ASSESSING SUCCESS OF MITIGATION TREATMENTS FOR DEER AND ELK HABITAT IMPACTED BY THE BULL MOUNTAIN PIPELINE

PROJECT UPDATE
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COLORADO PARKS AND WILDLIFE

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ABSTRACT

In 2008, the Colorado Division of Wildlife (now Colorado Parks and Wildlife, CDPW) and Gunnison Energy Corporation began the process of creating big game habitat improvement projects in order to offset negative impacts of the Bull Mountain pipeline in Garfield, Mesa, Delta, and Gunnison Counties, Colorado. The limiting factor for big game in the study area is winter browse. Therefore, two projects were designed to increase the availability and productivity of desirable winter browse species: a 73 ha hydro-ax treatment in the Muddy Creek drainage, completed in October of 2009, and a proposed burn of approximately 187 ha in the Divide Creek drainage. This report summarizes the first two years of vegetation monitoring; three additional years are planned. The productivity and utilization of browse forage was monitored in the following study areas: areas adjacent to the pipeline corridor within elk winter range on the north and south ends of the pipeline (to estimate the impact of pipeline construction), the Muddy Creek hydro-ax treatment area, a control area for the Muddy Creek hydro-ax treatment, the Divide Creek proposed burn area, and a control area for the Divide Creek burn. Five to twenty randomly selected plots were established in each area. Within each plot, bite mark diameters and shoot lengths were measured for a systematic subsample of current-year shoots. Shoots from off-plot locations were sampled, measured, dried and weighed. Species-specific relationships between shoot length or diameter measurements, and shoot productivity and mass removed by browsing were developed. Confidence intervals on treatment effects were obtained by bootstrap replication of the difference between yearly changes in treatment and control areas. From 2009 to 2010, there was no change in the productivity of desirable browse species in the pipeline monitoring plots. The estimated loss of forage due to the pipeline for the south end big game winter range was 712 kg/yr, and for the north end winter range was 2603 kg/yr. In the first year post-treatment, the Muddy Creek hydro-ax treatment caused a reduction in available forage of 2909 kg (90% CI: 365, 5613). This likely occurred because the hydro-ax treatment was implemented in late fall of the prior year, such that the plants had little opportunity to regrow prior to the winter. The Divide Creek burn awaits an appropriate weather window to occur. The lag time evident in this study between designing and realizing benefits from biologically meaningful mitigation treatments highlights the importance of pre-development planning for cost-effective mitigation.

Assessing Success of Mitigation Treatments for Deer and Elk Habitat Impacted by the Bull Mountain Pipeline

Annual Progress Report, April 15, 2009- January 15, 2011

Danielle B. Johnston

PROJECT OBJECTIVES

- Quantify big game winter forage resources lost due to Bull Mountain pipeline construction.
- Quantify amount of big game forage resources created by Muddy Creek hydro-ax treatment.
- Quantify amount of big game forage resources created by Divide Creek burn.
- Assess effectiveness of mitigation by comparing forage resources lost versus created.

SEGMENT OBJECTIVES

- Sample, measure, dry, and weigh at least 30 current-year shoots of preferred browse species. Develop regression equations which relate shoot diameter and length measurements to mass.
- Measure current-year shoot length and diameters for preferred browse species in 64 study plots.
- Assess yearly production and utilization of preferred browse species in plots adjacent to pipeline, and in Muddy Creek hydro-ax area, Muddy Creek control area, Divide Creek burn area, and Divide Creek control area.
- Compare year-to-year changes in each study area by bootstrap replication of yearly changes in plots within each study area.
- Assess effectiveness of hydro-ax treatment by comparing forage changes in treated versus control area.

INTRODUCTION

Actions which offset the impacts of disturbances to wildlife and wildlife habitat are desired by both operators and conservationists. However, designing biologically sound mitigation actions is often difficult, and the effectiveness of a given mitigation action is not easy to assess. A successful mitigation action for a particular wildlife species creates an increase in population offsetting any decrease caused by disturbance, and does so in a way that does not compromise other resources valuable in the ecosystem. A complete assessment of a mitigation action involves quantifying the effects of the disturbance and the mitigation on the population, and indirect effects of both on the ecosystem as a whole. In reality, inherent difficulties in linking specific changes on the landscape to wildlife populations and ecosystem dynamics mean that such assessments are rarely conducted.

Nonetheless, wildlife and wildlife habitats continue to be impacted by developments and mitigation actions continue to be carried out; therefore as much information as possible about the efficacy of these actions needs to be collected. For upland big game species, a critical factor is how disturbances and mitigation actions affect food availability, especially if there are specific food resources that are known to limit to the population. For big game in Colorado, winter forage availability is often the limiting factor in determining populations (Weisberg et al. 2002).

