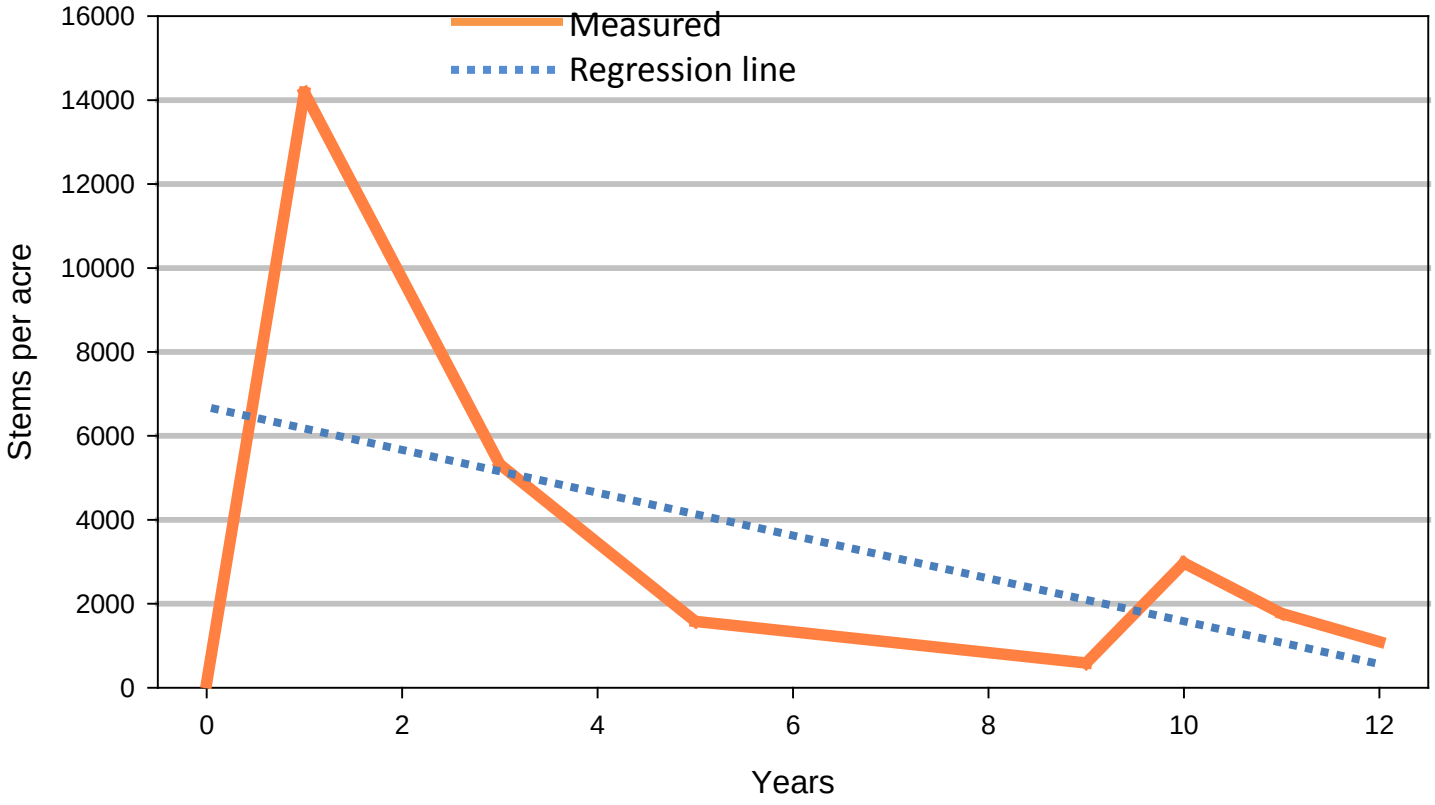
Mechanical: Sourwood regeneration



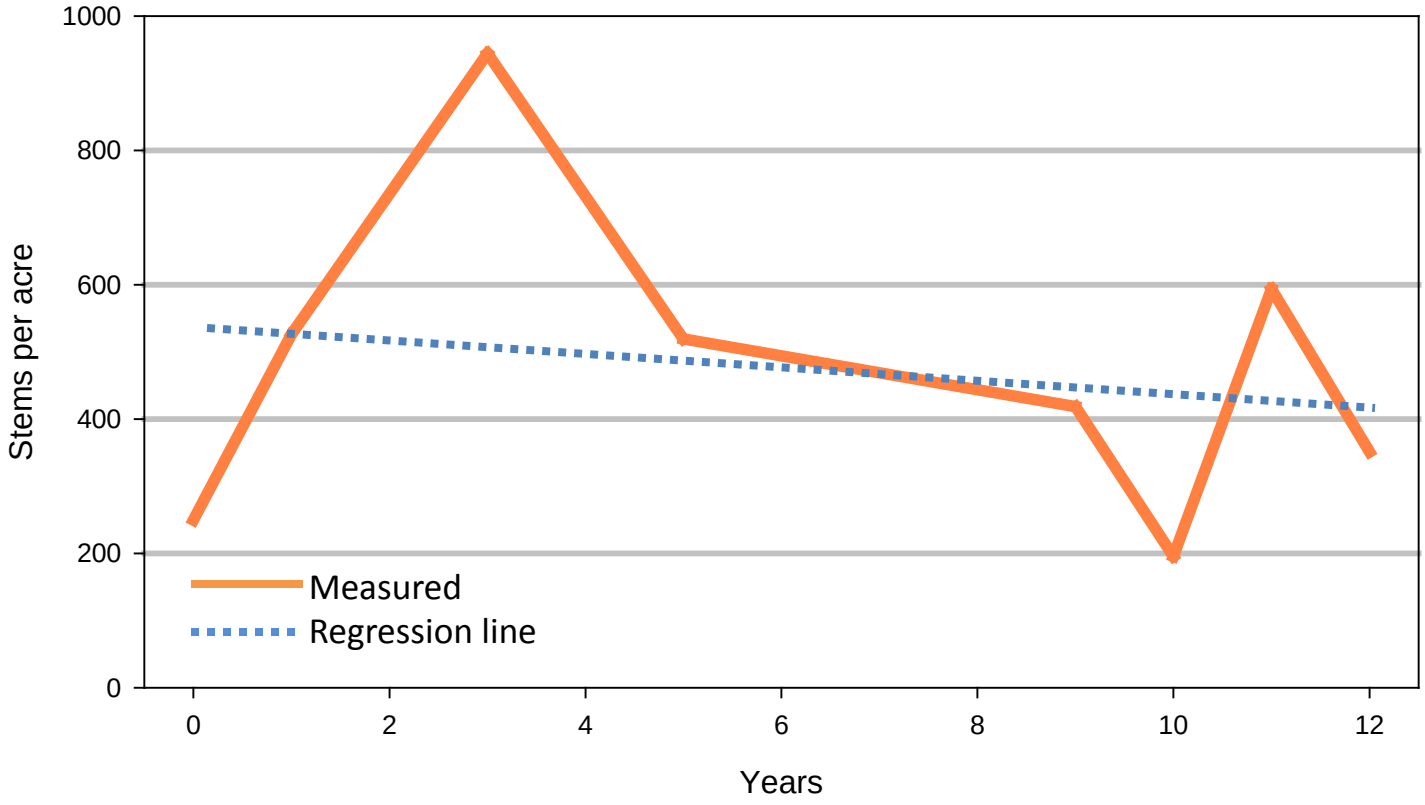
Mechanical + Burn: Sourwood regeneration



