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QUANTIFYING LOSSES OF UNDERSTORY FORAGE IN ASPEN STANDS ON
THE DIXIE AND FISHLAKE NATIONAL FORESTS

by

Barton R. Stam

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

In

Range Science

UTAH STATE UNIVERSITY
Logan, Utah

2004

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ABSTRACT

Quantifying Losses of Understory Forage in Aspen Stands on the
Dixie and Fishlake National Forests

by

Barton R. Stam, Master of Science

Utah State University, 2004

Major Professor: Dr. John C. Malechek
Department: Forest, Range, and Wildlife Sciences

The West has lost up to 60% of its historic aspen stands over the last century, probably as a result of the successional tendency of aspen to be replaced by coniferous species in the absence of periodic fires. One of several major impacts of this change is the loss of understory forage as conifer canopy cover increases. I measured understory biomass in aspen stands ranging from 0% to 81% absolute conifer cover in the canopy and found that understory production declines exponentially as conifers replace aspen. I also did an economic analysis to determine the value of the forage that is not being produced by aspen sites due to a presence of coniferous species within the tree canopy. Study results indicate significant losses in forage, marketable through the sale of livestock, and losses in revenue generated through grazing fees for the USDA Forest Service.

(43 pages)

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Thank you all for your help.

Barton Stam

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CHAPTER I

INTRODUCTION

Across eight of the western states (Arizona, Idaho, Utah, Wyoming, Colorado, Nevada, New Mexico, and Montana) quaking aspen (*Populus tremuloides*) stands have been reduced to about 40% of their historic range, as estimated by Bartos (2001). Numerous problems have arisen as a result of this immense loss. These include a decline in water yields from watersheds and a reduction in biodiversity (Bartos and Campbell 1998). Intact aspen sites are also among the most prolific producers of forage in the Intermountain West. Mueggler (1988) found that some aspen sites are capable of producing up to 4,260 kg/ha of air-dry understory material. However, this production can be reduced by 50% when conifers make up as little as 15% of the total tree basal area on the site (Mueggler 1985, 1988). This potential for producing large amounts of understory biomass makes aspen stands important as suppliers of forage for both wildlife and domestic livestock. As conifer encroachment on aspen stands continues, this supply of forage is dwindling. With the loss of forage comes a corresponding economic loss in the amount of the forage that is no longer being produced.

This gradual, but now substantial reduction of the forage base has another insidious impact on high elevation rangelands; a probable overstocking of both livestock and wild ungulates. Current stocking rates for livestock are generally based on historic assessments made decades ago. The loss of aspen associated forage, coupled with an increased forage demand from increasing numbers of elk may be resulting in a forage bottleneck on some ranges administered by the USDA Forest Service.

While the problem is now obvious, there has been little research to document these understory relationships in the aspen type. Therefore, this project was conceived in 2002 to provide an initial quantification of forage loss and its economic impact.

CHAPTER II

LITERATURE REVIEW

Harper (1973), in an unpublished abstract of a presentation, reported that there was little correlation between aspen overstory and herbaceous understory production unless conifers were present. However, when the conifers were present understory production fell from over 1,568 kg/ha air-dry forage to less than 111 kg/ha. Betters (1983) later suggested that research results conflict over whether an aspen overstory, in the absence of conifers, is related to understory production. These studies suggest that a predictable overstory-understory relationship may, indeed, exist only in aspen stands, which contain a conifer component.

In contrast to aspen stands, there has been much research on overstory-understory relationships in other conifer forest types in the West. For example, Jameson (1967) developed a prediction equation relating pinyon-juniper (*Juniperus spp.* and *Pinus edulis* and *P. monophylla*) canopy cover to herbage production. Understory herbage production used in developing this equation dropped from 672 kg/ha at 0% canopy cover to less than 111 kg/ha at over 90% canopy cover. Clary (1971) documented that as canopy cover increases from 0% to 80% perennial grass production declines from 694 kg/ha to about 45 kg/ha on pinyon-juniper sites in Arizona. In a later study, Clary et al. (1974) related pinyon-juniper basal area increases to herbaceous production decreases. Short et al. (1977) found that production of understory herbage production fell from over 1,100 kg of dry matter/ha to around 500 kg of dry matter/ha as tree density increased from 0 to 200 trees per hectare in pinyon-juniper woodlands. Bates et al. (2000) found, on the Steens

Mountain in Southeast Oregon, that understory production increased after pinyon-juniper stands were treated with thinning cuts. Understory biomass production reached 45.7 kg/ha in treated areas compared with 20.9 kg/ha in untreated areas, during the dry year of 1992. Differences were greater in 1993 when above average precipitation fell, and treated pinyon-juniper stands produced 329.0 kg/ha, while untreated stands produced only 37.9 kg/ha. Furthermore, Ffolliott (1983) reviewed a number of studies that described understory production as a function of the overstory in ponderosa pine (*Pinus ponderosa*) forests of Eastern Arizona. Again, understory production declined as the tree canopy density increased. The overstory factors used to develop these relationships were crown cover and tree basal area (BA).

In general, research results indicate that while a coniferous component in the canopy of a forest cover type may have a negative impact on understory biomass production, an aspen canopy appears to have no consistent effect. This is probably due to different physical structure and physiological properties associated with deciduous aspens and evergreen conifers.

CHAPTER III

METHODS

Research Objectives

The primary objectives of this research were:

1. Estimate the amount of understory biomass that has been lost, and the nature of the decline, due to conifer encroachment of aspen stands within selected study sites.

Ho: Understory biomass production losses are linear as aspen stands are succeeded by coniferous species.

Ha: Understory biomass production declines along a curvilinear gradient as aspen stands succeed to conifers.

2. Estimate the economic value of the understory biomass lost through conifer encroachment on aspen sites within selected study sites.

Ho: Economic losses are consistent throughout all aspen community types.

Ha: Economic losses vary from one aspen community type to another.

Study Area

The study sites selected for this study were located in the following areas: the Cedar City Ranger District of the Dixie National Forest, the Richfield Ranger District of the Fishlake National Forest and on privately owned land on Cedar Mountain, east of Cedar City, Utah. Exact study site locations are given in Universal Transverse Mercator (UTM) units in Appendix A. Study sites ranged in elevation from 2,618 to 3,035 meters and had a mean of 2,815 meters. Mean annual precipitation for the study sites over the last 23 years

was 68-78.2 cm (Utah Snotel 2004). Most of the precipitation at these elevations comes as winter snow with up to one third coming from summer monsoons. Large mountain meadows are frequently interspersed among stands of aspen, conifers (*Picea engelmannii* and *Abies concolor* and *lasiocarpa*), and mixed aspen/conifer cover types. Soils are generally derived from sedimentary limestone parent materials.