Losses in winter forage for big game often occur following development activities because shrubs, which are an important component of the winter diet, are slow to re-establish. Management actions which improve the availability or palatability of shrubs in the surrounding area are therefore an appropriate mitigation action in this circumstance. This was the approach taken by the Gunnison Energy Corporation (GEC) and Colorado Parks and Wildlife (CDPW) to mitigate impacts of the Bull Mountain pipeline Corridor, constructed in 2008. The Bull Mountain pipeline runs through Garfield, Mesa, Delta, and Gunnison counties in western Colorado, and crosses critical big game winter ranges near both its southern and northern ends (Figure 1). Two mitigation projects, one near each end of the pipeline, were designed in co-operation with the US Forest Service to offset impacts to winter ranges (Figure 1). In the Muddy Creek basin near the southern end of the pipeline, a mechanical mitigation treatment (hydro-ax) was carried out in October of 2009 (Figure 1). The mechanical treatment consisted of mulching the aboveground growth of Gambel's oak (*Quercus gambelii* Nutt.) and Saskatoon serviceberry [*Amelanchier alnifolia* (Nutt.) Nutt. Ex M. Roern.] in a mosaic pattern over 73 ha (180 acres).   Both Gambel's oak and serviceberry are known to vigorously resprout from the roots, and the regrowth is generally more palatable and available than is mature growth. Near the northern end of the pipeline, a burning treatment was proposed (Figure 1). This burn has not yet taken place because a favorable weather window for conducting the burn has not yet occurred. The rationale for the burn is similar to that of the mechanical treatment: to improve the availability and palatability of species such as Gambel's oak and serviceberry.

Plots in undisturbed habitat adjacent to the pipeline corridor were used to estimate the loss of forage due to pipeline construction. Plots within treatment areas and nearby control areas were used to assess the benefit of treatments. The approach used is to assess both the productivity of shrub forage and, by examining bite marks, the consumption of this forage. Assessing consumption is important because the usefulness of a food resource varies over space, depending on snow depth, slope, and proximity to game trails.

In order to maximize useful information with the existing budget, not every study area is monitored in every year. Table 1 summarizes the areas monitored in 2009- 2011. The objective of this report is to provide an update on the monitoring of pipeline impacts and the mitigation treatments, and contains results from the 2009 and 2010 monitoring efforts.

STUDY AREA

The Bull Mountain pipeline is 41 km long. The northern end of the pipeline intersects big game winter range for approximately 18 km, the northernmost 6 km of which occurs on private, primarily agricultural land and was excluded from this study. The remaining 12 km stretch of pipeline, as well as the Divide Creek burn and control areas (Figure 1) comprise the northern end study zone, which varies in elevation from 2100 to 2500 m.   Mean annual precipitation varies with elevation from ~480 to ~690 mm. The area is dominated by Saskatoon serviceberry, Gambel Oak, big sagebrush, and chokecherry, with an understory of *Poa* sp., *Erigeron* sp., *Achillia millefolium,* and *Mahonia repens.*

The southern end of the pipeline intersects big game winter range for approximately 9 km (Figure 1). This area was well as the Muddy Creek hydro-ax and control areas comprise the southern end study zone, which varies in elevation from 2240 to 2550 m. Mean annual precipitation varies with elevation from ~480 to ~640 mm. The area is dominated by Gambel Oak, mountain snowberry (*Symphoricarpos oreophilus* A. Gray), Saskatoon serviceberry, big sagebrush (*Artemisia tridentata* Nutt.) and apsen, with an understory dominated by *Poa* sp., *Phleum pratense, Hymenoxys hoopesii, Achillia millefolium, Linum lewesii,* and *Erigeron* sp.

METHODS

Six types of sites along the pipeline were selected to study: areas adjacent to the pipeline corridor within elk winter range on the north and south ends of the pipeline (to estimate the impact of pipeline construction), the Muddy Creek hydro-ax treatment area, a control area for the Muddy Creek hydro-ax treatment, the Divide Creek proposed burn area, and a control area for the Divide Creek burn. Plots within each area were selected using a spatially balanced random sample, which ensured that plots were spread evenly within each study site. The number of plots varied with the size of the area (Table 1). Plots were permanently marked and locations recorded with GPS. Two transects were established in each plot: one extending due north, and another due east (Figure 2). In 2009, the transect length used was 30m. Preliminary analysis revealed that sufficient data could be collected using transects of 15 m in length. Therefore, the transect length was shorted to 15 m in 2010 and only data taken from within 15 m of the transect origin was analyzed from the 2009 data. Along each transect, line-intercept cover values were recorded to the nearest cm for all shrub and tree species. Photographs were taken from the ends of each transect facing the origin.

Detailed measurements on availability and consumption of desirable browse species were made within 1 m^2 subplots located every 5 m along the transects (Figure 2). Six subplots per plot were measured. All data was collected in early spring, before plants leafed out for the growing season. Productivity measurements therefore reflect the prior summer's growth, and utilization measurements reflect the prior winter's consumption of this growth.

Desirable browse species in the study areas included Gambel Oak, Saskatoon serviceberry, mountain mahogany (*Cercocarpus montanus* Raf.), chokecherry (*Prunus virginiana* L.), currant (*Ribes inerme* Rydb.), Rocky Mountain maple (*Acer glabrum* Torr.), and aspen (*Populus tremuloides* Michx.). Within each subplot, we quantified production of shoots of the current year, which are recognizable because they are flexible, have a bud scar at their base, and usually do not branch. Shoots were included in the subplot if they originated 2 m or less from the ground surface. A subsample of available shoots was selected for measurement using an unbiased protocol which simultaneously provides a count of browsed and unbrowsed shoots (Bilyeu et al. 2007). If a shoot was unbrowsed, its length was recorded. If a shoot was browsed, both shoot basal diameter and diameter at the browse point were recorded. If bite marks into older wood occurred, indicating that a current-year shoot had been entirely consumed, that was noted and a diameter measurement was taken at the bite mark.