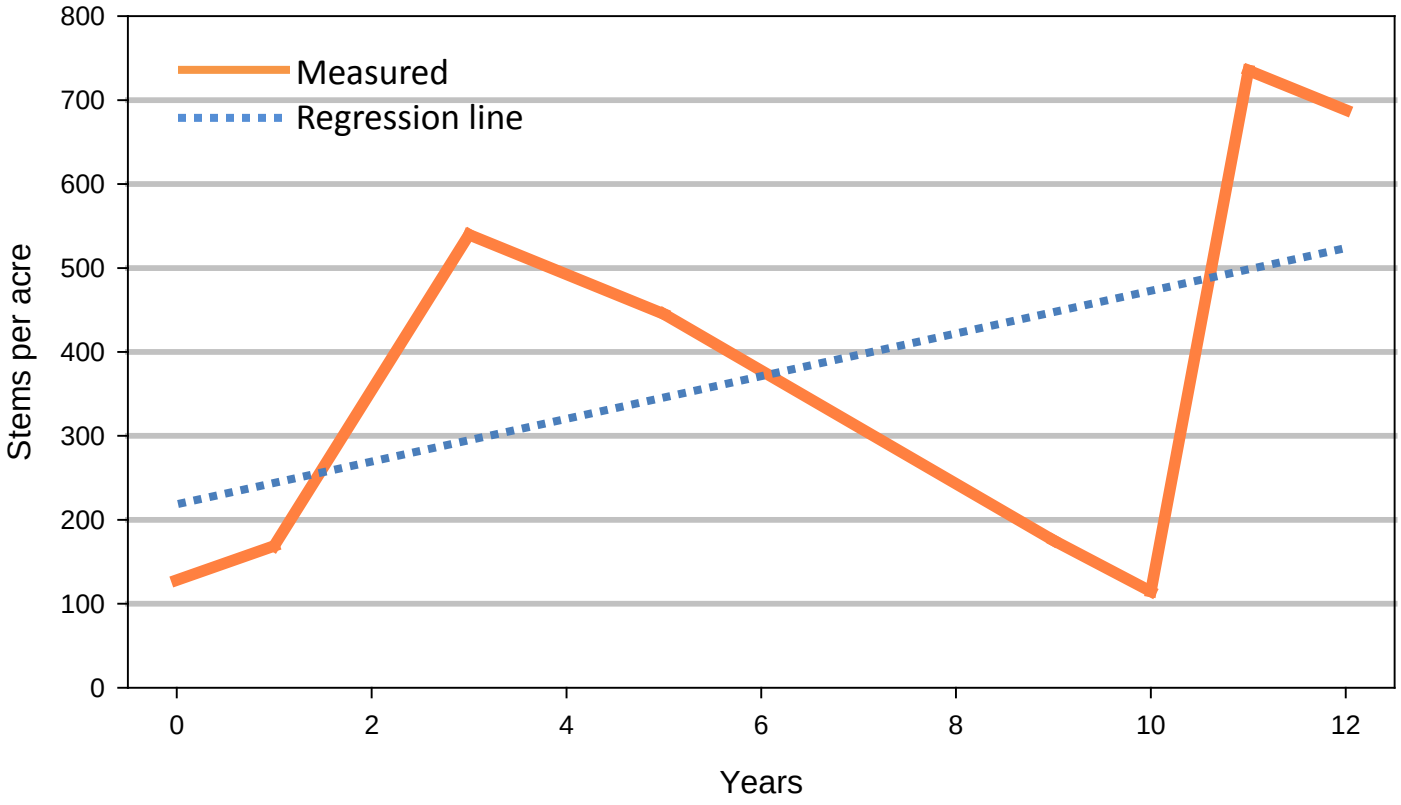
Burn Only: Yellow-poplar regeneration



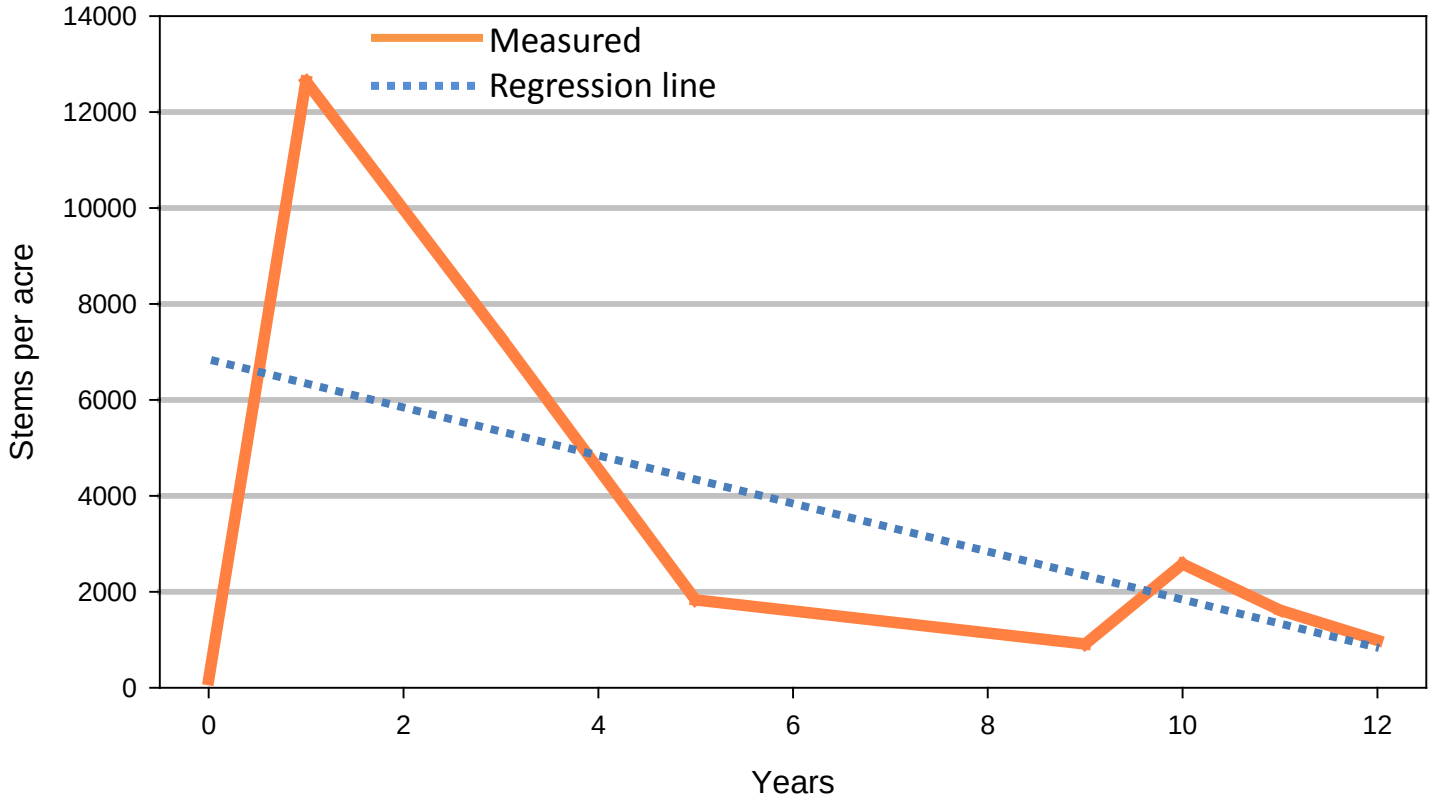
Control: Yellow-poplar regeneration



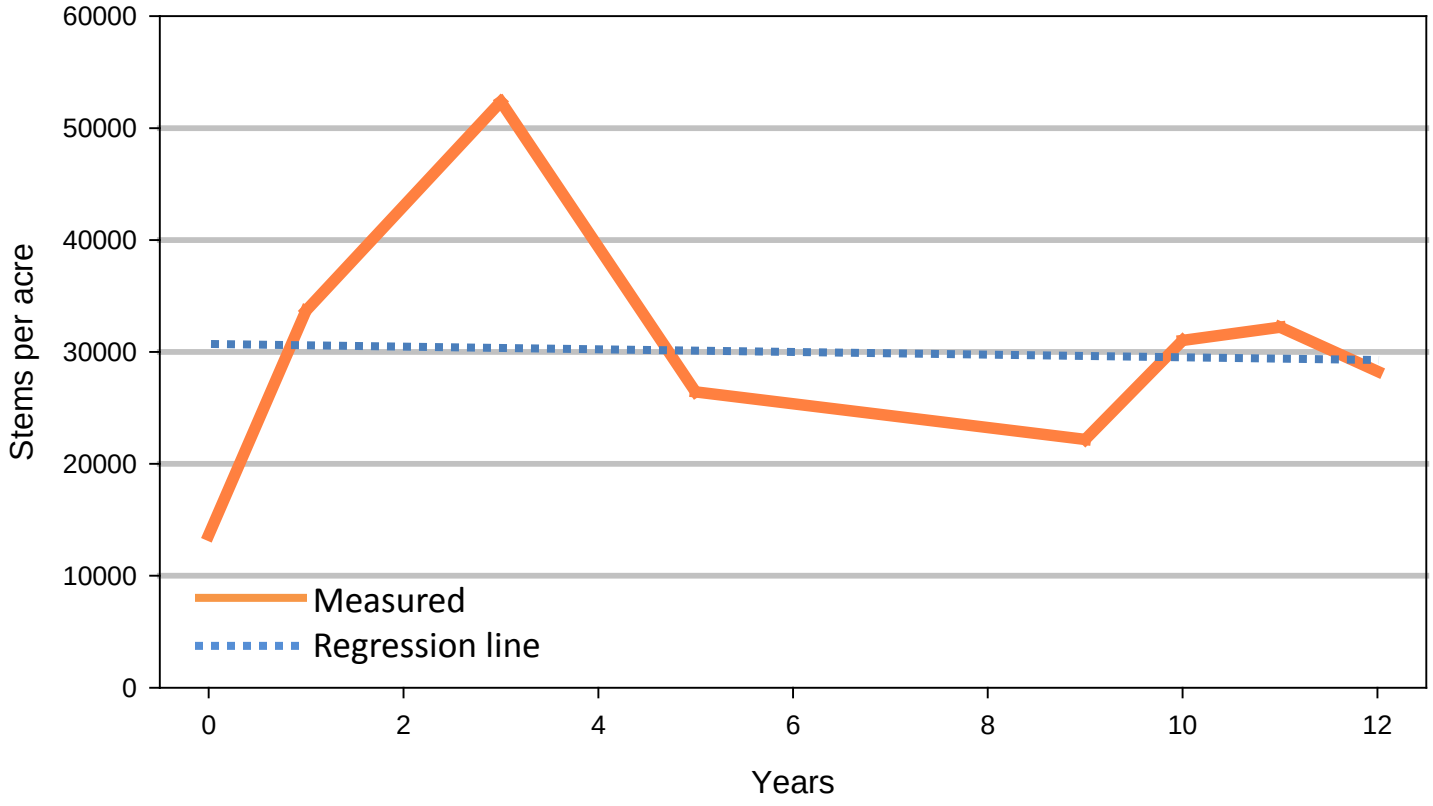
Mechanical: Yellow-poplar regeneration



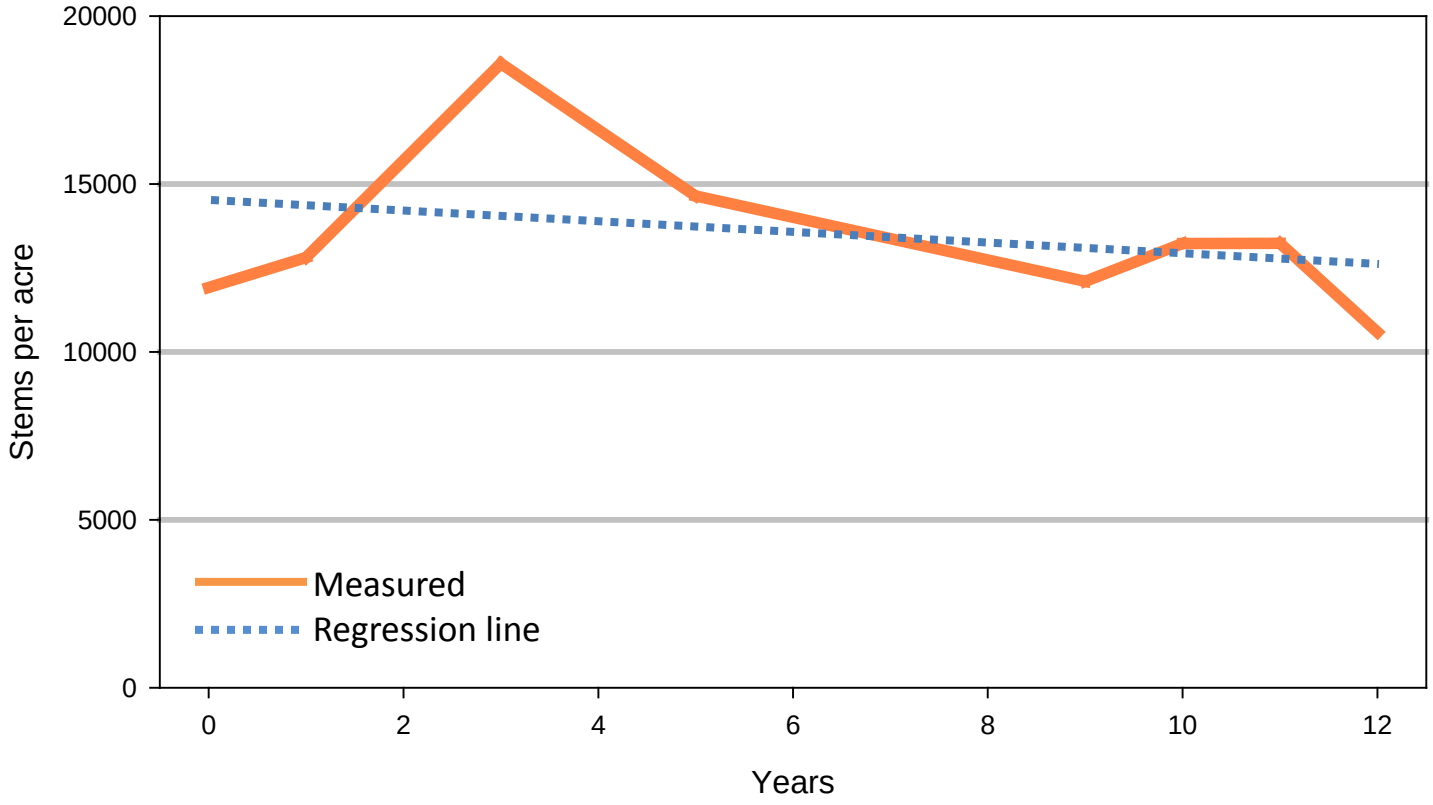
Mechanical + Burn: Yellow-poplar regeneration