Site Sampling

Mueggler (1988) defined 56 aspen community types (i.e., units of land with similar species dominance and composition) in the West, each with a different inherent potential to grow forage. Thirteen community types were sampled in this study in order to gain a perspective of how conifers in the stand influence the community's ability to produce understory biomass. Appendix B contains a listing of the community types that we sampled. Mueggler's (1988) Aspen Community Types of the Intermountain Region was used to select aspen community types that were common to the study areas selected and had varying potentials to produce understory biomass. Mueggler's work was also used to place each study site sampled into a high or low potential category, based on the site's inherent characteristics for producing understory biomass. It was also critical that sites with differing levels of conifer encroachment be selected for sampling to assess the decline in understory production, as the conifer component of the canopy increased. According to Mueggler's community type key, when the conifer component of an aspen stand exceeds 10%, the community type changes. Therefore, sites with a heavy conifer component were sampled that had once been the same community type as those with little or no conifers.

At each sample site, a center point for transects was randomly chosen. Four 30-meter transect lines were established radiating from this center post, in the four cardinal directions. Transect lines were demarcated by the use of an engineering-style tape with metric units.

The sampling methods used included; weight estimate (Pechanec and Pickford 1937), reference unit (Kirmse and Norton 1985), point-intercept (Cook and Stubbendieck 1986), and tree B.A. (Husch et al. 1982) by species.

A 1.0-m² quadrat square frame was placed at 7.62-meter intervals along the right side of each transect, which yielded 16 quadrat placements per site. Herbaceous biomass in each quadrat was then estimated by the weight estimate technique. Pre-sampling work showed that this technique produced accurate and repeatable estimates of biomass. However, it required some training and calibrating to obtain accuracy. Each morning sampling began by making estimates of the weights (in grams) of herbaceous biomass present within the quadrat frame, by species. This estimate was then recorded and the actual weight measured by clipping the plants at ground level and weighing them with a hand-held scale. The first 2-4 plots measured each day served to “calibrate our eyes” to the forage biomass. Once these initial plots were done, only estimates were made of the forage within the remaining plots sampled that day. Each day, at least 2 samples of each plant species found in the area were collected, bagged, weighed, and brought back to a lab to be dried. This gave plant biomass on a dry-weight basis.

The technique used for estimating the biomass of shrubs was the reference unit method. Shrubs were sampled if they were rooted within the 3-sided quadrat frame as it was placed at each 7.62-meter interval. When a shrub was found within the frame, a

reference unit, or a couple of branches of current growth from the same species of shrub, but one outside the frame, was clipped. This reference unit was then compared to the shrub in the frame and an estimate was made at how many reference units the shrub contained. The weight of the reference unit was then measured on a hand-held scale. This weight was then multiplied by the number of reference units required to make up the shrub. Only the current year's growth of shrub biomass was considered because it is the material that herbivores are able to utilize. All estimates were converted to a dry-weight basis.

A fundamental assumption of this study was that the amount of biomass produced varies as a function of the amount of conifers in the canopy. Hence, species composition and canopy coverage of the overstory was measured at each site. Canopy cover was measured from the ground by a line-point intercept technique. Cover readings were taken at 1-meter intervals along each transect, using a canopyometer (Fig. 1). The

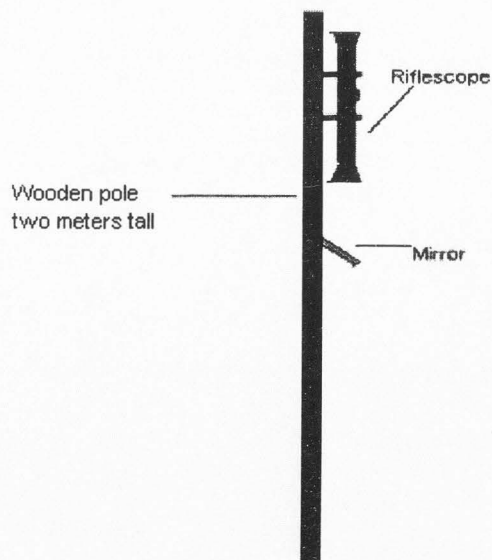


Fig. 1. Illustration of the canopyometer used for point intercept data collection.

canopyometer is a device that facilitated point sampling of the tree canopy. Point sampling of the canopy can be difficult because of the height of the canopy above the observer. This presents the problem of having to strain one's neck by looking up and the difficulty of focusing on a finite point from which to sample. The canopyometer solved both of these problems. It consisted of a wooden pole (2.5 cm diameter x 2 m length), rifle scope, and a mirror. The crosshairs in the scope allowed the observer to pinpoint one spot while the mirror relieved one from having to strain their neck because the image is viewed at the observer's level as reflected in the mirror. The canopyometer was held vertically and placed at 1.0 - meter intervals along each of the transect lines (120 points per site). The observer sees the image of the tree canopy in the mirror and records the point intersected by the crosshairs as open sky, or by tree species. Data were then summarized and analyzed as absolute canopy cover, by species. For example if 30 points were intercepted by aspen canopy and 60 by a conifer species, out of 120 points total, on a particular transect, that would be reported as 25% aspen and 50% conifer cover. The BA of each tree species was measured using the Bitterlich technique (Husch et al. 1982). The angle gauge used had a factor of 10.

In addition to these measurements, the following information was recorded at each site: slope, aspect, elevation, and location in UTM units, using a surveyor's compass and a Global Positioning System receiver. The field research took place during the summers of 2002 and 2003. During 2003, we were able to re-sample the 11 sites sampled in 2002, plus 16 additional sites, which gave a sample size of 27 for data taken in 2003.

Statistical Analyses

Understory biomass data were analyzed using PROC MIXED (SAS v8.2 1999). SAS code used for this procedure can be found in Appendix C. A predictive equation was developed using data from 2003, as this dataset had a larger sample size. This equation may be used to predict biomass production given a specified level of coniferous species present in the canopy. To prevent predicting biomass values below zero, data were transformed to a log scale. Preliminary statistical analysis also showed no statistical differences between high and low potential sites. As a result, we combined the data for these sites into one group, which yielded the predictive equation.