These measurements were used to estimate shoot productivity and mass of tissue removed by browsing. This required developing allometric relationships between the measurements taken and mass. We quantified the following relationships for each species: Predicted mass removed from bite mark diameter (when bite occurs within a shoot of the current year), predicted shoot productivity from shoot length, predicted shoot productivity from shoot bud scar diameter, predicted mass removed from bite mark diameter (when bite occurs in wood older than one year), and predicted shoot productivity from bite mark diameter (when bite occurs in wood older than one year). To quantify these relationships, we sampled, measured, dried, and weighed 40-150 samples of each species. For details on the development of these allometric relationships, see Appendix A.

To calculate productivity per subplot, we multiplied average shoot weight by the total number of shoots in the subplot. To estimate utilization, we multiplied the average of the estimated mass of tissue removed by each bite by the total number of bites taken in the subplot. Subplot values were then averaged to the plot level. All calculations were done individually for each browse species, and then total plot browse productivity and utilization were summed over species.

Mean productivity and utilization of desirable browse species in each area of interest (pipeline north end, Divide Creek burn area, Divide Creek control area, pipeline south end, Muddy Creek hydro-ax area, and Muddy Creek control area) was determined for each measurement year. Sampling error was estimated as the standard deviation of 1000 bootstrap samples of plot values within each area. 95% confidence intervals on year-to-year differences within areas were determined by calculating the differences in productivity and utilization between years for each plot, and then using the percentile method on these differences with 10,000 bootstrap samples. The effect of the hydro-ax treatment was analyzed by comparing the year-to-year changes in the treatment versus the control area. A 90% confidence interval on the difference between treatment and control area year-to-year changes was calculated using the percentile method on the difference between the yearly differences of treatment and control areas with 10,000 bootstrap samples (Efron and Tibshirani 1993).

Throughout the Results, the year "2009" will refer to browse available or consumed over the winter of 2008-09, while "2010" will refer to browse available or consumed over the winter of 2009-10.

RESULTS

South zone

There was no detectable change in the productivity of desirable browse species from 2009 to 2010 in the Pipeline South End or Muddy Creek control areas (Figure 3). There was a reduction in the productivity of desirable browse species from 2009 to 2010 in the Muddy Creek hydro-ax area of 3.5 g/m^2 (95% CI: 0.94, 6.23; Figure 3). Comparison of 2009 versus 2010 values for the Muddy Creek control area versus Muddy Creek hydro-ax area reveals a hydro-ax effect of -4.0 g/m^2 (90% CI: -7.7, -0.5).

There was no change in the utilization of desirable browse species from 2009 to 2010 in the Pipeline South End or Muddy Creek control area sites. In the Muddy Creek hydro-ax area, utilization fell by 0.15 g/m^2 (95% CI: 0.0, 0.42; Figure 4).

The average productivity of desirable browse species in the Pipeline South End area over 2009 and 2010 was 2.5 g/m^2, and the area of pipeline intersecting big game winter range on the south end was 27.2 ha. Therefore, the estimated forage lost due to the pipeline on the south end is 725 kg per year (Table 2).

North zone

There was no change in the productivity of desirable browse species from 2009 to 2010 in the Pipeline North End area (Figure 5). Productivity values for the Divide Creek burn area and Divide Creek control area in 2010 are also included in Figure 5.

In the Pipeline North end area, utilization fell from 2009 to 2010 by 3.7 g/m^2 (95% CI: 0.86, 8.41; Figure 6). Utilization rates for the Divide Creek burn area and the Divide Creek control area in 2010 are also included in Figure 6.

The average productivity of desirable browse species in the Pipeline North End area over 2009 and 2010 was 7.3 g/m^2, and the area of pipeline intersecting public land big game winter range on the north end was 34.3 ha (Table 2).. The estimated forage lost due to the pipeline on the north end is 2603 kg per year.

The species composition of desirable browse species productivity and utilization are given in Appendix B.

DISCUSSION

The productivity and utilization of desirable browse species in the Muddy Creek hydro-ax area fell in the first year following treatment, but did not fall in control or pipeline areas. The hydro-ax treatment was implemented in October of 2009; therefore the plants had little opportunity to regrow prior to the winter. This caused the initial impact of the treatment on big game winter forage to be negative. The Divide Creek burn has yet to occur, because the appropriate and safe conditions for burning have not yet been met.

Two years following pipeline impacts, beneficial mitigation has yet to occur; the balance sheet comparing forage losses and gains remains negative (Table 2). In future years, this will likely change as the hydro-axed plants regrow and the Divide Creek area is burned and regrows. Nonetheless, we can expect a minimum lag time of 3 to 5 years between pipeline construction and mitigation benefit.

While forage production was consistent from year to year in the areas adjacent to the pipeline corridor, utilization of forage in the North zone was 5-fold lower in the winter of 2009-10 than in 2008-9 (Figure 6). In the winter of 2009-10, dense elk herds were noted in the lowest elevation portions of the winter range, probably because early snows prevented use of the slopes comprising the study area (Will Spence, District Wildlife Manager, *personal communication*). This illustrates that forage productivity in a given area may benefit big game only sporadically, as game utilize different areas in different years depending on weather conditions.