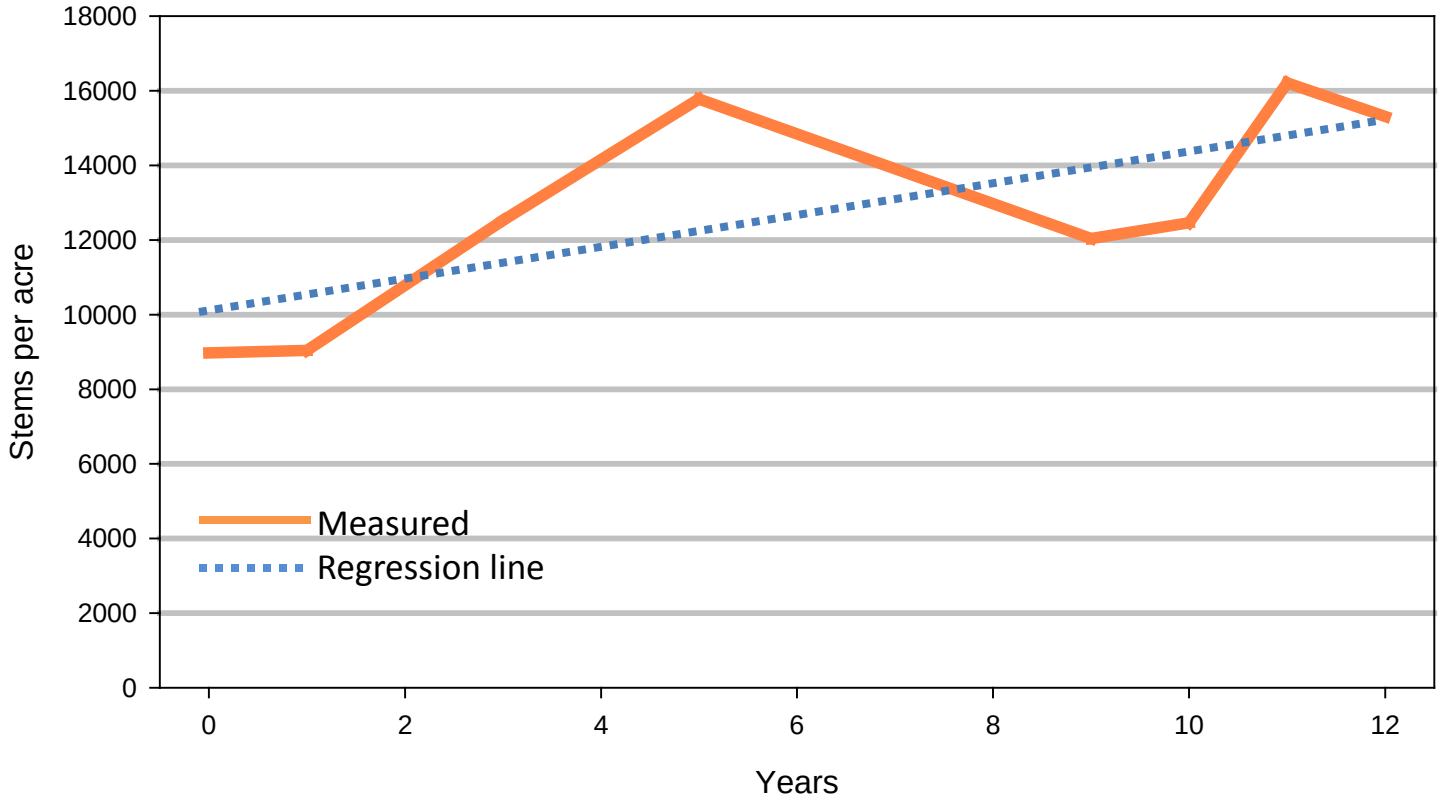
Burn Only: All species regeneration



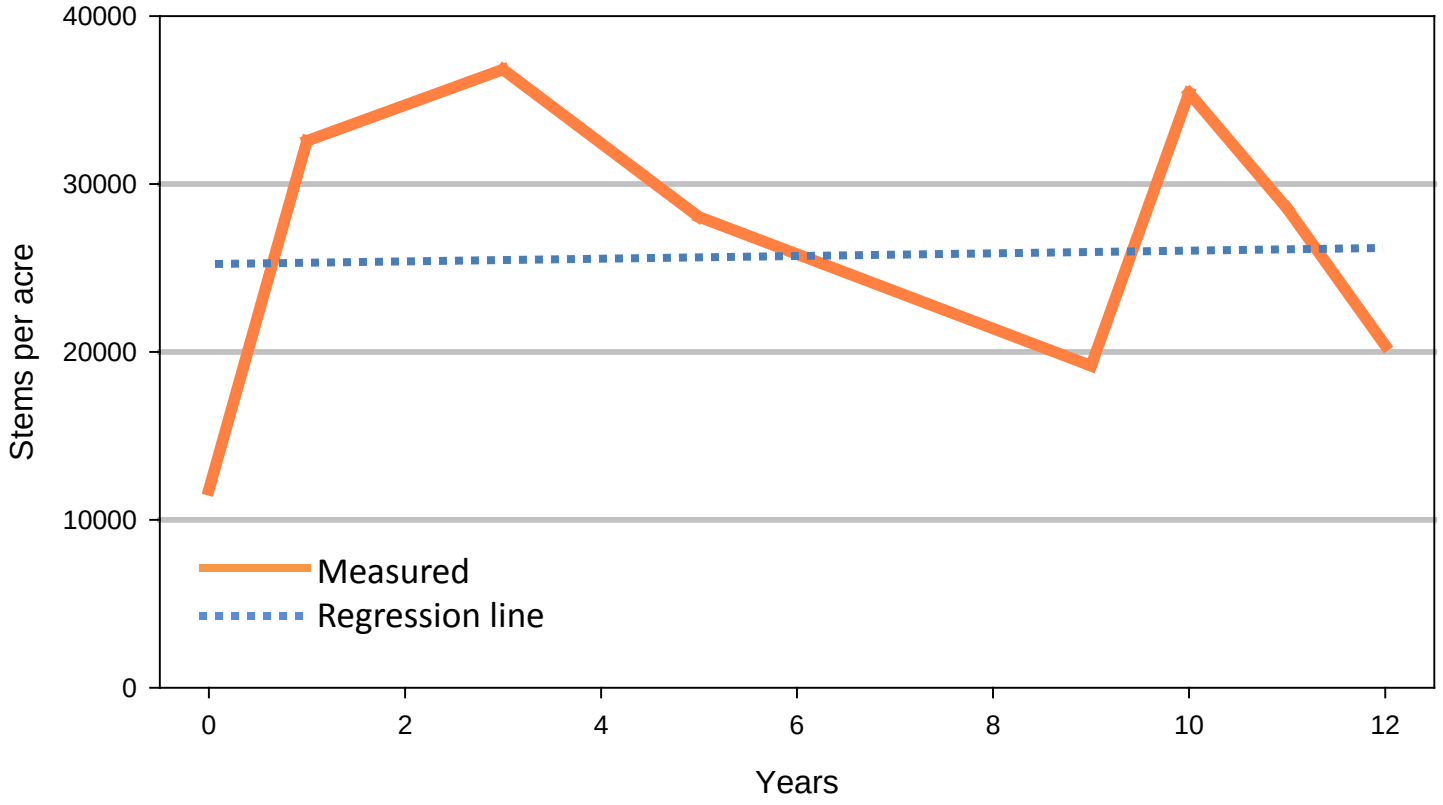
Control: All species regeneration



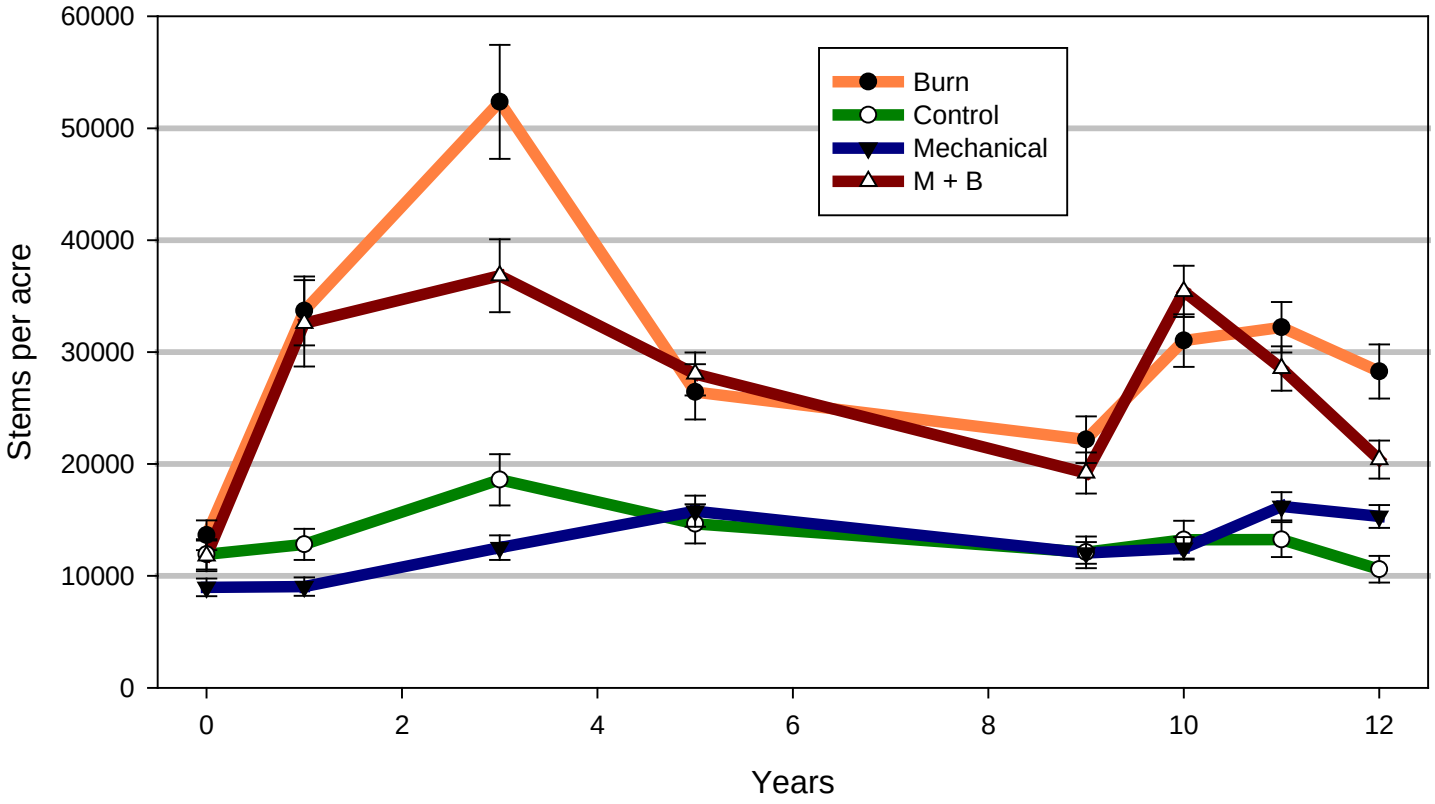
Mechanical: All species regeneration



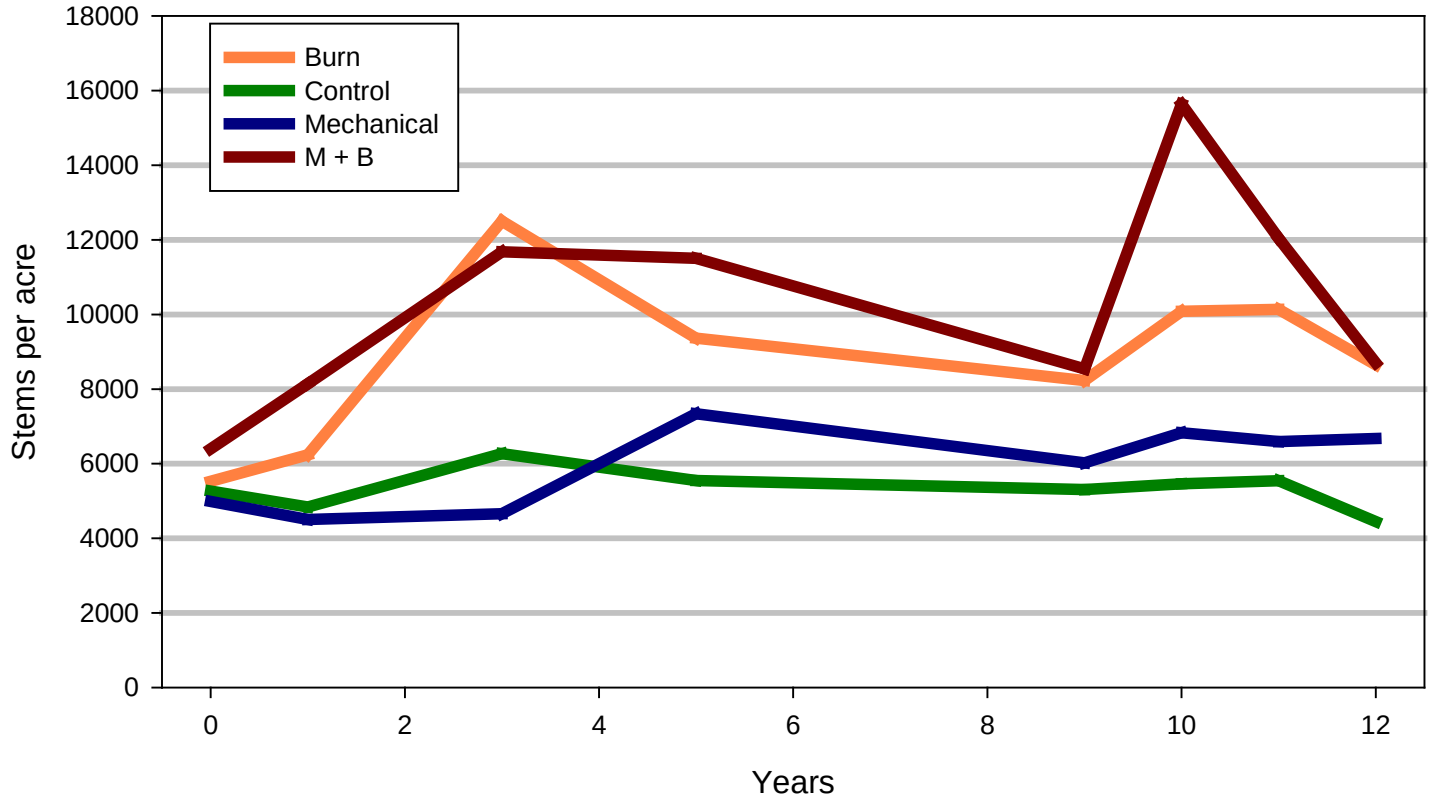
Mechanical + Burn: All species regeneration



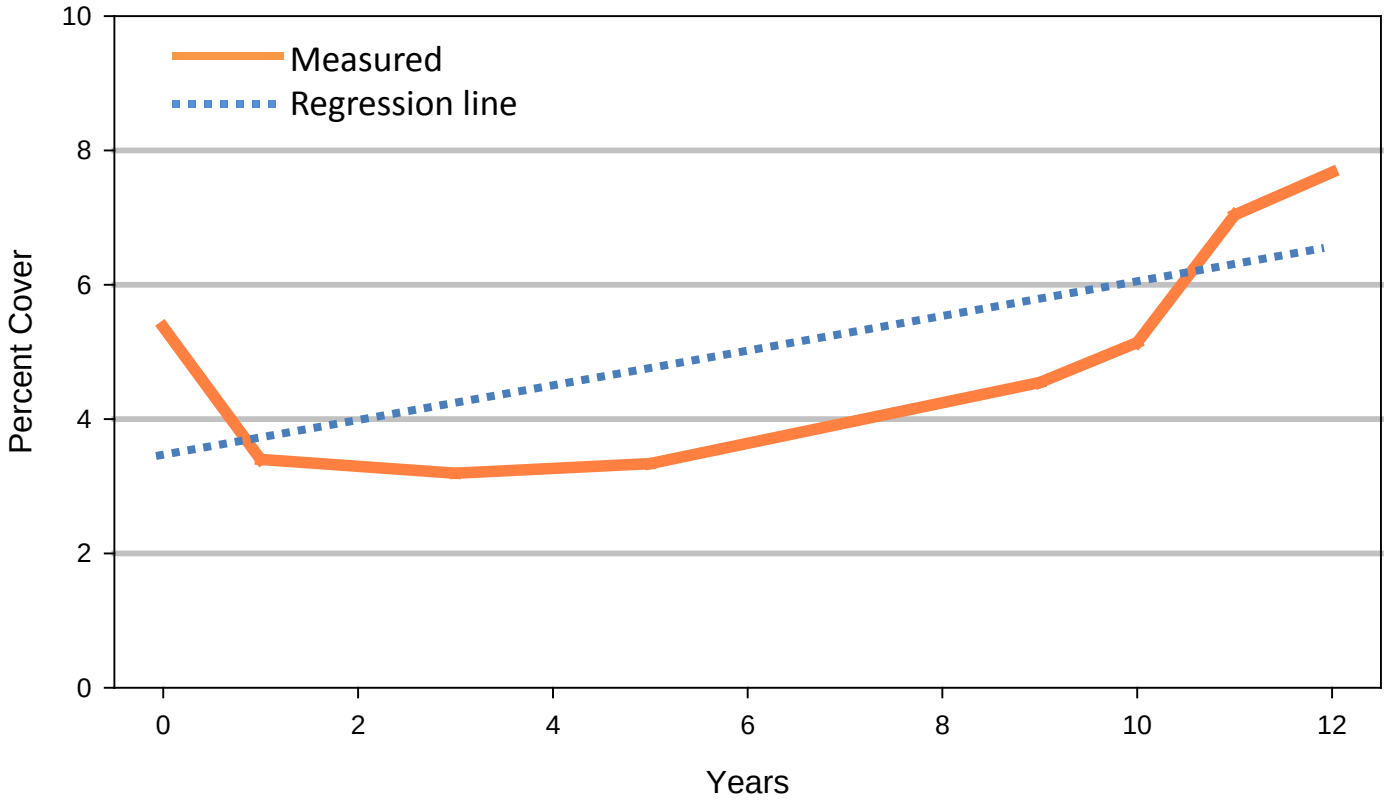
Regeneration Density – All Species All Treatments



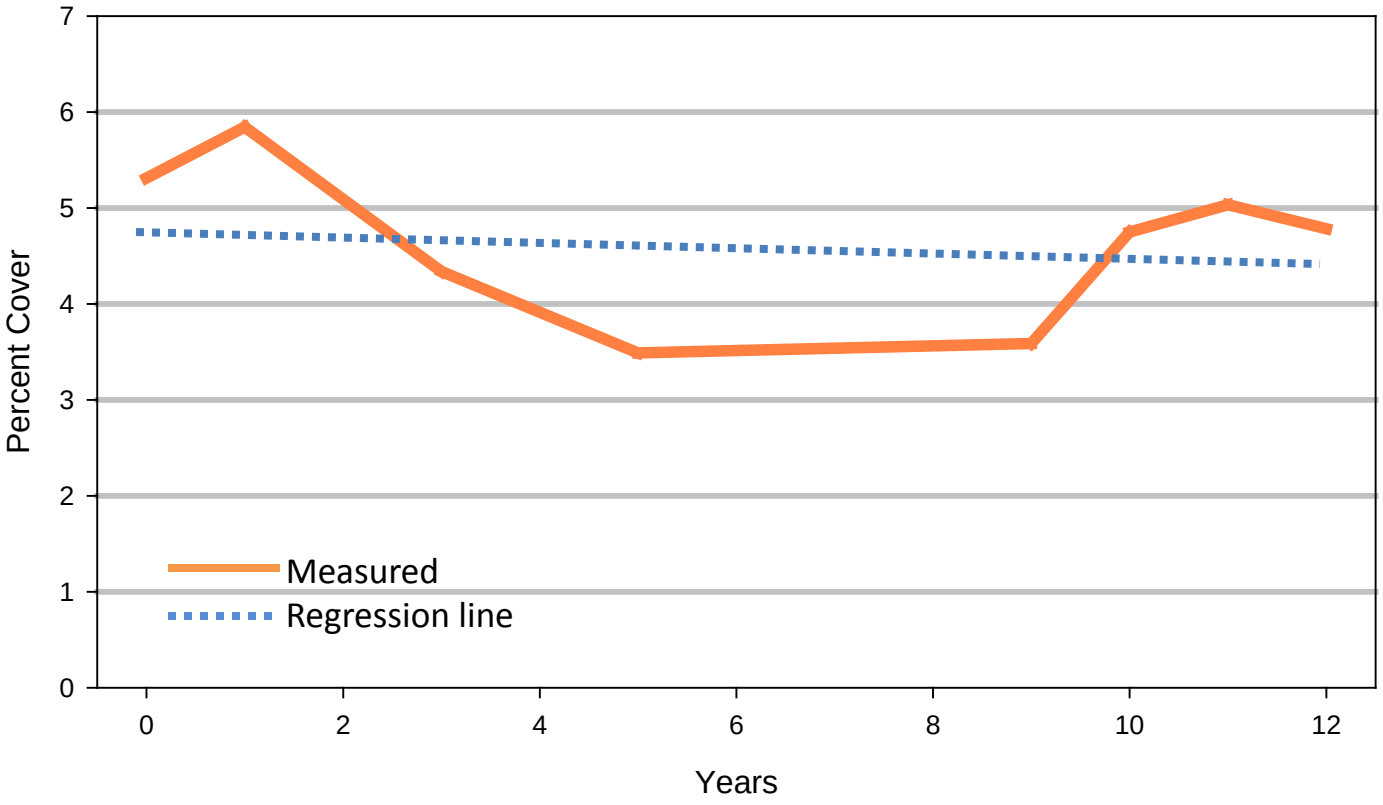
Regeneration Density – Oaks - All Treatments