Economic data were analyzed using a partial budgeting technique (Kay and Edwards 1999). This technique was used to compare the value of the forage that is present today, with what would have been present if there had been no conifer encroachment, in terms of: a) grazing fee revenue to the USDA Forest Service and b) forage potentially marketed through the sale of livestock. The amount of additional forage that would have been available had absolute conifer cover in the canopy remained at 15% or less was calculated, using the mean understory biomass production from the study sites that had $\leq 15\%$ conifer cover. In order to provide a range of possible additional understory biomass amounts that would have been realized had the aspen loss not occurred, calculations were run assuming three different levels of current understory biomass production for lost hectares of aspen (0, 60, and 187 kg/ha). Bartos and Campbell's (1998) work was used for estimates on hectares of lost aspen. Their data indicates that 184,714 hectares of aspen have been lost to conifer succession on the two forests. Total available Animal Unit Months (AUMs) were then calculated for this forage

*USFS use a factor of 1.32/AU for cow/calf pairs on summer range, thereby giving an AUM value of 359 kg/AU

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base, assuming 50% utilization and 272 kg/AUM (Holechek et al. 1998). A 3-month grazing season (July-September), was assumed in determining how many Animal Units these aspen sites could have supported with less than 15% absolute conifer cover in the tree canopy. Average calf body weight gains of 92.7 kg were used, based on data collected in a study done by Olson et al. (1999). This study took place in the same area as our study areas and was conducted during a typical grazing season for the area of mid-June to mid-September. Cow/calf pairs were grazed on aspen type grazing allotments and calves were weighed before and after the grazing season. These data were used because they represent results from cattle grazing regimes that are similar both spatially and temporally to the economic objectives of this study. The average calf body weight gains were multiplied by average 2003 selling prices for both steer and heifer calves (\$2.23/kg and \$2.07/kg, respectively) (USDA Agricultural Marketing Service 2004). With these prices the revenue that would have been generated had the conifer encroachment not occurred resulting in a higher available forage base and therefore allowed additional cow/calf pairs to be grazed was calculated (Appendix D). These additional AUMs were also multiplied by the current grazing fee of \$1.43/AUM (USDA Forest Service 2004) to calculate revenue that would have been generated (for the current year) for the USDA Forest Service if the additional grazing had occurred in the absence of conifer encroachment.

* Personal interview w/ Dave Grider, USFS, Dixie N.E

CHAPTER IV

RESULTS AND DISCUSSION

Decline of Forage

Raw data collected from the study sites during the summers of 2002 and 2003 are presented in Appendix A. Absolute conifer cover in the canopy appeared to increase from 2002 to 2003 on seven of the 11 sites that were sampled both years (Table 1). These increases ranged from less than 1% to 3%, and a t-test showed that these differences were significant ($P \leq 0.05$). Understory biomass production increased on nine of the 11 sites from 2002 to 2003 (Table 1). These increases ranged from 1% to 90%. Again, a t-test showed these numbers to be significant ($P \leq 0.05$). Some of this increase in production can be attributed to higher amounts of precipitation in 2003 than in 2002. Total precipitation for 2002 was 36.6 cm, during 2003 a total of 58.7 cm were measured. Both of these years however, were below the 23 year average of 78.2 cm. These precipitation data were taken from the Utah Snotel (2004) Webster Flat station, which is within 10 km of sites sampled during both research years of 2002 and 2003. During 2002 study site understory biomass production ranged from 9 to 954 kg/ha across the 11 sites sampled. Absolute conifer cover ranged from a low of 0% to a high of 76%. Understory production for 2003 ranged from 10 to 1,482 kg/ha, while absolute conifer cover values were recorded from a high of 81% to a low of 0%. These data, from both years, show that as the conifer component of the tree canopy increases, understory biomass production decreases exponentially. Thus, the null hypothesis that understory production

Table 1. Changes in understory biomass production and conifer cover.

Study site	2002 prod. kg/ha	2003 prod. kg/ha	%prod. Change	2002 % conifer	2003 % conifer
Miner's Peak	954	1482	55%	0	0
Crystal #1	637	1208	90%	4	5
Crystal Powerline	227	298	31%	19	23
Crystal #2	182	337	85%	50	52
Crystal #3	45	85	89%	76	75
Jim's #1	227	198	-13%	1	4
Dark Hollow	186	268	44%	0	0
Strips A	186	222	19%	0	0
Seth's Site	182	173	-5%	0	0
Strips B	77	84	9%	35	36
Jim's #2	9	10	11%	59	60

decreases as a linear function is rejected. Scatter diagrams of the data for 2002 and 2003 are shown respectively in Figures 2 and 3. The predictive equation based on the data from 2003 is (1): $y = (e^{(6.2516 - 0.0378 * \% \text{ conifer})}) * 1.1204$. Where "y" is the expected level of understory biomass production and "e" is a constant of approximately 2.71828. The line representing this equation is illustrated in Figure 4. The p-value for this data is less than 0.0001, indicating that it is highly probable that the slope of the line, drawn by the predictive equation is not zero. While the Proc Mixed procedure does not calculate an r^2 value, an "r² like" value of 0.9252 was calculated using the following equation (2): $1 - (\text{variance of the residuals} / \text{variance of log biomass})$, or $1 - (0.1003 / 1.3402)$ (Turner, D.L. Rocky Mountain Research Station. Personal communication).

These data indicate that once coniferous species represent about 20% of absolute tree canopy cover the level of conifer encroachment in the canopy becomes the dominating factor determining how much understory biomass the stand is capable of