The difficulties inherent in designing and carrying out biologically appropriate mitigation treatments are apparent in this project. The comparison of forage losses and gains used here is illustrative, but it is also incomplete in that it ignores indirect impacts on wildlife, which often exceed the direct effects (Sawyer et al. 2009). In the case of the Bull Mountain pipeline, the indirect effect of disturbance was greatest during pipeline construction. In order to efficiently offset this, mitigation treatments would have needed to be in place prior to pipeline construction. Preventing an impact to a population is preferable to augmenting the population following a decline, because it circumvents swings in populations which can be detrimental to other aspects of the ecosystem.

Several lessons may be taken from this project in order to produce more cost-effective mitigation in the future. Firstly, it is imperative to design, and if possible, implement mitigation *prior* to creating impacts. While CDPW recognizes that the energy industry is extremely volatile, making such long-range planning difficult, assessing the potential for effective mitigation should be part of the initial planning of the development of new oil and gas fields. Secondly, the requirement that mitigation projects be in the immediate vicinity of impacts should be relaxed. In the case of big game, populations have large ranges, which may afford flexibility in where mitigation occurs. This flexibility must be utilized if effective mitigation is to take place; an added benefit of more dispersed mitigation is that operators need not reveal any detail about their development plans to potential competitors. Lastly, this project illustrates the benefit of monitoring in order to assess the effectiveness of mitigation and thereby design better mitigation in the future. All parties involved desire to see mitigation dollars used as cost-effectively as possible. By collaborating willingly and openly early in the development process, such as through a comprehensive development plan process, operators and regulators can achieve this goal.

FUTURE WORK

As of fall 2010, approximately $108k of the $130k directly allocated to CDPW for monitoring remained. This amount is sufficient to cover monitoring for three to four additional years, which will allow enough time to monitor benefits of treatments as plants regrow. For the Divide Creek burn and control areas, baseline data will be collected every other year, rather than every year, until the burn occurs, in order to save funding for post-burn monitoring. The total yearly forage balance sheet will be updated following each monitoring year.

ACKNOWLEDGEMENTS

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TABLES

Table 1. Monitoring plan for the six study areas.

Area	Number of plots sampled	Monitored in 2009	Monitored in 2010	To be monitored in 2011	Treatment date
Pipeline - N end winter range	9	YES	YES	YES	n/a
Divide Creek burn area	20	NO	YES	NO	Yet to occur
Divide Creek control area	15	NO	YES	NO	n/a
Pipeline - S end winter range	8	YES	YES	YES	n/a
Muddy Creek hydro-ax area	5	YES	YES	YES	October 2009
Muddy Creek control area	7	YES	YES	YES	n/a

Table 2. Balance sheet of winter forage losses or gains due to pipeline construction and mitigation treatments.

		2009		2010	
pipeline or mitigation Area	**Size of area (ha)***	**Browse lost or gained (g/m2)**	**Browse lost or gained (kg)**	**Browse lost or gained (g/m2)**	**Browse lost or gained (kg)**
Pipeline N end winter range	34.3†	-8.15	-2795.5	-7.03	-2411.3
Divide Creek Burn	187.4	0	0	0	0
North zone total		-8.15	-2795.5	-7.03	-2411.3
Pipeline S end winter range	27.2	-2.62	-712.6	-2.71	-737.1
Muddy Creek hydro-ax treatment	72.9	0	0	-3.99	-2908.7
South zone total		-2.62	-712.6	-6.7	-3645.8
			2009		**2010**
		OVERALL TOTALS (kg)	-3508.1		-6057.1

*Areas impacted by the pipeline are calculated based on a pipeline corridor width of 30 m.

†For the area impacted by the pipeline on the northern end, the northernmost 6.3 km (totaling 18.9 ha) was excluded from these calculations, as this portion of the pipeline occurred on private land and was not sampled.