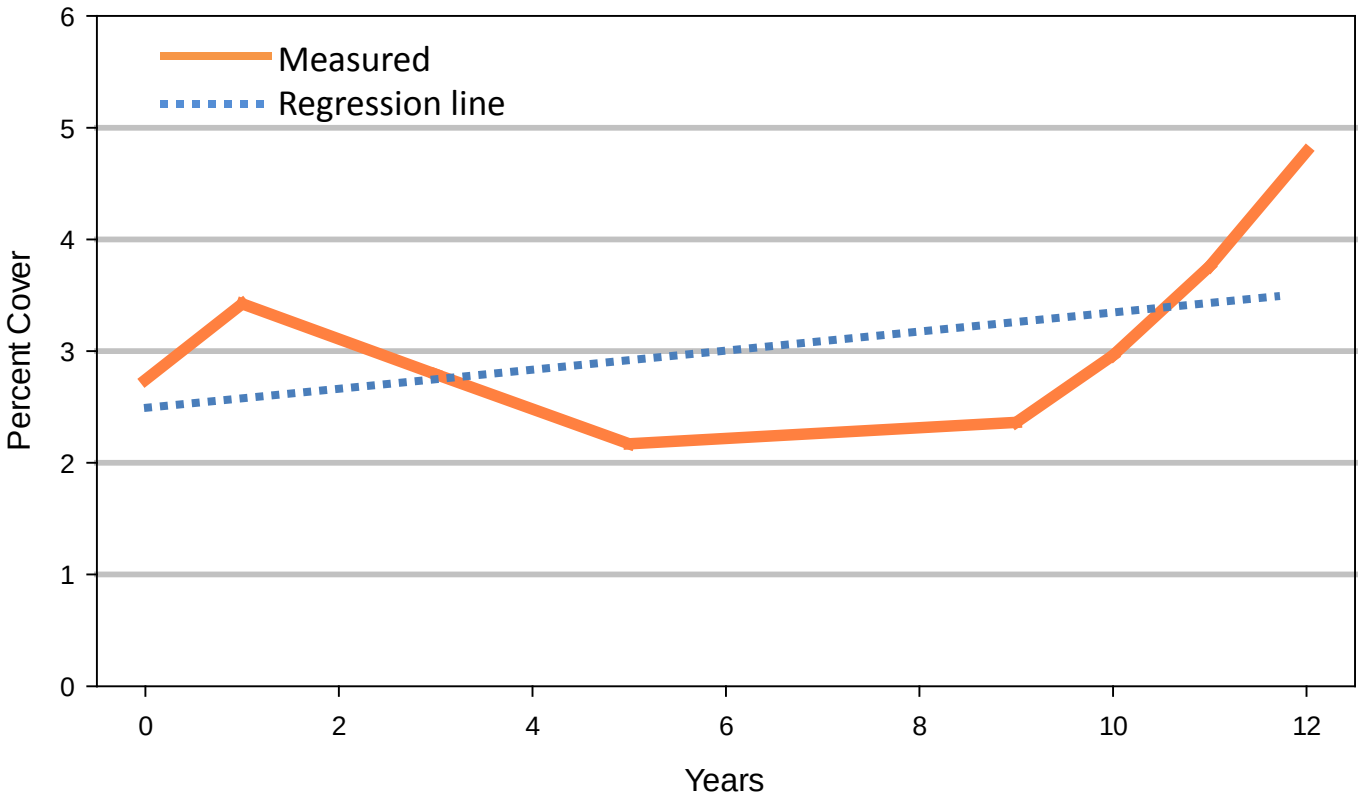
Burn Only: Forest Floor Cover - Forbs



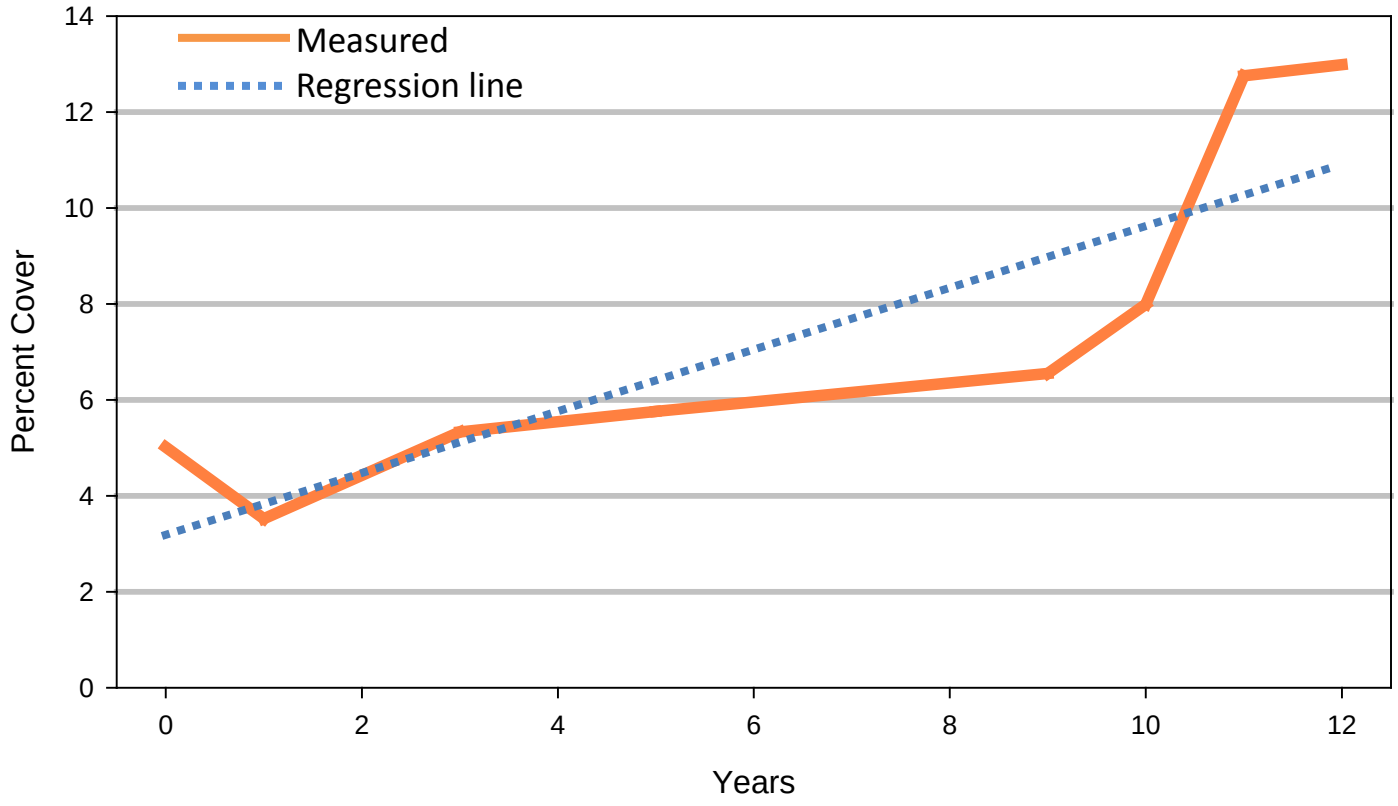
Control: Forest Floor Cover - Forbs



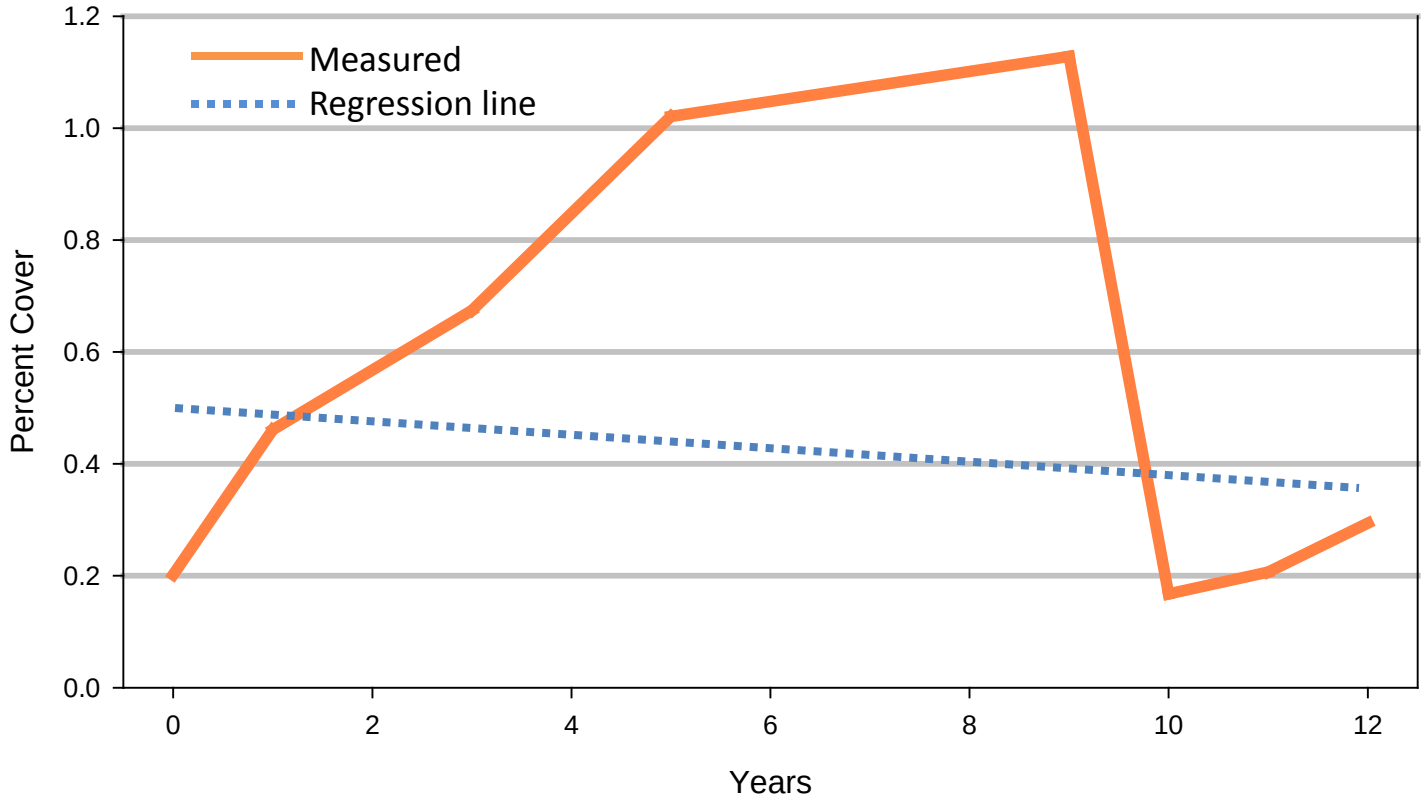
Mechanical: Forest Floor Cover - Forbs



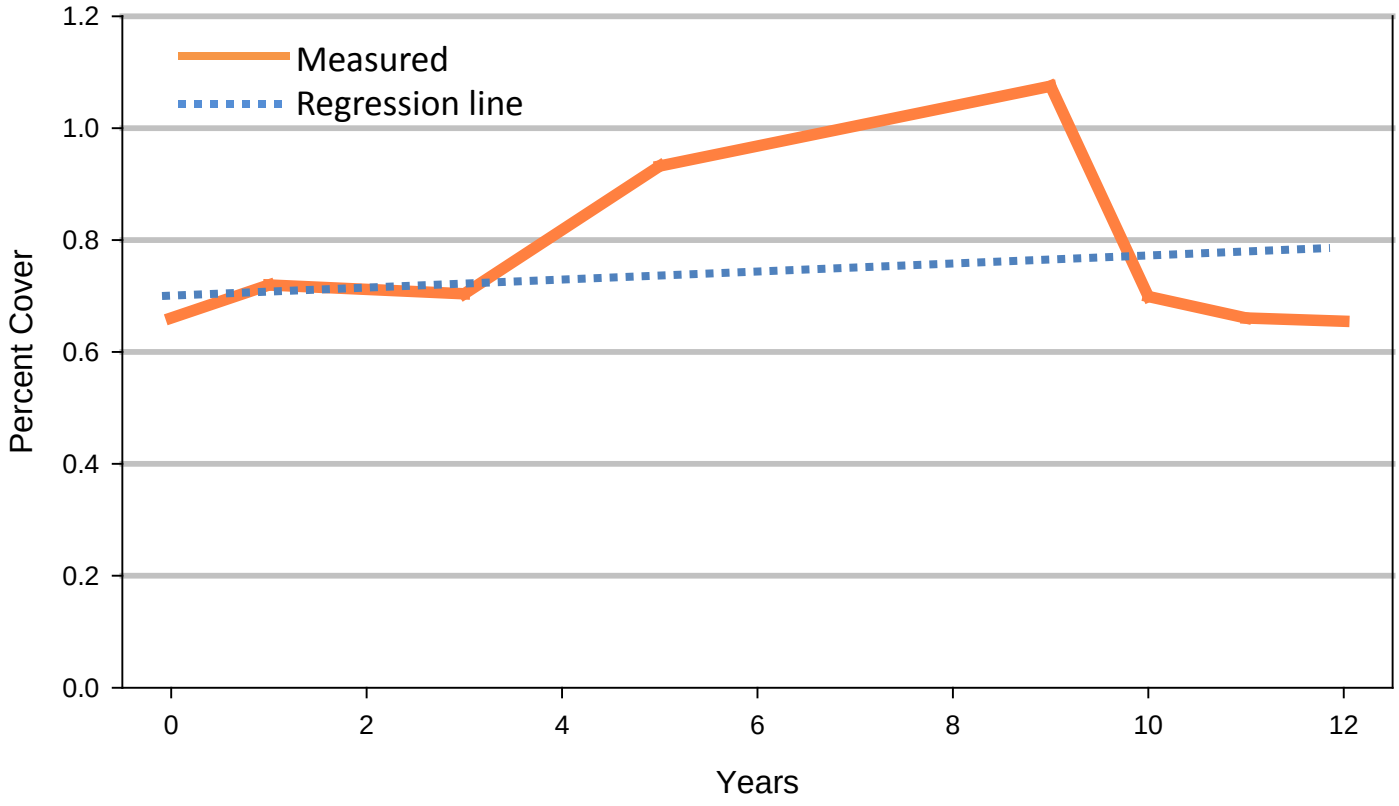
Mechanical + Burn: Forest Floor Cover - Forbs