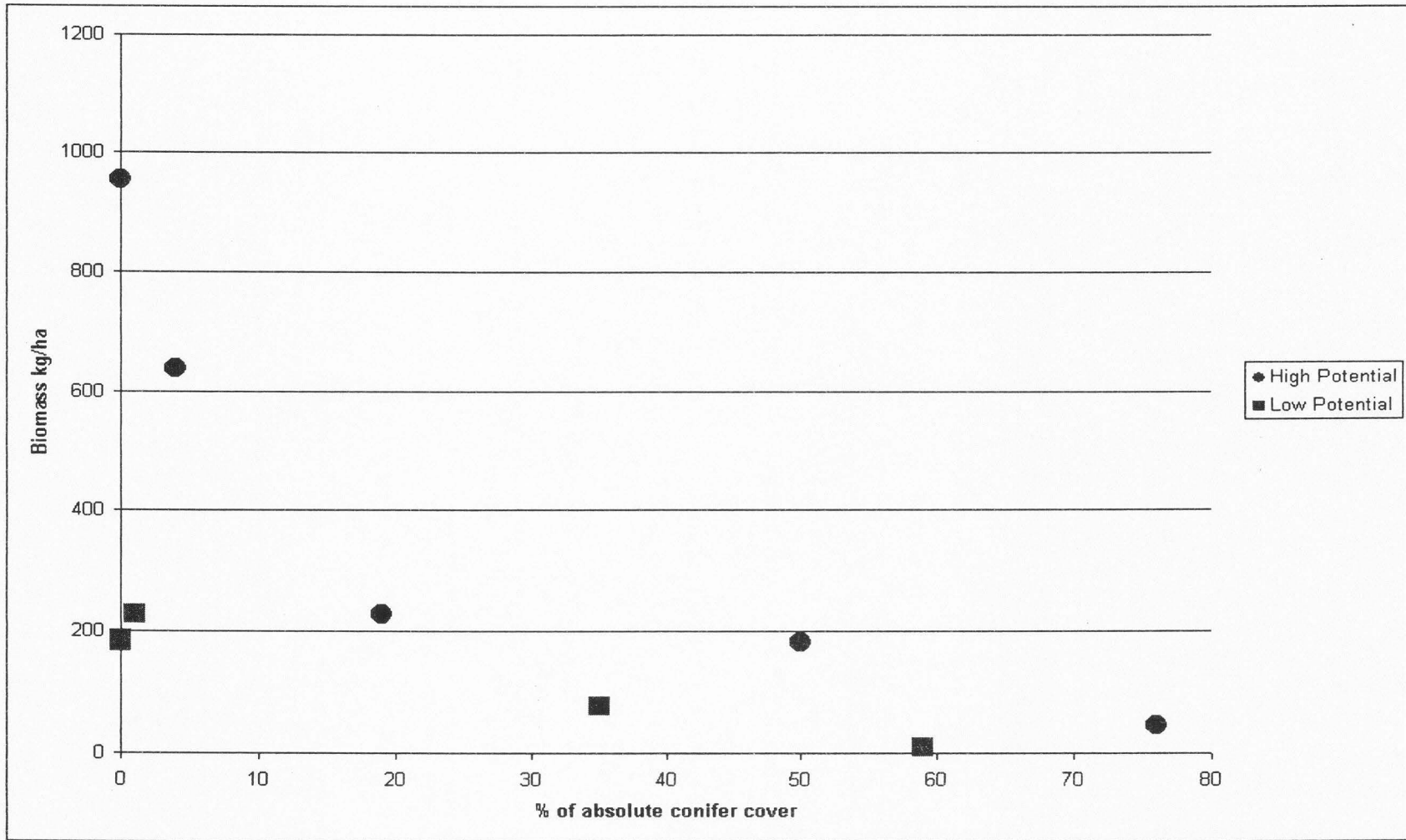


Fig. 2. Relationship of conifer canopy coverage (%) to understory biomass production. Original 2002 data points on high and low potential sites.

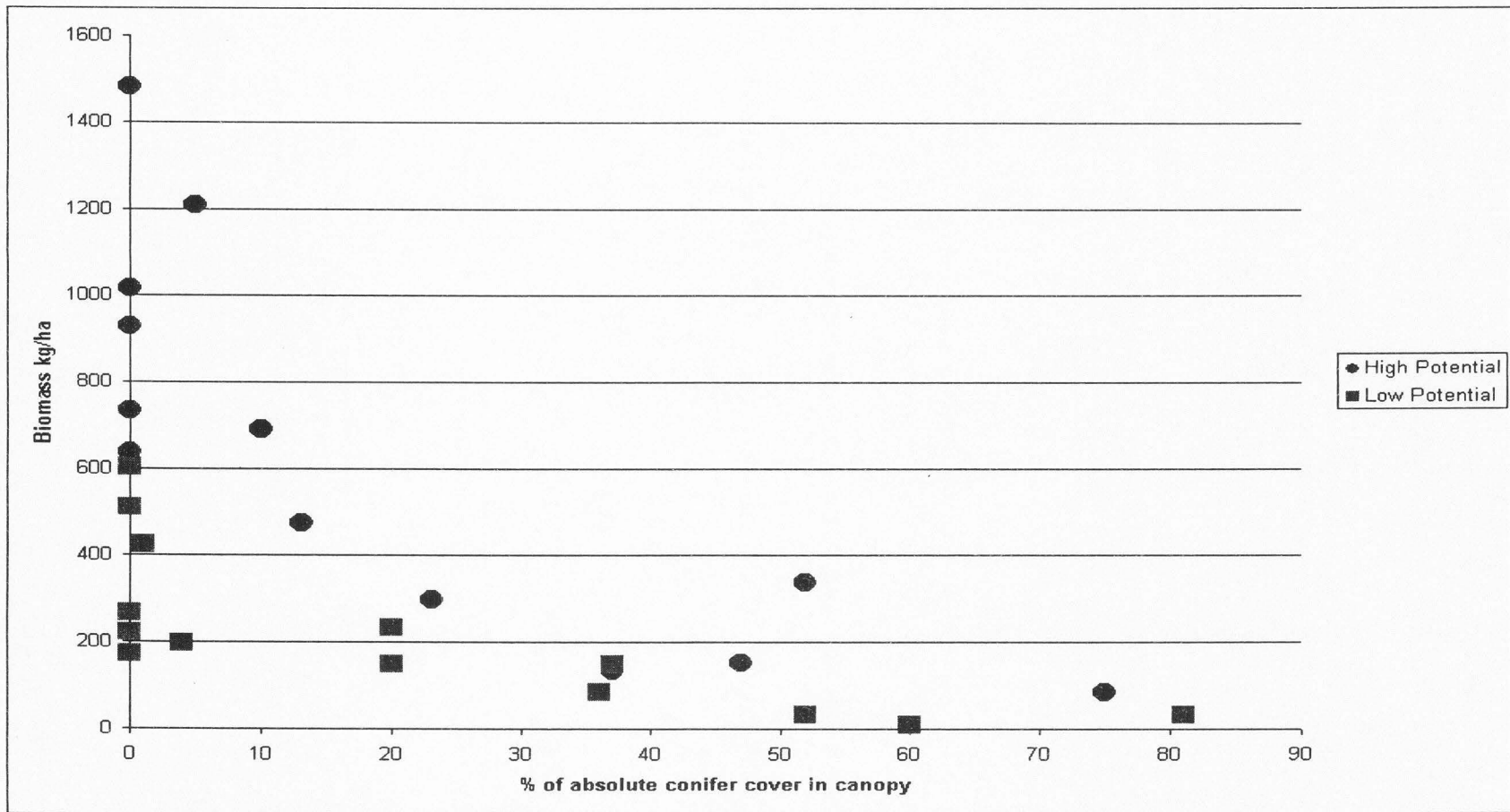


Fig. 3. Relationship of conifer canopy coverage (%) to understory biomass production. Original 2003 data points on high and low potential sites.