FIGURES

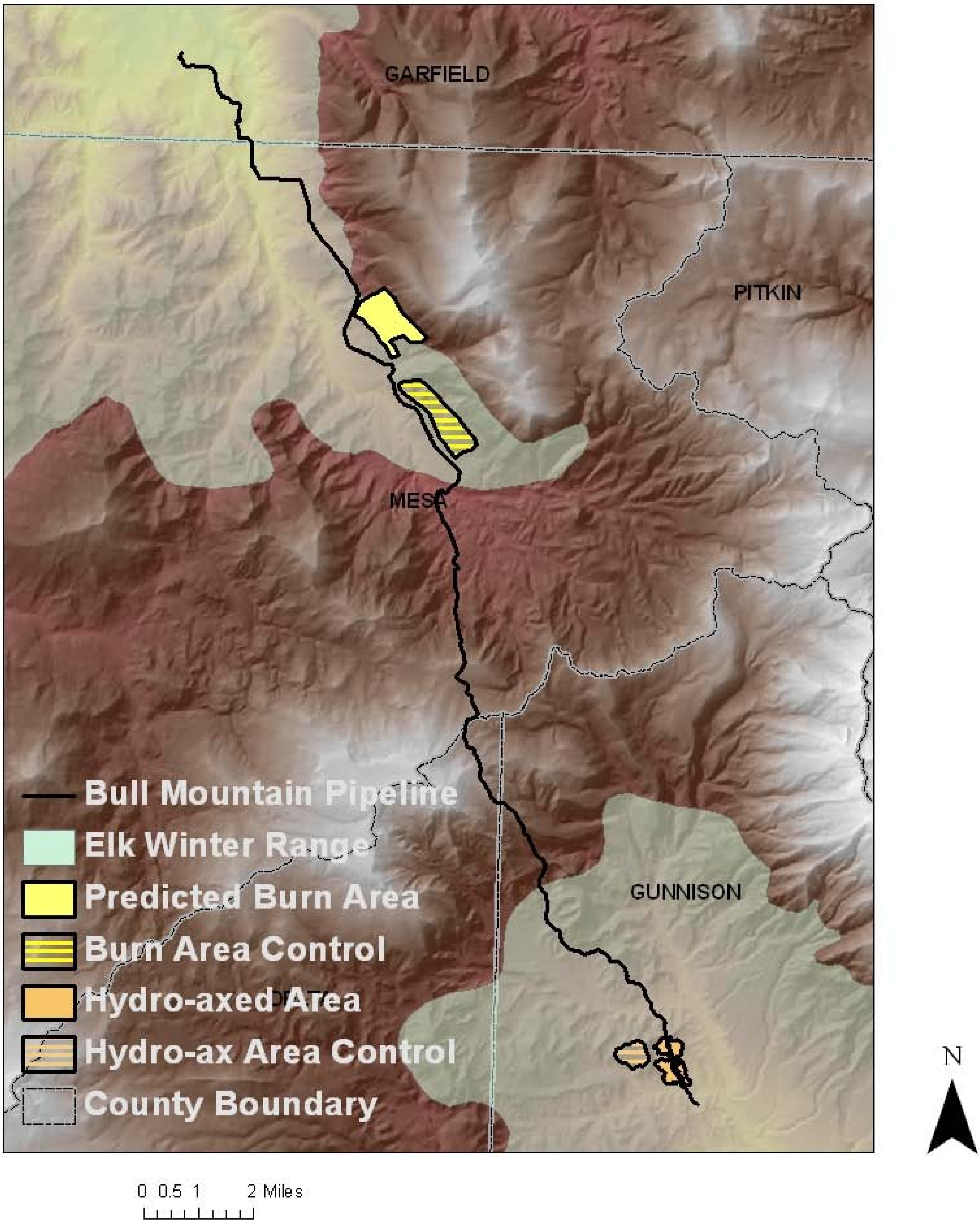


Figure 1. Overview of pipeline and mitigation areas. The burn area indicated is the highest-priority subset of planned burns for Divide Creek.

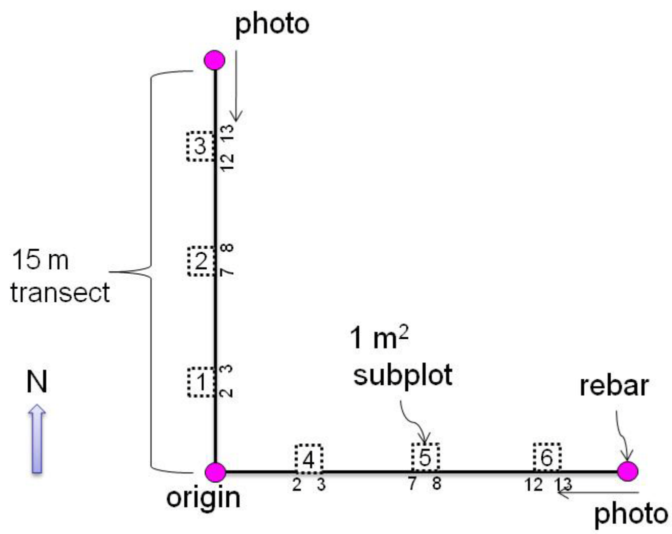


Figure 2. Layout of monitoring plots. Cover values for all shrub and tree species were recorded along each transect. Detailed measurements on availability and consumption of desirable browse species were made at six 1 m^2 subplots every 5 m along the transects.