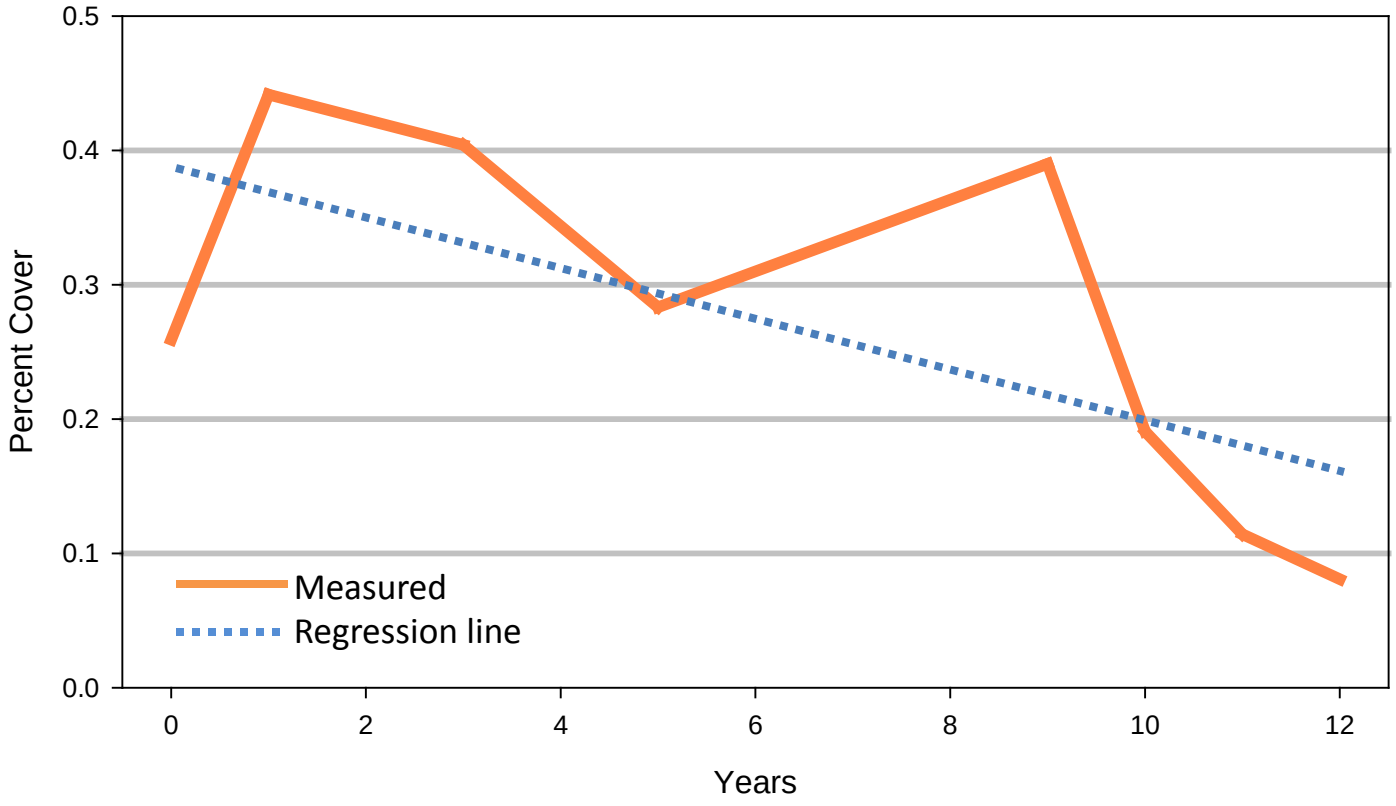
Burn Only: Forest Floor Cover - Grass



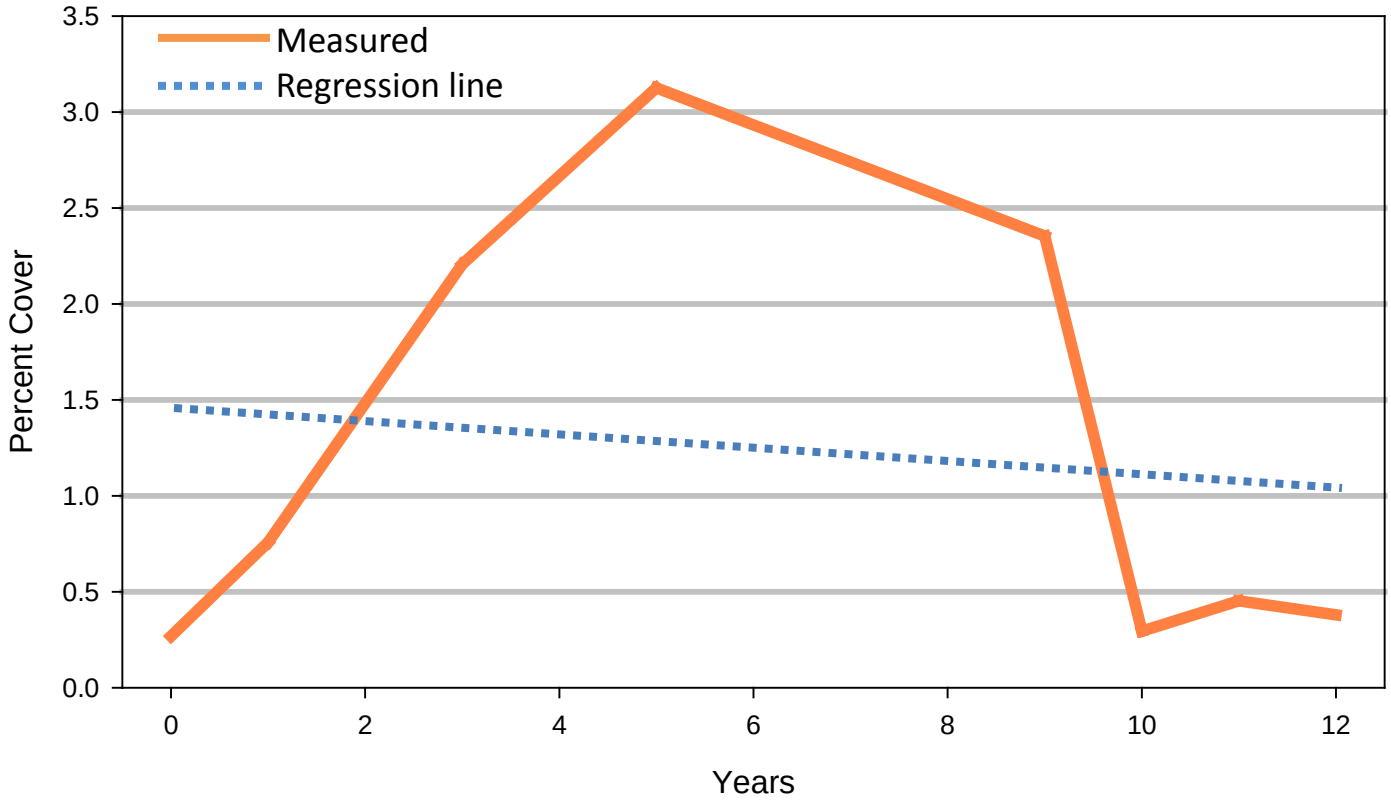
Control: Forest Floor Cover - Grass



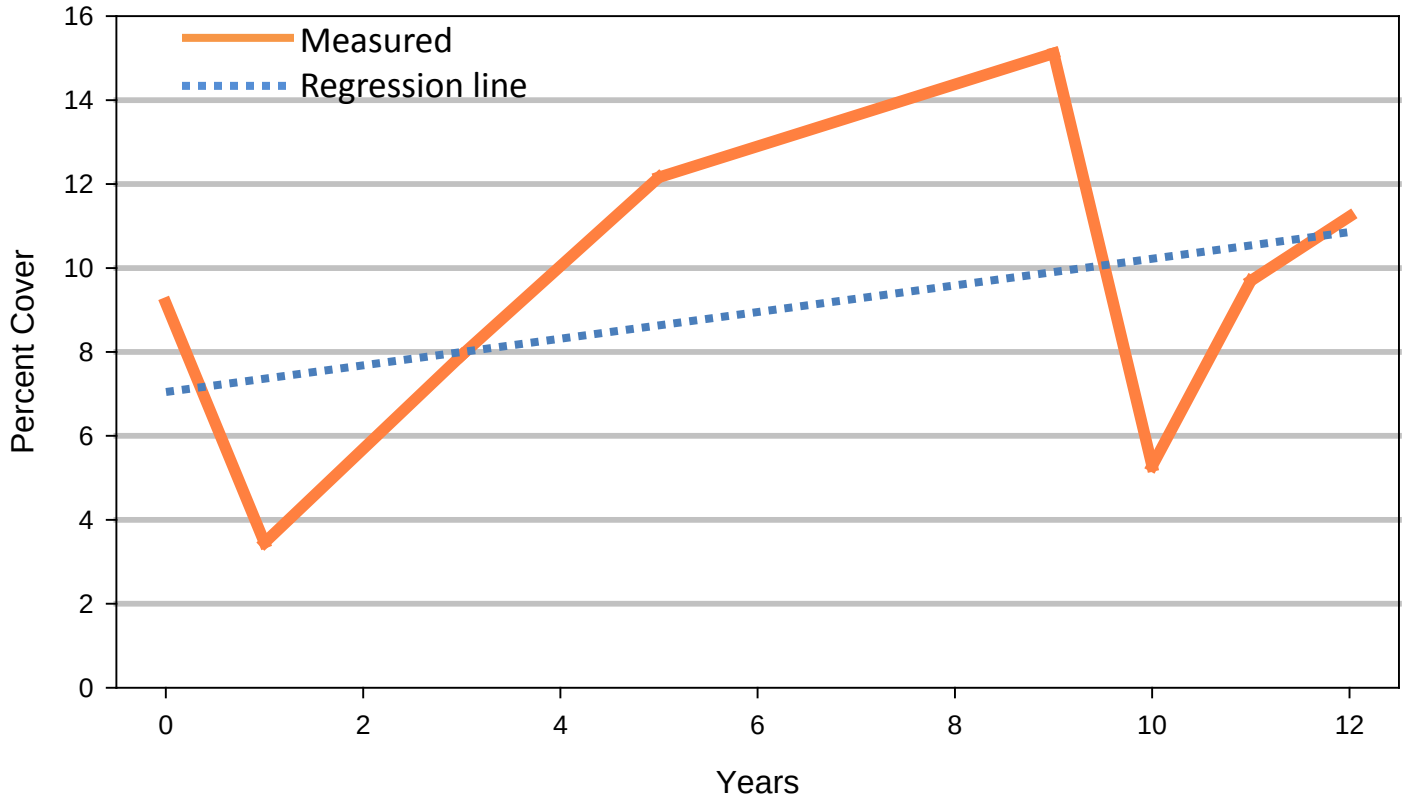
Mechanical: Forest Floor Cover - Grass



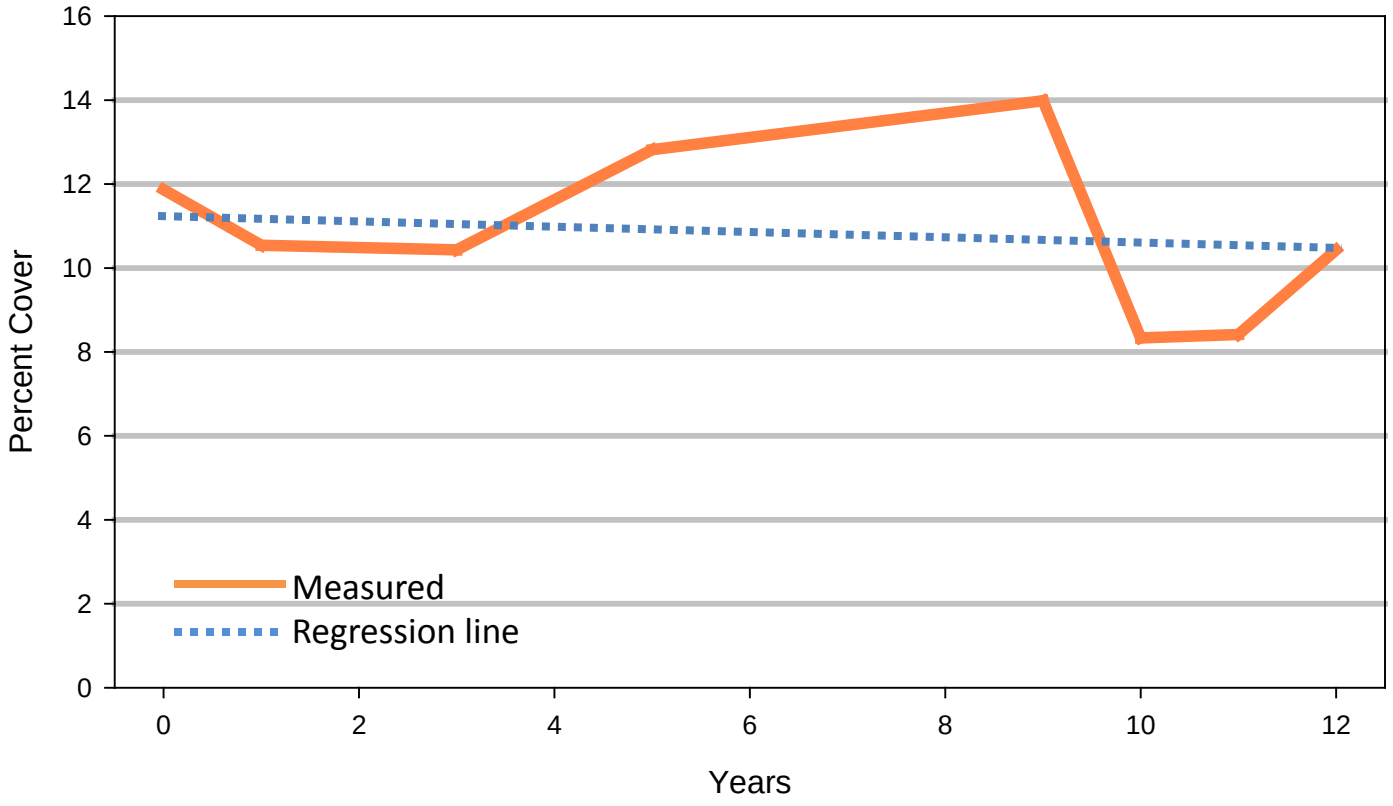
Mechanical + Burn: Forest Floor Cover - Grass