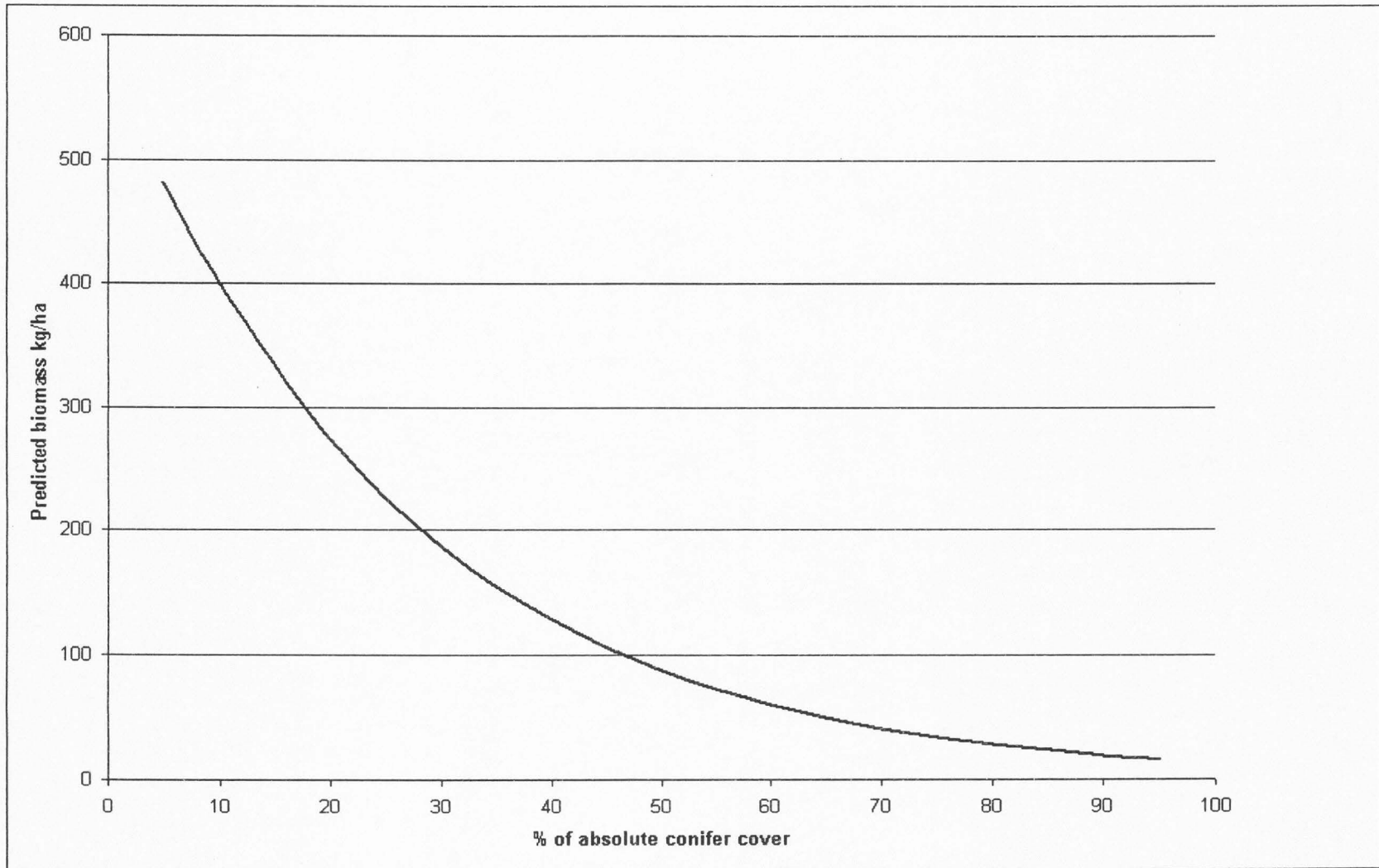


Fig. 4. Predicted relationship between absolute conifer cover and understory biomass production.

producing. When conifers represent less than this, or are absent, other site properties such as elevation, precipitation, aspect, soil type and depth, and the understory plant community determine the quantity of understory biomass produced. Supporting this assertion is the high level of variability in production among stands where conifers made up less than 10% of the canopy (see Figs. 2 and 3). These sites varied from 198 to 1,482 kg/ha during 2003 even within the same community types, and no relationship between canopy cover and understory biomass production was apparent. Figure 3, especially, illustrates this variability of understory production from sites with little or no conifer component. This finding is also corroborated by Harper's (1973) study mentioned in Chapter II, wherein he found that there was no relationship between the canopy coverage of pure aspen stands and their understory production.

Data acquired during two years with different levels of precipitation, both below normal, has presented some interesting information. The sites that increased the most in biomass production were generally those that had the least amount of absolute conifer cover. It appears that, given the lack of competition for resources from conifers, these aspen sites are able to respond readily to increased soil moisture. While some sites with heavy conifer encroachment did increase production between the 2 years overall production was already so low that any gains in production were of little consequence.

Conifers influence understory production in several ways. Competition for soil moisture, as mentioned, is an obvious one and obstructing precipitation from the soil is another. When snow falls on a stand with conifers, much of the snow is intercepted by branches and needles. This snow often sublimates into the atmosphere and is effectively lost from the system (Fisher and Binkley 2000). Water loss from higher levels of annual

evapotranspiration of conifers also contributes to less soil moisture available for understory plant growth (Bartos and Campbell 1998). Thick conifer canopies are also effective at blocking sunlight and hindering photosynthesis of understory species. This is not so much the case in pure aspen stands. Sunlight is able to penetrate an aspen canopy readily relative to a conifer canopy. This may be due, in part, to the aspen leaves' tendency to move with any slight breeze or "quake" as in the common name quaking aspen (Lambers et al. 1998).