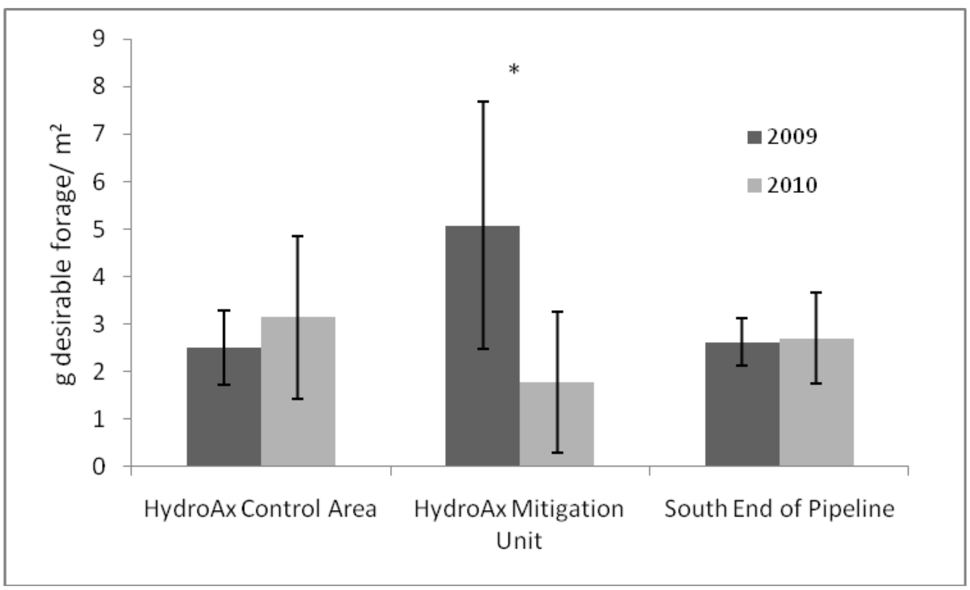


Figure 3. Productivity of desirable browse in the southern study zone. Error bars are the standard deviation for 1000 bootstrap samples. Star denotes a significant difference between measurement years at $\alpha = 0.05$.

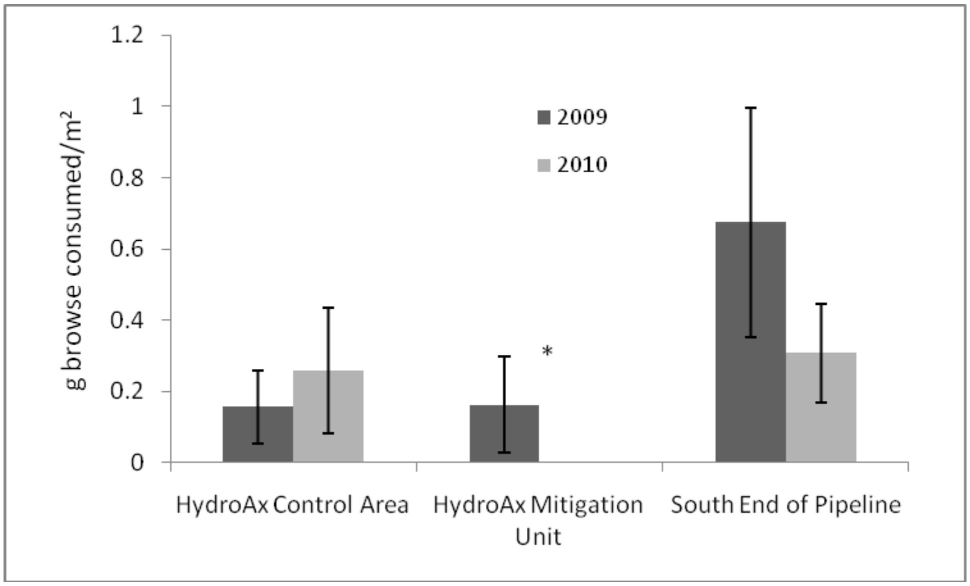


Figure 4. Utilization of desirable browse in the southern study zone. Error bars are the standard deviation for 1000 bootstrap samples. Star denotes a significant difference between measurement years at $\alpha = 0.05$.

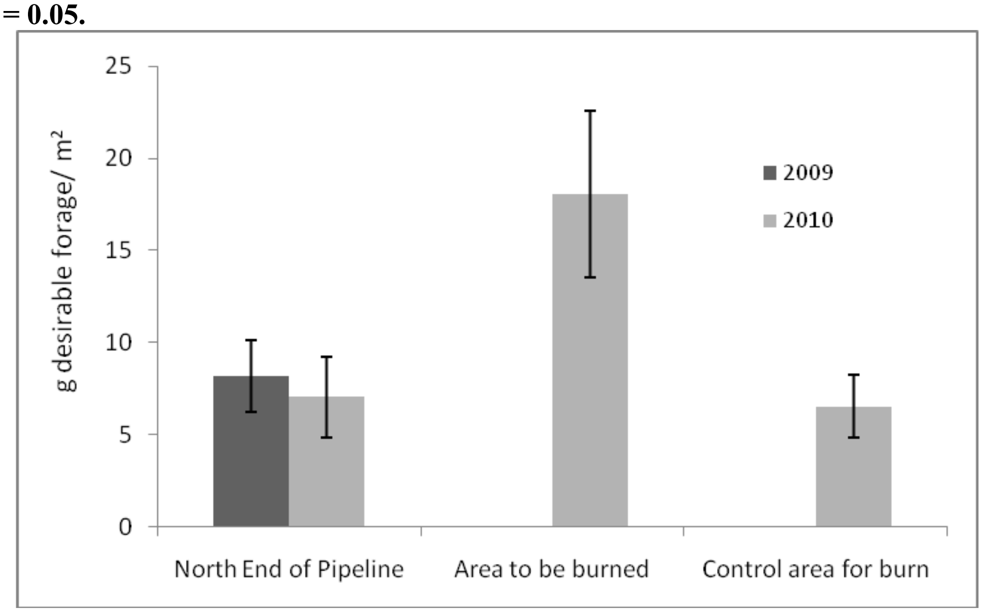


Figure 5. Productivity of desirable browse in study areas in the northern study zone. Error bars are the standard deviation for 1000 bootstrap samples.