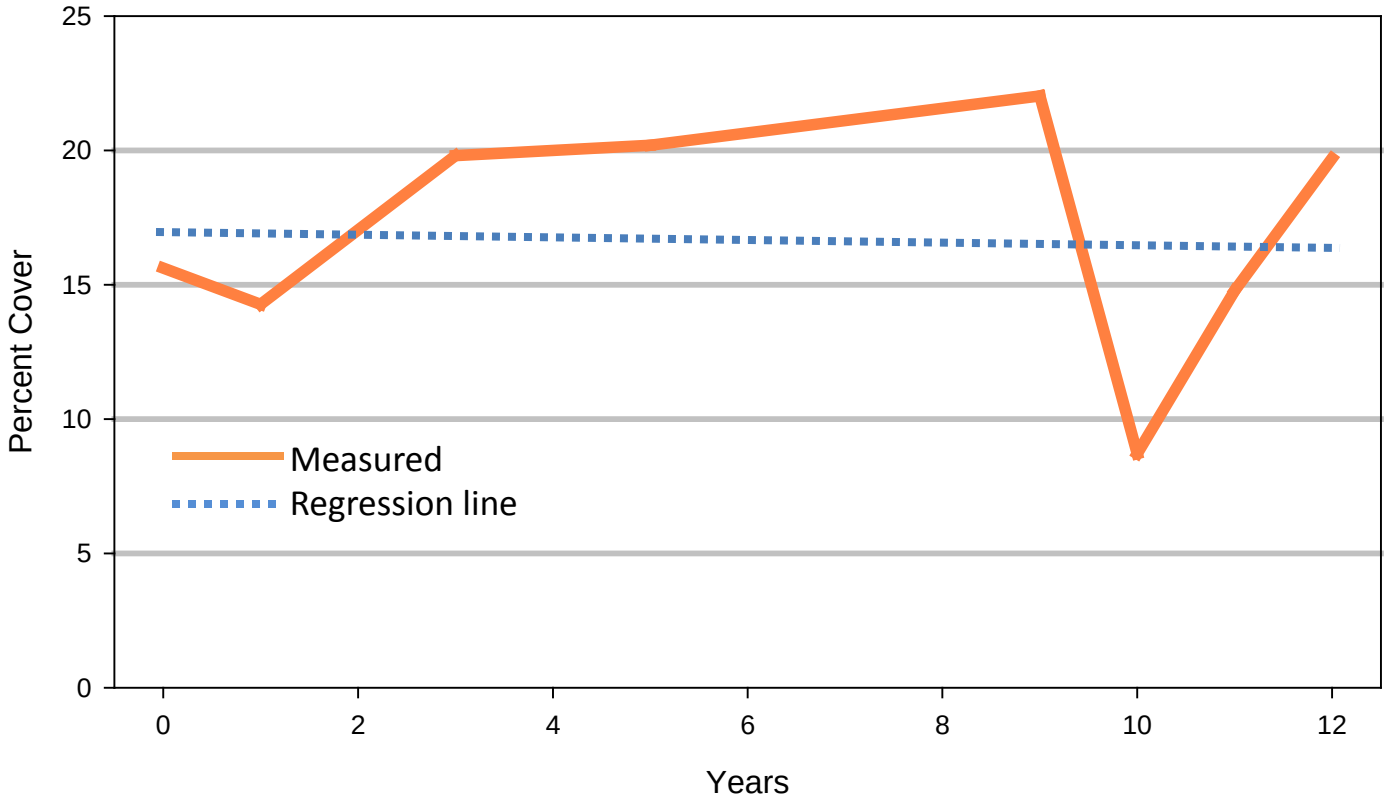
Burn Only: Forest Floor Cover - Shrubs



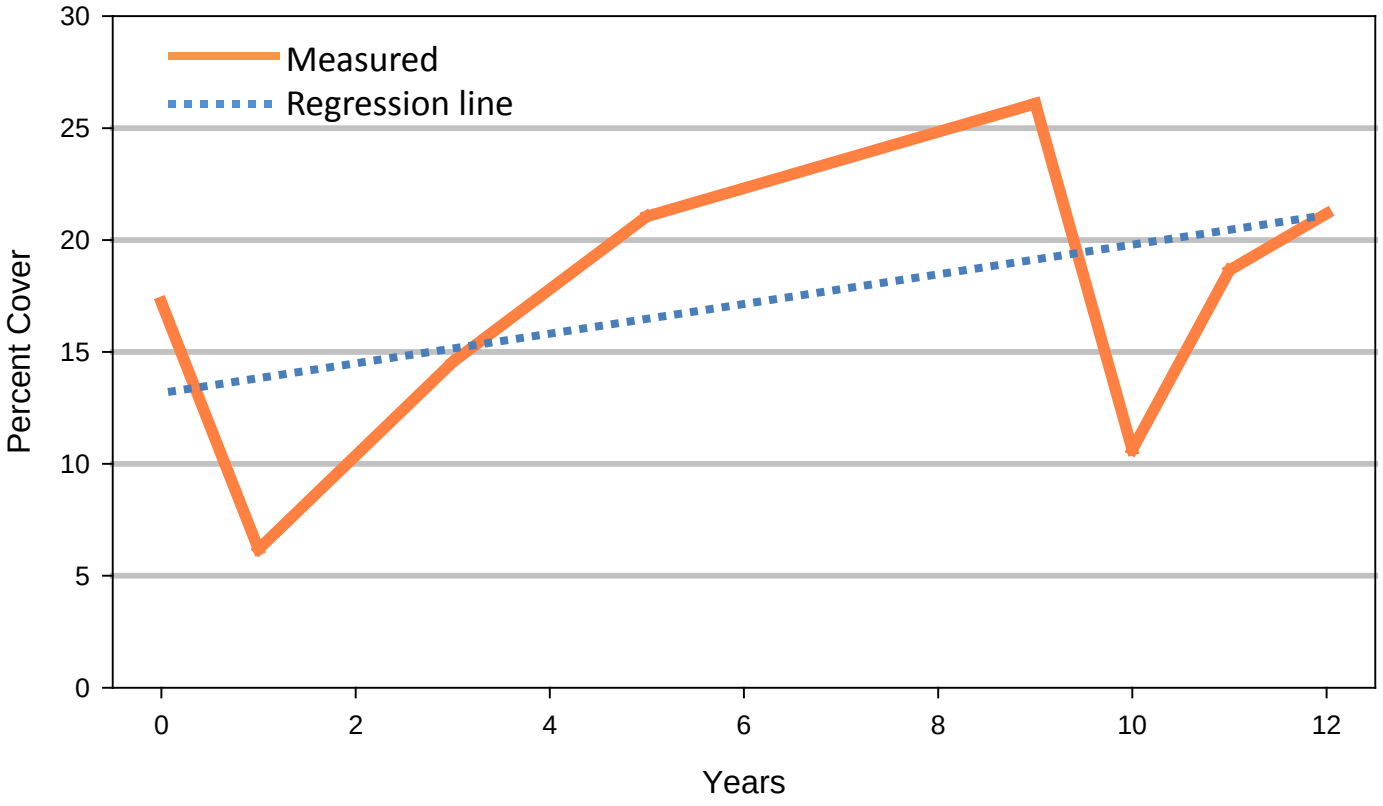
Control: Forest Floor Cover - Shrubs



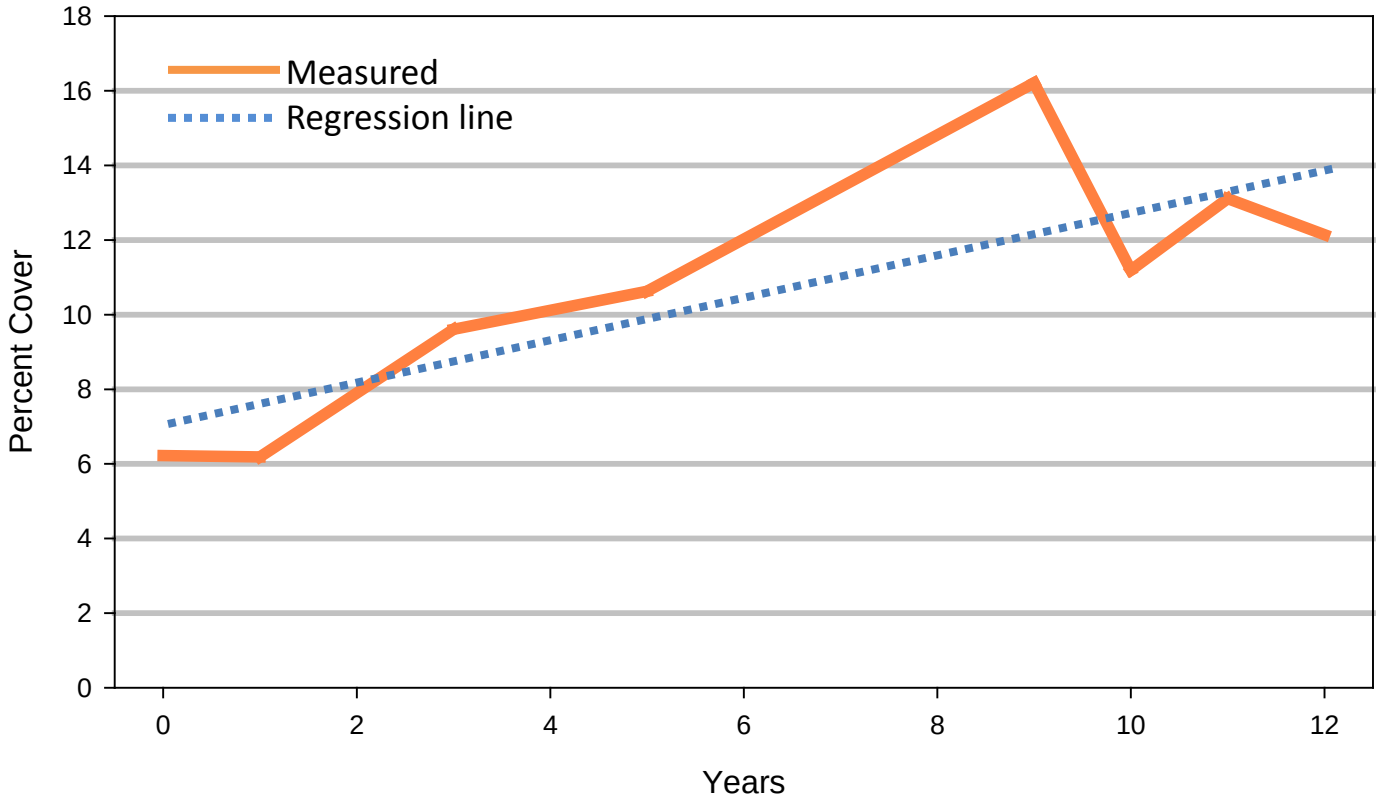
Mechanical: Forest Floor Cover - Shrubs



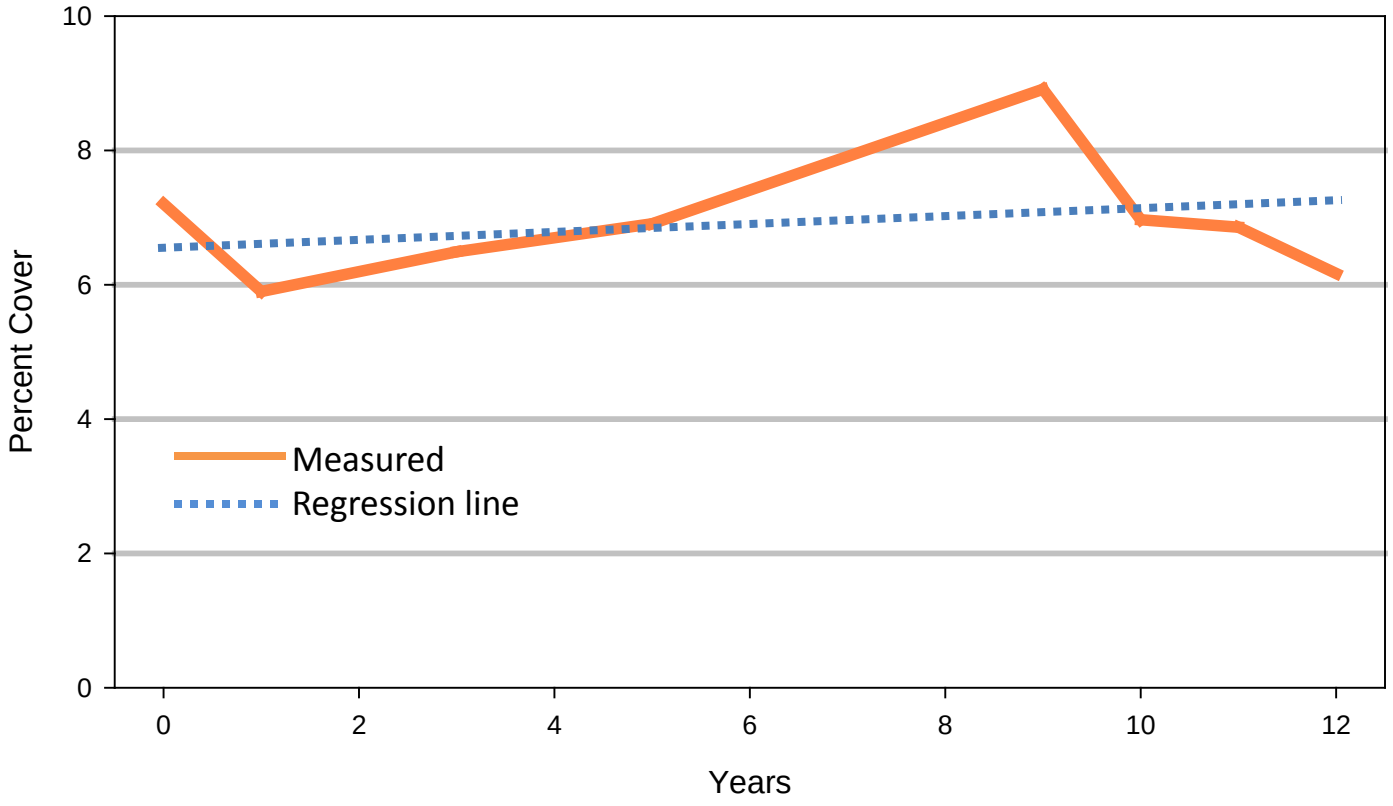
Mechanical + Burn: Forest Floor Cover - Shrubs