During pre-sampling work, it was hypothesized that there would be different levels in production among aspen stands with similar levels of conifer cover, yet with different inherent site characteristics. Statistical analysis however, as mentioned, did not support this. Additional studies may be needed to determine if a difference does indeed exist. I believe that differences probably do exist in aspen stands with little or no conifer component. However, as conifer cover increases, reductions in understory biomass are so rapid and dependent on the conifer influence (and less on other characteristics), that differences in levels of production due to other site properties all but disappear.

Economic Losses

Using the calculations described in the statistical analysis section (p. 10), and the equation shown in Appendix D, it was calculated that had conifer encroachment been limited to less than 15% absolute conifer cover, an additional ^{* 10,887,235} \$14,369,489 in revenue could have been generated during the current year, in calf sales to livestock producers that graze on the Fishlake and Dixie National Forests. This figure assumes that there is absolutely no understory biomass production on the historic aspen sites that are now

* See re-calculation in Appendix D, pp. 33-36

dominated by conifers. In reality, while production would be low, there would still be a small amount of forage produced on these sites. In order to account for this possibility, estimates of additional forage were made assuming two additional levels of current understory biomass production on these sites. These assumed levels of production were 60 and 187 kg/ha. These levels, (predicted by *equation 1* on p. 13), correspond, respectively, with 60 and 30% of the canopy being coniferous species. Using these different levels of production allowed for a range of possible losses in revenue to be estimated. If the historic aspen sites now average 30% absolute cover by conifers in the canopy, then additional revenue would be ^{7,691,182}~~\$10,151,000~~. Assuming conifer coverage was 60% then additional revenue would be ^{9,861,611}~~\$13,015,811~~. It should be emphasized that these figures represent gross revenue, not profit. Furthermore, this revenue would only be realized by livestock producers if the additional forage was allocated totally to livestock grazing.

This additional grazing capacity could also have generated as much as ^{234,342}~~\$309,297~~ in the current year alone, if it was all allocated to livestock, in livestock grazing fees for the two forests. If current biomass production levels were at 60 and 187 kg/ha then additional revenue for the forests would only be ^{212,269}~~\$280,164~~ and ^{165,548}~~\$218,499~~. This additional biomass could also be allocated totally to other uses such as wildlife forage, watershed protection, etc. If this was the case, then additional grazing fee revenue for the Forests would be zero.

These estimates are based on very conservative numbers and the actual numbers may be much higher. The mean understory biomass production of 637 kg/ha was measured during a year when only 75% of normal precipitation fell, preceded by a year

when only 47% of normal was received. Other sources suggest that average understory biomass production levels for aspen stands are typically much higher. For example, Mueggler (1988) reported a mean of 1,095 kg/ha for aspen stands that he sampled. Today's livestock producers are continually struggling to maintain economic viability and any additional revenue would be of great benefit. Furthermore, in a time where many federal agencies are fighting to maintain budgets and complete their required land management duties additional revenue would also be beneficial for them.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

With many demands for forage in the Intermountain West, including increasing elk herds and an on-going demand for livestock grazing, losing such prolific producers of forage as aspen stands does not bode well for the future of grazing animals on the forests. The results of this study suggest that when conifers occupy as little as 20% of a stand's canopy a significant decline in understory biomass production results. This lost biomass would have provided needed feed for wild and domestic ungulates, and represents an economic loss to the stakeholders and land management agencies of our natural systems. Land managers need to take action now to prevent further decline of this valuable resource.

In order to maintain resources such as forage within aspen sites, the aspens themselves must remain dominant in the stand (Bartos and Campbell 1998). A study conducted by Ohms (2003) showed that decadent aspen stands were capable of regenerating if subjected to a disturbance such as partial cuts or fire. Disturbance of aspen stands, either human-induced or natural occurrences, may be necessary to revitalize aspen stands and recover some of the lost forage producing capabilities in historic aspen stands that are now dominated by coniferous species. Maintaining properly functioning aspen stands will help ensure that these systems will continue as prolific producers of forage for wildlife and domestic livestock. These recommendations should not be taken to suggest that a widespread extensive extermination of conifers should be conducted. Conifer stands themselves provide protective cover, shade, habitat, and commercial

products for wildlife, livestock, and humans. However, a balance of conifer and aspen cover should be maintained. This balance will be dependent on the management goals of a particular area.

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APPENDICES

Appendix A

Attributes of study sites

2002 Data

Site name	Area	UTM	% conifer	Dry weight kg/ha	Potential*	Elevation	Aspect
Miner's Peak	Cedar Mtn	N 4158739 E 856723	0	954	Hi	2657	NE
Crystal #1	Cedar City	N 4168607 E 862778	4	637	Hi	2715	W
Crystal Powerline	Cedar City	N 4169281 E 862559	19	227	Hi	2761	N
Crystal #2	Cedar City	N 4168520 E 862745	50	182	Hi	2717	W
Crystal #3	Cedar City	N 4168483 E 862789	76	45	Hi	2715	W
Jim's #1	Cedar City	N 4176228 E 875513	1	227	Lo	2930	S
Dark Hollow	Cedar City	N 4184293 E 870806	0	186	Lo	2731	W
Strips A	Cedar City	N 4162875 E 871544	0	186	Lo	2964	NW
Seth's Site	Cedar City	N 4176153 E 875271	0	182	Lo	2939	SE
Strips B	Cedar City	N 4162777 E 871471	35	77	Lo	2954	W
Jim's #2	Cedar City	N 4176208 E 875584	59	9	Lo	2932	S