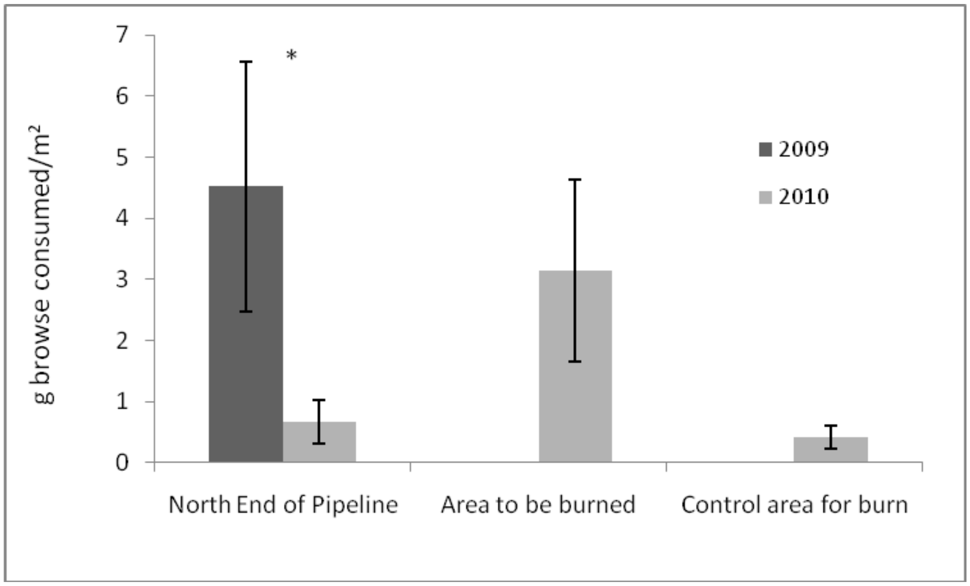


Figure 6. Utilization of desirable browse in study areas in the northern study zone. Error bars are the standard deviation for 1000 bootstrap samples. Star denotes a significant difference between measurement years at $\alpha = 0.05$.

APPENDIX A: DEVELOPMENT OF ALLOMTERIC RELATIONSHIPS

All samples for development of allometric relationships were taken from off-plot locations. Samples were clipped at a point basal of the bud scar of a focal current year shoot. Three diameter measurements were recorded immediately in the field: 1. The diameter at the point clipped (called here the “old wood diameter”); 2. Shoot basal diameter of the focal shoot; and 3. A third diameter within the focal shoot, apical of the bud scar (called here the “top cut diameter”; Figure A1). In the lab, a length measurement was taken for each shoot from bud scar to tip, and the sample was dried at 105° C for 36 h. The sample was weighed in three portions: 1. Portion basal of the shoot basal diameter (the wood older than one year); 2. Portion between the basal diameter and the top cut diameter; and 3. Portion between the top cut diameter and the shoot tip (Figure A1). The relationship between the weight of Portion 3 and the top cut diameter was used to estimate mass removed when a bite occurs within a shoot of the current year. The relationship between the weight of Portion 2 + Portion 3 and shoot length was used to estimate the productivity of the current-year shoot when the shoot was not browsed. The relationship between the weight of Portion 2 + Portion 3 and the bud scar diameter was used to estimate the productivity of the current-year shoot when the shoot was browsed (and a length measurement is therefore not available). The relationship between the weight of Portion 1+ Portion 2 + Portion 3 and the old-wood diameter was used to estimate mass removed when a bite occurred in wood older than one year. The relationship between the weight of Portion 1+ Portion 2 and the old-wood diameter was used to estimate productivity of the current-year shoot when a bite occurred in wood older than one year. Regression relationships were determined using SAS PROC GLM. Some variables required transformations to achieve linearity and homogeneity of variance. A summary of the transformations used, R^2 values, and regression parameters is provided in Table A1.

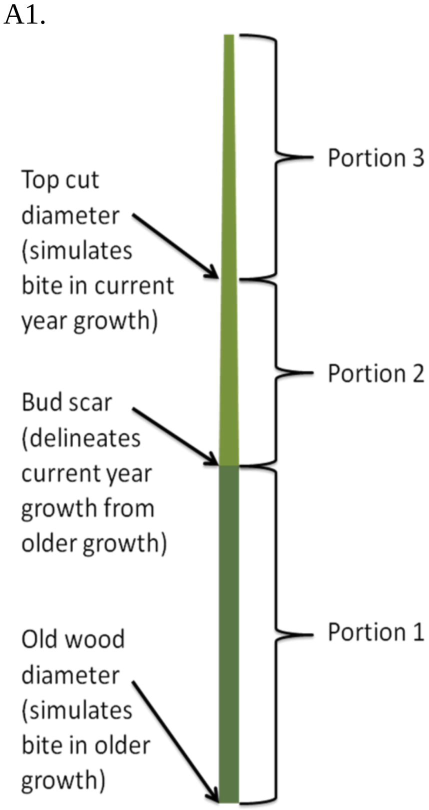


Figure A1. Terminology used in developing shoot regressions.