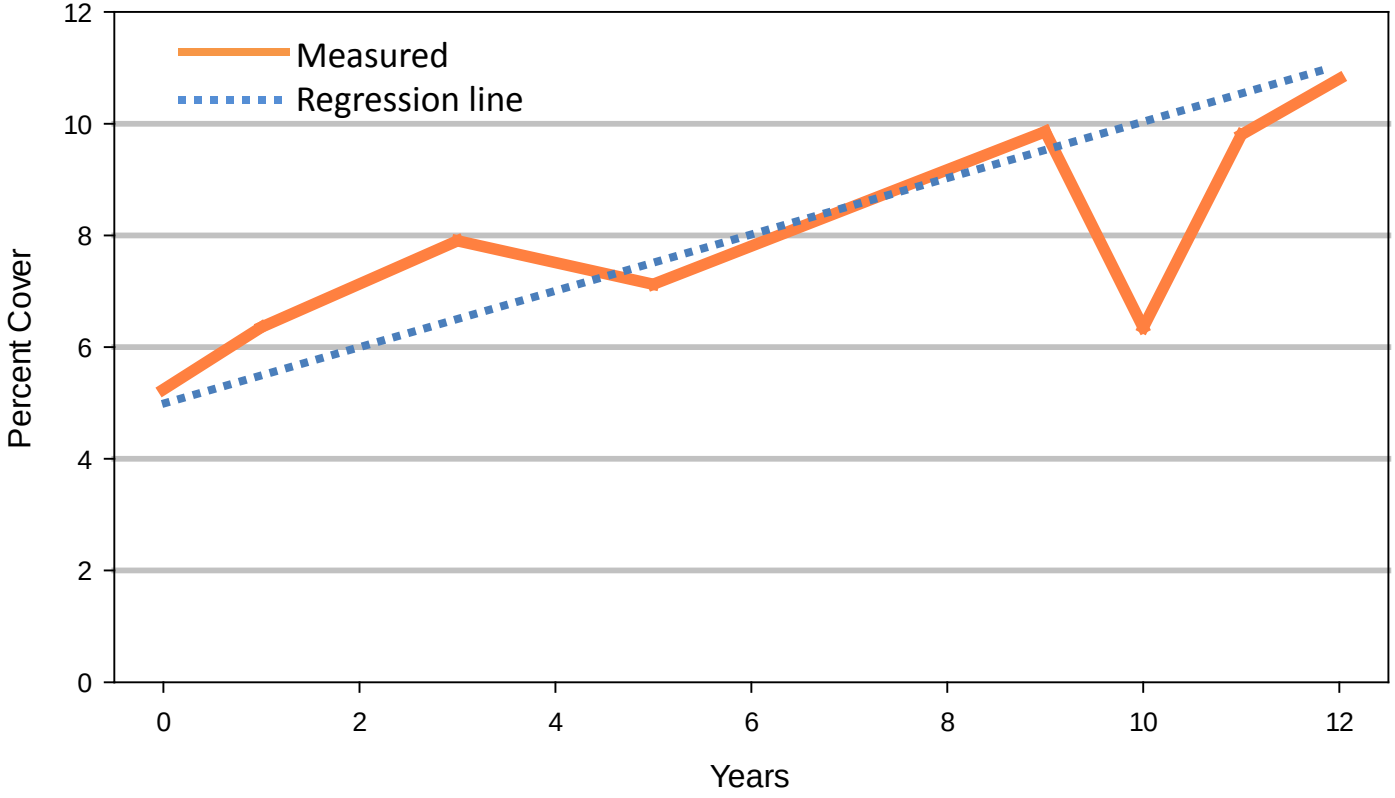
Burn Only: Forest Floor Cover - Trees



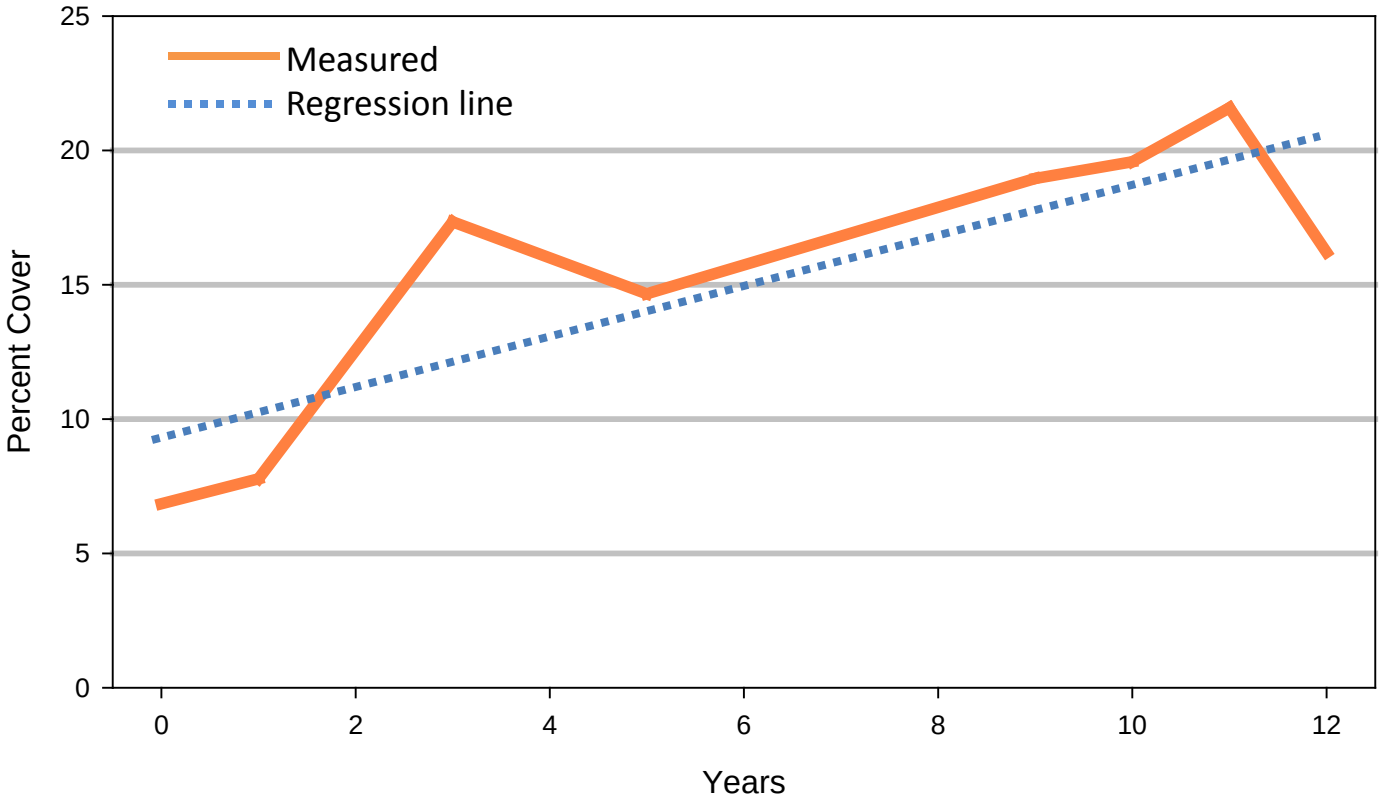
Control: Forest Floor Cover - Trees



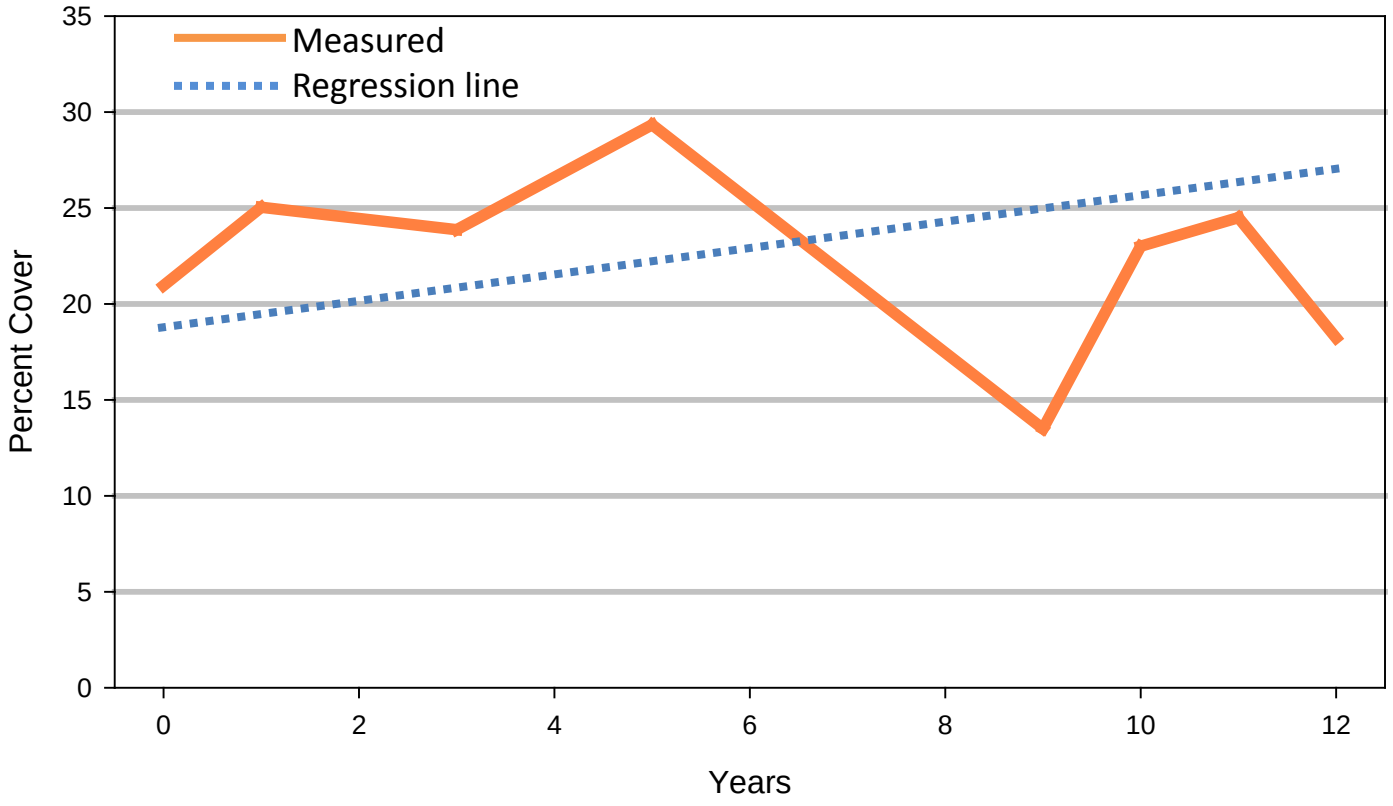
Mechanical: Forest Floor Cover - Trees



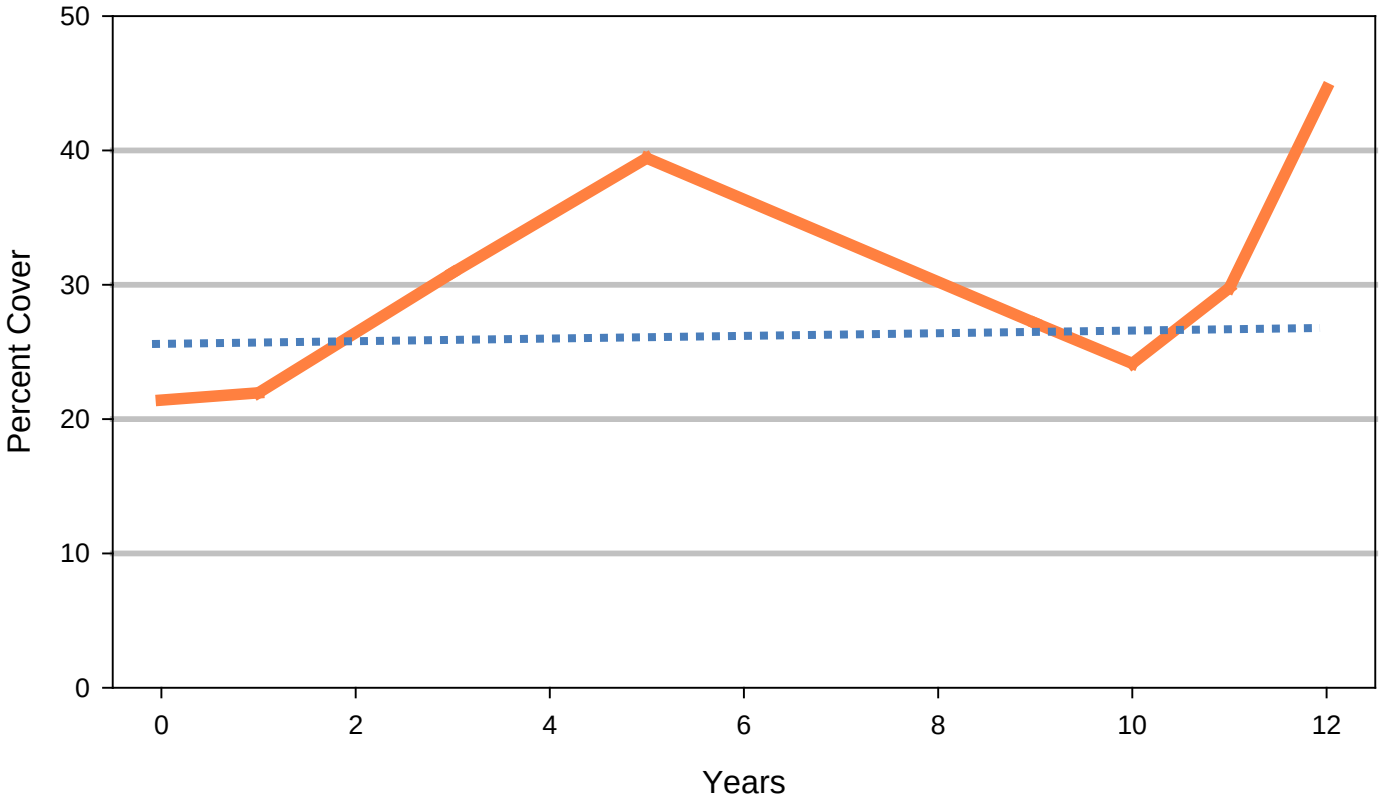
Mechanical + Burn: Forest Floor Cover - Trees



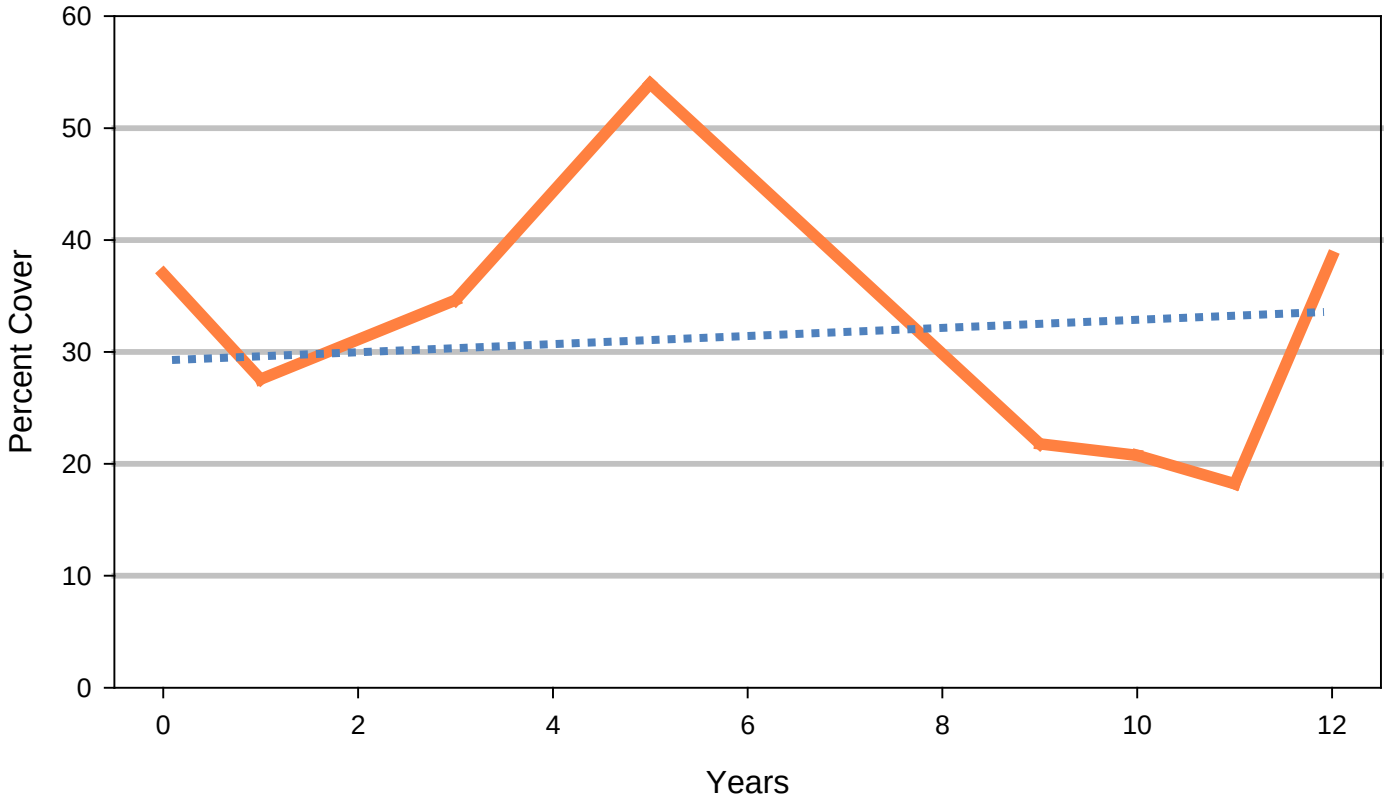
Burn Only: Forest Floor Cover – All Species



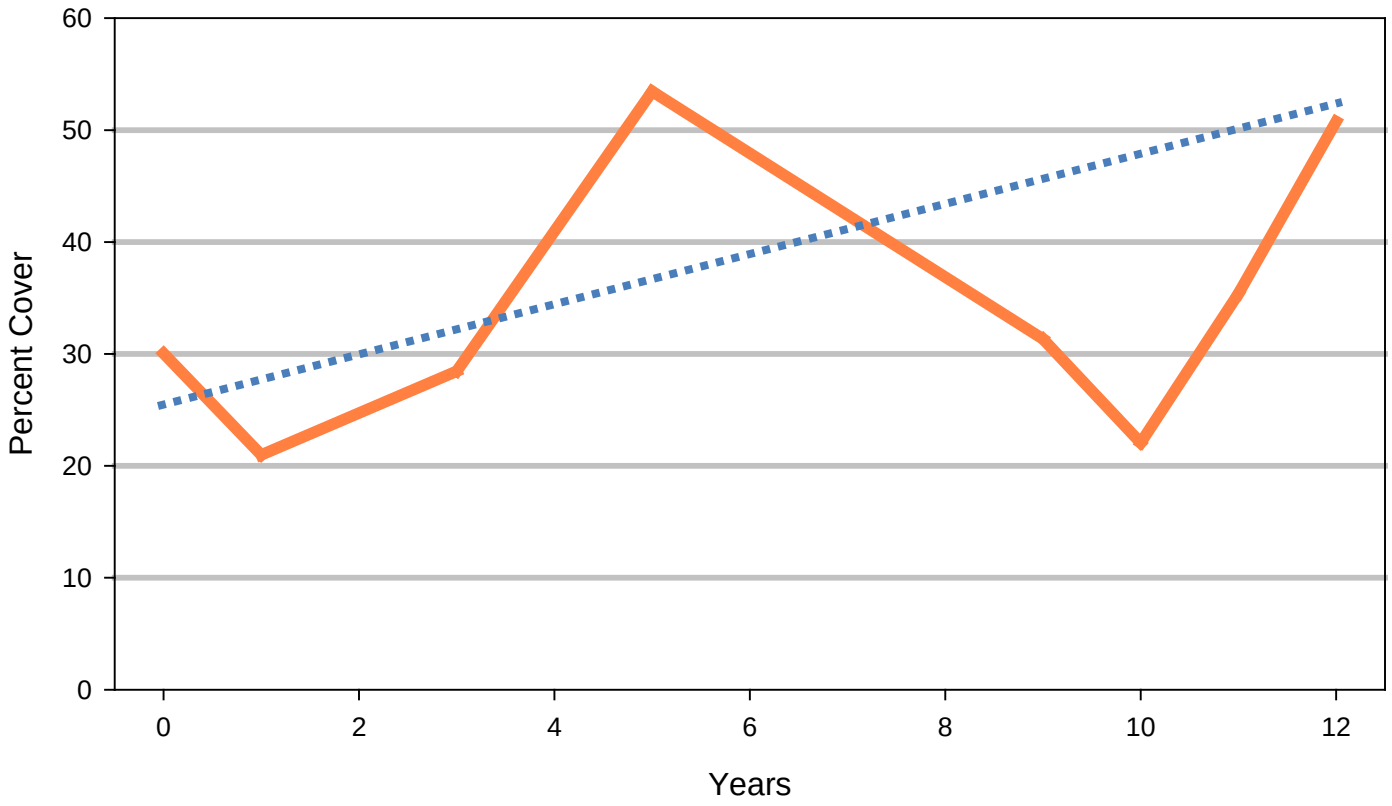
Control: Forest Floor Cover – All Species



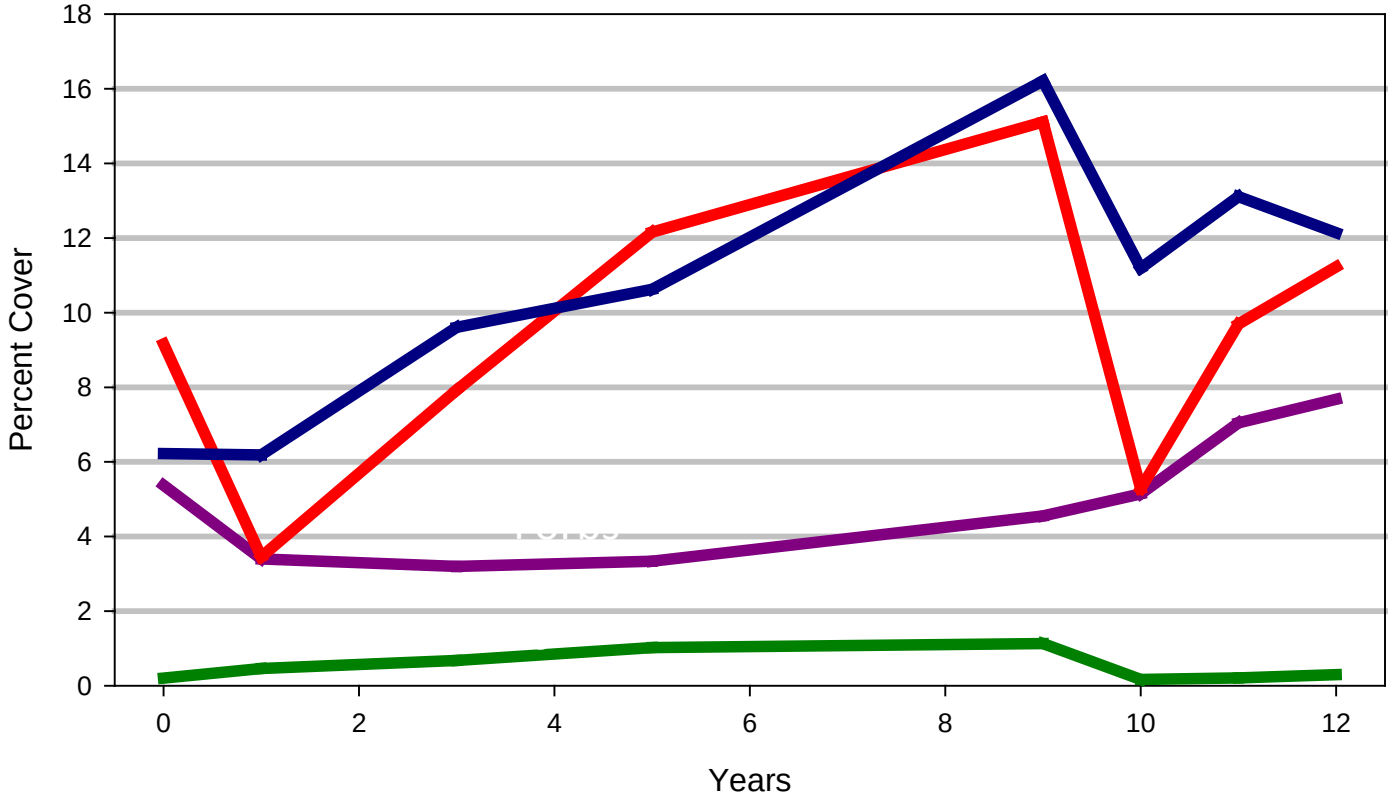
Mechanical: Forest Floor Cover – All Species