2003 Data

Site Name	Area	UTM	% conifer	dry-weight kg/ha	Potential*	Elevation	Aspect
Miner's Peak	Cedar Mtn	N 4158739 E 856723	0	1482	Hi	2657	NE
Second Last	Richfield	N 4305014 E 965282	0	1013	Hi	2874	NE
Dale's Goose	Richfield	N 4306216 E 965718	0	926	Hi	2750	E
Little Deer	Richfield	N 4305695 E 965480	0	733	Hi	2834	NW
My Last	Richfield	N 4305273 E 965509	0	637	Hi	2838	E
Crystal #1	Cedar City	N 4168607 E 862778	5	1208	Hi	2715	W
Carson's Favorite	Richfield	N 4302352 E 965146	10	688	Hi	3019	E
Birdhouse	Richfield	N 4302600 E 964870	13	473	Hi	3035	E
Crystal Powerline	Cedar City	N 4169281 E 862559	23	298	Hi	2761	N
Bend in the Road	Richfield	N 4303627 E 965002	37	132	Hi	2939	N
Storm Site	Cedar City	Unavailable	47	152	Hi	unavailable	E
Crystal #2	Cedar City	N 4168520 E 862745	52	337	Hi	2717	W
Crystal #3	Cedar City	N 4168483 E 862789	75	85	Hi	2712	W
Dead Bobcat	Richfield	N 4272619 E 937813	0	604	Lo	2618	N
Ford Tough	Richfield	N 4269404 E 935870	0	510	Lo	2796	NW
Dark Hollow	Cedar City	N 4184293 E 870806	0	268	Lo	2731	W
Strips A	Cedar City	N 4162875 E 871544	0	222	Lo	2964	NW
Seth's Site	Cedar City	N 4176153 E 875271	0	173	Lo	2939	SE
Where's North	Richfield	N 4272195 E 937320	1	426	Lo	2667	E
Jim's #1	Cedar City	N 4176228 E 875513	4	198	Lo	2930	S
No Rules	Richfield	N 4269586 E 935933	20	232	Lo	2785	N
Carson's Last	Richfield	N 4265041 E 933918	20	149	Lo	2830	NE
Strips B	Cedar City	N 4162777 E 871471	36	84	Lo	2954	W
Prison Crew	Richfield	N 4267552 E 935135	37	148	Lo	2728	NE
Half-n-Half	Richfield	Unavailable	52	35	Lo	unavailable	N
Jim's #2	Cedar City	N 4176208 E 875584	60	10	Lo	2932	S
Daily Double	Richfield	N 4272109 E 937274	81	33	Lo	2659	E

*See page 6.

Appendix B

Study site community types as defined by Mueggler (1988)

Miner's Peak	Populus tremuloides/Tall forb
2nd Last	Populus tremuloides/Bromus carinatus
Dale's Goose	Populus tremuloides/Bromus carinatus
Little Deer	Populus tremuloides/Bromus carinatus
My Last	Populus tremuloides/Bromus carinatus
Crystal Springs #1	Populus tremuloides/Bromus carinatus
Carson's Favorite	Populus tremuloides/Bromus carinatus
Birdhouse	Populus tremuloides/Bromus carinatus
Crystal Springs P.	Populus tremuloides/Bromus carinatus
Bend in the Road	Populus tremuloides-Abies lasiocarpa/Tall forb
Storm Site	Populus tremuloides-Abies lasiocarpa/Tall forb
Crystal Springs #2	Populus tremuloides-Abies lasiocarpa/Symphoricarpos oreophilus/Tall forb
Crystal Springs #3	Unclassified Populus tremuloides-Abies lasiocarpa
Dead Bobcat	Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus/Bromus carinatus
Ford Tough	Populus tremuloides/Amelanchier alnifolia-Symphoricarpos oreophilus/Bromus carinatus
Dark Hollow Trail	Populus tremuloides/Thalictrum fendleri
Strips #A	Populus tremuloides/Stipa comata
Seth's Site	Populus tremuloides/Artemisia tridentata
Where's North	Populus tremuloides/Symphoricarpos oreophilus/Poa pratensis
Jim's #1	Populus tremuloides/Poa pratensis
No Rules	Populus tremuloides-Abies lasiocarpa/Symphoricarpos oreophilus/Thalictrum fendleri
Carson's Last	Populus tremuloides-Abies lasiocarpa/Symphoricarpos oreophilus/Thalictrum fendleri
Strips #B	Unclassified Populus tremuloides-Abies lasiocarpa
Prison Crew	Populus tremuloides-Abies lasiocarpa/Carex rossii
Half	Populus tremuloides-Abies lasiocarpa/Carex rossii
Jim's #2	Unclassified Populus tremuloides-Abies lasiocarpa
Daily Double	Unclassified Populus tremuloides-Abies lasiocarpa

Appendix C

SAS code for the PROC MIXED procedure

```
options ls=120 ps=67;

PROC IMPORT OUT=fulldata
      DATAFILE= "E:\data\Barton Stam\fulldata3.wk1"
      DBMS=WK1 REPLACE;
      GETNAMES=YES;
RUN;

data fulldata;
  set fulldata;
  logbiom=log(biomassd);
run;

proc print data=fulldata;
run;

title 'heterogeneous slope model for biomass on %conifer';
run;
proc mixed data=fulldata CL;
  class site_nam area potentia;
  model biomassd=potentia | pct_coni/outp=pred solution CL;
  random area(potentia);
run;

title2 'Check normality of residuals from MIXED model';
run;
proc univariate data=pred normal plot;
  var resid;
run;

title 'heterogeneous slope model for log(biomass) on %conifer';
run;
proc mixed data=fulldata CL;
  class site_nam area potentia;
  model logbiom=potentia | pct_coni/outp=pred solution CL;
  random area(potentia);
run;

title 'HOMOgeneous slope model for log(biomass) on %conifer';
run;
proc mixed data=fulldata CL;
  class site_nam area potentia;
```

```
model logbiom=potentia pct_coni/outp=pred solution CL;
random area(potentia);
run;
```

```
title 'HOMOgeneous slope & Intercept model for log(biomass) on %conifer';
run;
```

```
proc mixed data=fulldata CL;
class site_nam area potentia;
model logbiom=pct_coni/outp=pred solution CL;
random area(potentia);
estimate '5% conifer' int 1 pct_coni 5/CL;
estimate '10% conifer' int 1 pct_coni 10/CL;
estimate '20% conifer' int 1 pct_coni 20/CL;
estimate '30% conifer' int 1 pct_coni 30/CL;
estimate '40% conifer' int 1 pct_coni 40/CL;
estimate '50% conifer' int 1 pct_coni 50/CL;
estimate '60% conifer' int 1 pct_coni 60/CL;
estimate '70% conifer' int 1 pct_coni 70/CL;
estimate '80% conifer' int 1 pct_coni 80/CL;
estimate '90% conifer' int 1 pct_coni 90/CL;
estimate '95% conifer' int 1 pct_coni 95/CL;
ods output estimates=estimate;
run;
```

```
data pred;
set estimate;
*backtransform from log to biomass scale;
lower_log=lower;
lower+exp(lower);
```

```
estimate_log=estimate;
estimate=exp(estimate);
```

```
StdErr_log=stderr;
stderr=exp(stderr);
```

```
upper_log=upper;
upper=exp(upper);
rename label=pct_conifer;
drop df tvalue probt alpha;
run;
```

```
proc print data=pred;
run;
```

```
PROC EXPORT DATA= pred
OUTFILE= "e:\data\Barton Stram\pred.xls"
DBMS=EXCEL2000 REPLACE;
```

```
RUN;
```

```
title2 'Check normality of residuals from MIXED model';  
run;  
proc univariate data=pred normal plot;  
  var resid;  
run;
```

```
*do printer plot of predicted values and confidence limits;  
proc plot data=pred;  
  plot (lower estimate upper)*pct_conifer/overlay;  
run;
```

```
*do higher resolution plot of predicted values and confidence limits;  
symbol1 color=blue interpol=join value=none height=1;  
symbol2 color=red interpol=join value=none height=1;  
symbol3 color=blue interpol=join value=none height=1;
```

```
proc gplot data=pred;  
  plot (lower estimate upper)*pct_conifer/overlay;  
run;
```