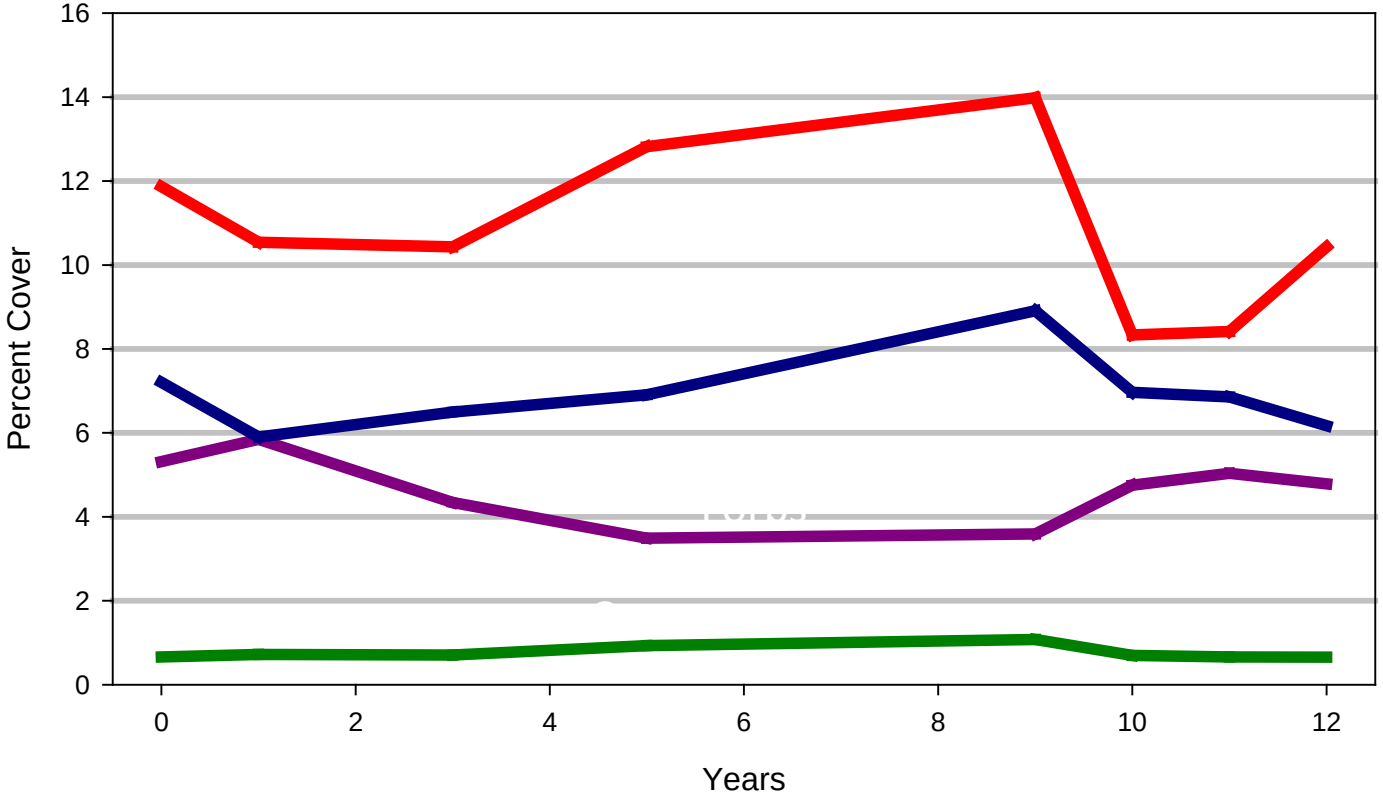
Mechanical + Burn: Forest Floor Cover – All Species



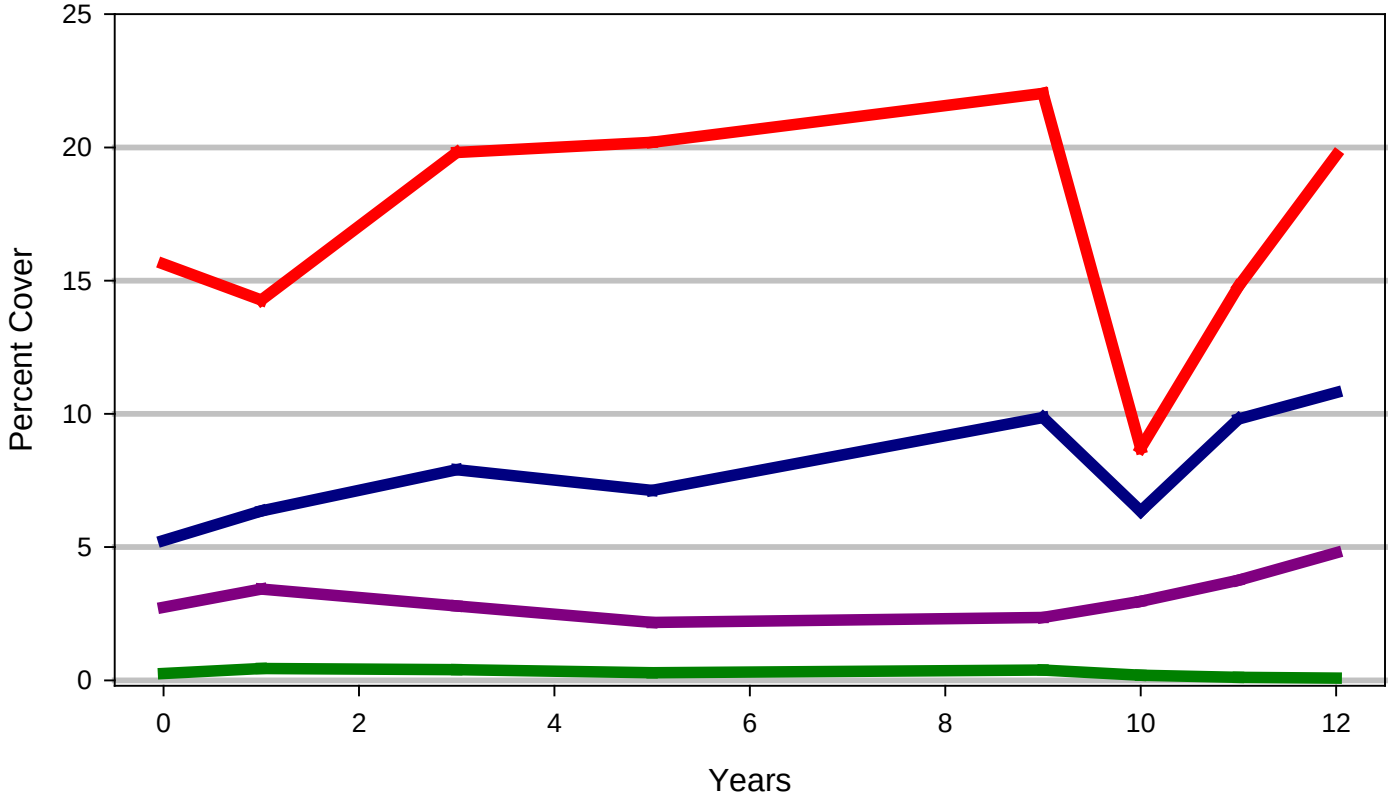
Burn Only: Forest Floor Cover – All Species Groups



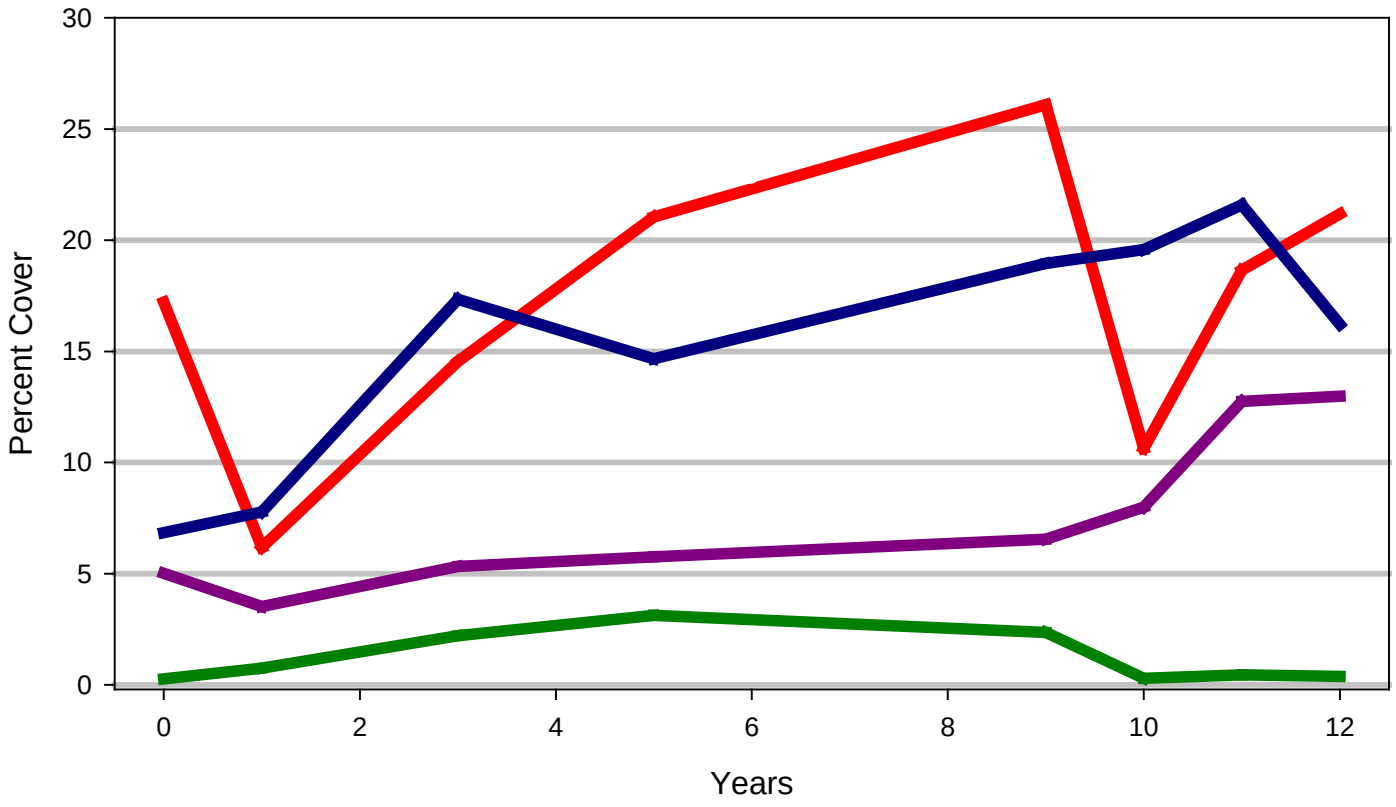
Control: Forest Floor Cover – All Species Groups



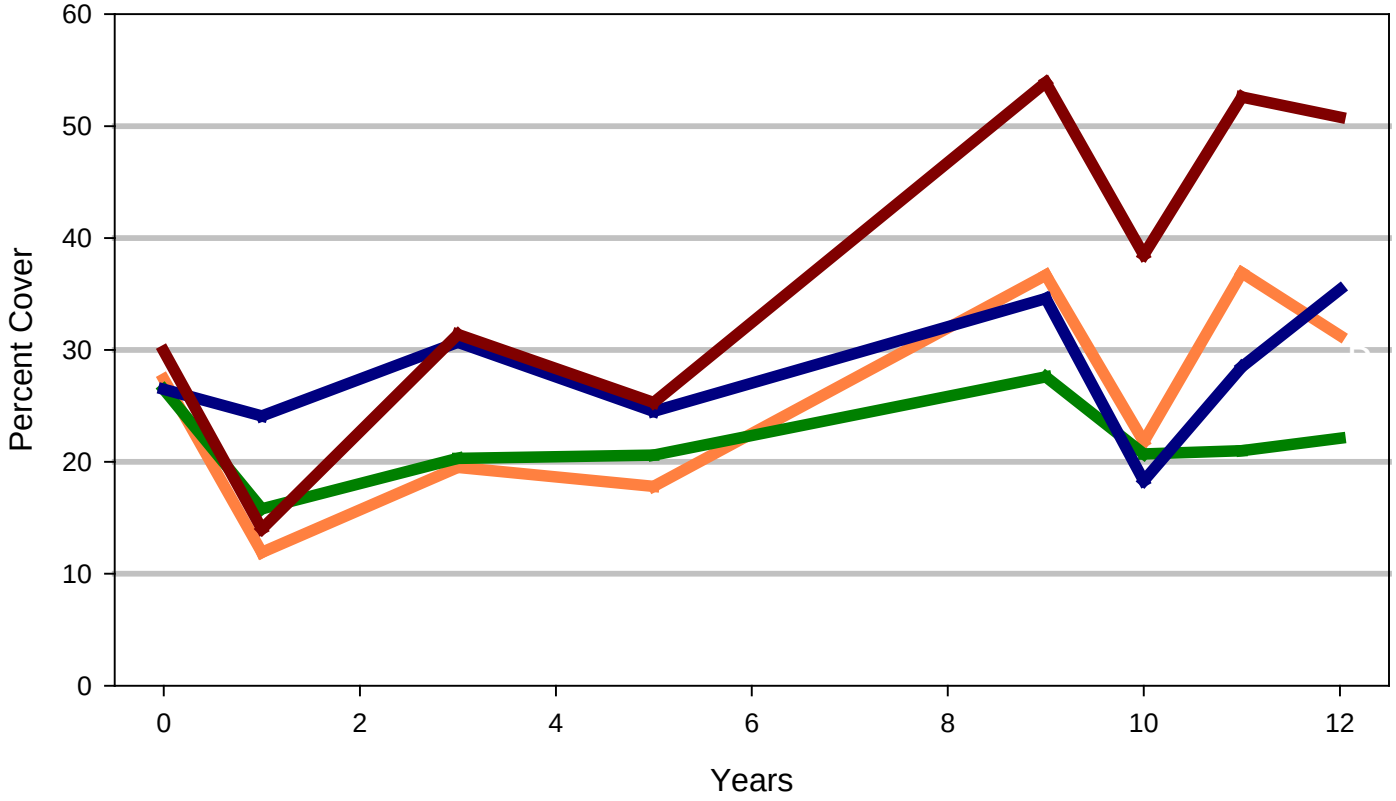
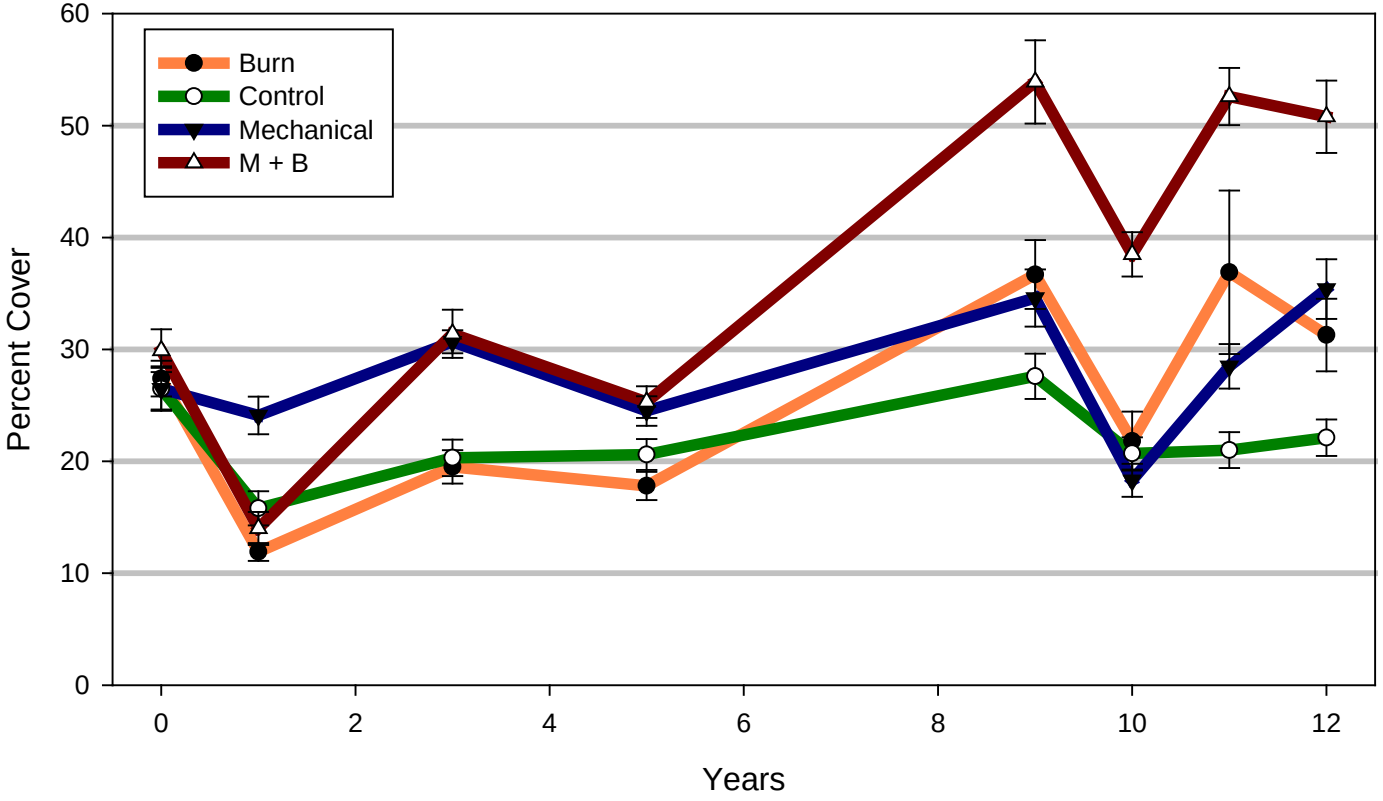
Mechanical: Forest Floor Cover – All Species Groups



Mechanical + Burn: Forest Floor Cover – All Species Groups



Forest Floor Cover – All Treatments
All Species Groups



Forest Floor Cover – All Treatments
All Species Groups