Appendix D

Approach for calculating gross revenue lost due to conifer encroachment

A. Potential AUMs of forage not realized

Biomass lost = Hectares of lost aspen * Mean production for stands with < 15% conifer –
forage remaining in hectares of lost aspen (0, 60, and 187 kg/ha)

$$117,662,818 \text{ kg} = 184,714 \text{ ha} * 637 \text{ kg/ha} - 0 \text{ kg/ha}$$

$$106,579,978 \text{ kg} = 184,714 \text{ ha} * 637 \text{ kg/ha} - 184,714 * 60 \text{ kg/ha}$$

$$83,121,300 \text{ kg} = 184,714 \text{ ha} * 637 \text{ kg/ha} - 184,714 * 187 \text{ kg/ha}$$

Total available forage (without the conifer succession) = Biomass lost * 50% utilization

$$58,831,409 \text{ kg} = 117,662,818 \text{ kg} * .50$$

$$53,289,989 \text{ kg} = 106,579,978 \text{ kg} * .50$$

$$41,560,650 \text{ kg} = 83,121,300 \text{ kg} * .50$$

Total AUMs = Total available forage / 272 kg/AUM (Holechek 1998)

$$163,876 \quad 359$$

$$216,292 \text{ AUMs} = 58,831,409 \text{ kg} / 272 \text{ kg/AUM}$$

$$148,440 \quad 359$$

$$195,919 \text{ AUMs} = 53,289,989 \text{ kg} / 272 \text{ kg/AUM}$$

$$115,768 \quad 359$$

$$152,797 \text{ AUMs} = 41,560,650 \text{ kg} / 272 \text{ kg/AUM}$$

B. Number of marketable calves

Allowable animal units (AUs) for 3-month grazing season = Total AUMs / 3

$$54,625 \quad 163,876$$

$$72,097 \text{ AUs} = 216,292 \text{ AUMs} / 3 \text{ months}$$

* USFS uses a factor of 1.32 AUM for cow/calf pairs on Summer Range

Excel serv uses a factor of 1.32 for cow-calf pairs (David Grider, pers. comm, Nov. 2009)

49,480 148,440
~~65,306~~ AUs = 195,919 AUMs / 3 months
 38,589 115,768
 50,932 AUs = 152,797 AUMs / 3 months

Number of steer calves that would be marketable = Allowable animal units / 2*

Number of heifer calves that would be marketable = Allowable animal units / 2*

27,313	54,625	27,313	54,625
36,049 steer calves =	72,097 AUs / 2	36,049 heifer calves =	72,097 AUs / 2
24,740	49,480	24,740	49,480
32,653 steer calves =	65,306 AUs / 2	32,653 heifer calves =	65,306 AUs / 2
19,295	38,589	19,295	38,589
25,466 steer calves =	50,932 AUs / 2	25,466 heifer calves =	50,932 AUs / 2

C. Potential cattle weight gain from "lost" forage biomass

Total pounds of body weight gained by all steer calves = Number of steer calves *

Average body weight gain while on aspen type grazing allotments

2,531,915 27,313
 3,341,742 kg = 36,049 steer calves * 92.7 kg
 2,293,398 24,740
 3,026,933 kg = 32,653 steer calves * 92.7 kg
 1,788,647 19,295
 2,360,698 kg = 25,466 steer calves * 92.7 kg

Total pounds of body weight gained by all heifer calves Number of heifer calves *

Average body weight gain while on aspen type grazing allotments

2,531,915 27,313
 3,341,742 kg = 36,049 heifer calves * 92.7 kg
 2,293,398 24,740
 3,026,933 kg = 32,653 heifer calves * 92.7 kg
 1,788,647 19,295
 2,360,698 kg = 25,466 heifer calves * 92.7 kg

*Assumes a 50:50 sex ratio of males:females

D. Gross revenue from unrealized cattle weight gain

Gross revenue from steer calves = Total pounds of body weight gained by all steer calves

* market price

$$\$7,452,084 = 3,341,742 \text{ kg} * \$2.23/\text{kg}$$

$$\$6,750,060 = 3,026,933 \text{ kg} * \$2.23/\text{kg}$$

$$\$5,264,356 = 2,360,698 \text{ kg} * \$2.23/\text{kg}$$

Re-calculated these using Excel table attached on opposite pg.

Gross revenue from heifer calves = Total pounds of body weight gained by all heifer calves * market price

$$\$6,917,405 = 3,341,742 \text{ kg} * \$2.07/\text{kg}$$

$$\$6,265,751 = 3,026,933 \text{ kg} * \$2.07/\text{kg}$$

$$\$4,886,644 = 2,360,698 \text{ kg} * \$2.07/\text{kg}$$

Total lost gross revenue = Market price of body weight gain by steer calves + heifer calves =

$$\$7,452,084 + \$6,917,405 = \$14,369,489$$

$$\$6,750,060 + \$6,265,751 = \$13,015,811$$

$$\$5,264,356 + \$4,886,644 = \$10,151,000$$

The additional gross revenue generated by lost production due to conifer encroachment

would be ^{10,587,235} \$14,369,489 if there is no current understory biomass production on the

hectares of historic aspen stands. In reality, there is some current level of production. If

this production is 60 or 187 kg /ha, an additional ^{9,861,611} \$13,015,811, or ^{7,691,182} ~~\$10,151,000~~,

respectively, could be generated had the conifer coverage in these hectares remained at $\leq 15\%$.