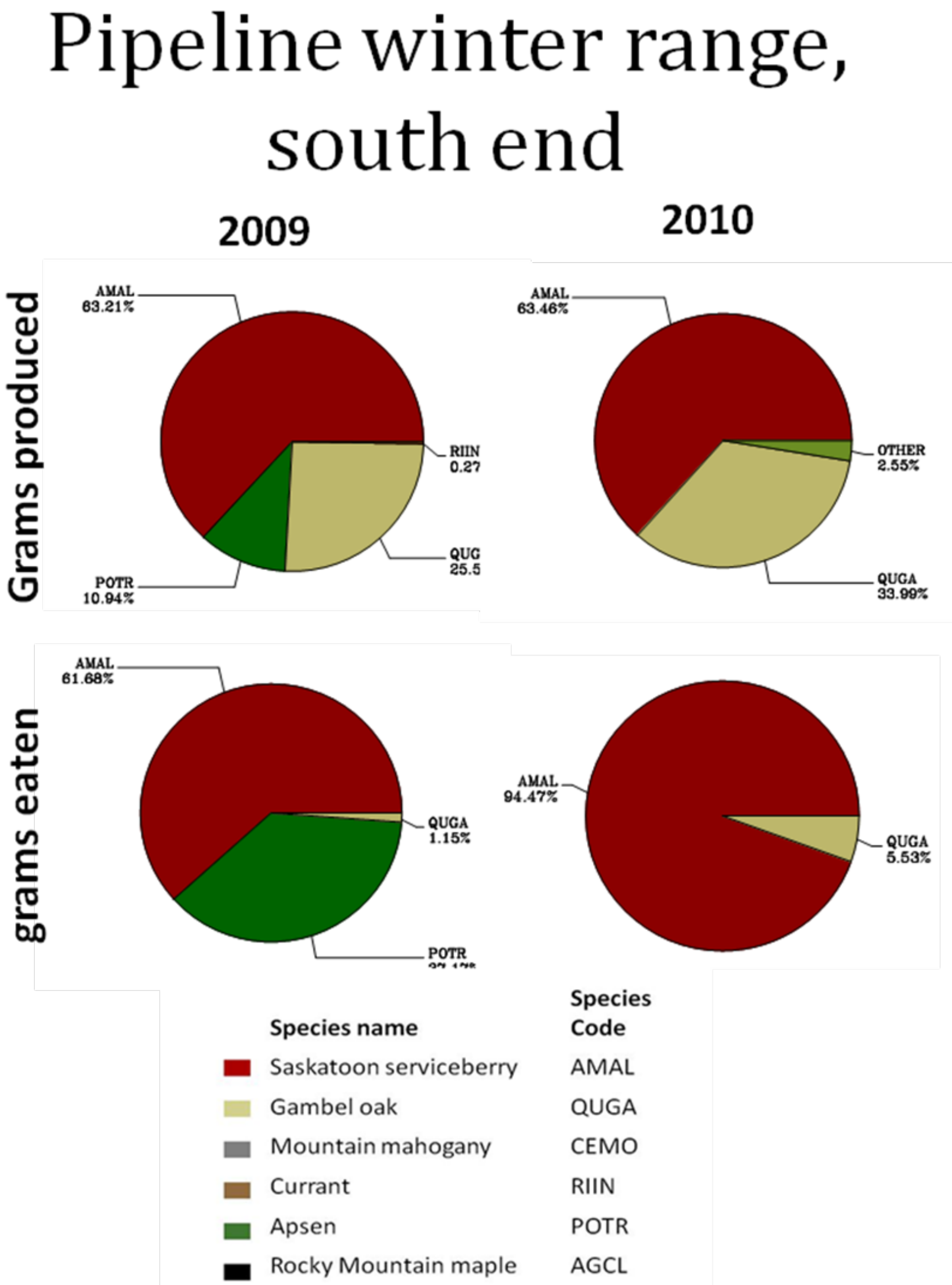
Table A1. Allometric equations for predicting browse consumed and utilized from shoot measurements.

Species	Mass fraction predicted (g)	Predictor variable: length (cm) or diameter (mm)	Equation	Linear parameters: slope	Linear parameters: intercept	R^2
Rocky Mountain Maple (n = 50)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-4.99	3.73	71
	Portion 2 + Portion3	shoot length	$\exp\left[m*\log(length)+b\right]$	-4.92	1.28	77
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.72	0.79	69
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.44	0.76	71
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.53	0.7	62
Saskatoon serviceberry (n = 150)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-4.24	2.76	33
	Portion 2 + Portion3	shoot length	$\exp\left[m*(length)+b\right]-0.25$	-1.31	0.052	89
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.71	0.81	86
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.4	0.73	85
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.62	0.73	79
mountain mahogany (n =45)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-4.14	2.25	20
	Portion 2 + Portion3	shoot length	$\exp\left[m*(length)+b\right]-0.25$	-1.33	0.052	91
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.51	0.79	64
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.15	0.62	64
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.31	0.6	56
quaking aspen (n = 120)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-4.99	3.76	67
	Portion 2 + Portion3	shoot length	$\exp\left[m*(length)+b\right]-0.25$	-1.28	0.05	88
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.32	0.63	90
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.11	0.6	85
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.11	0.53	88
chokecherry (n = 55)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-3.31	1.58	49
	Portion 2 + Portion3	shoot length	$\exp\left[m*\log(length)+b\right]$	-4.29	1.37	88
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.46	0.66	65
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.27	0.61	67
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.44	0.62	62
Gambel oak (n = 150)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-4.3	2.62	61
	Portion 2 + Portion3	shoot length	$\exp\left[m*(length)+b\right]-0.25$	-1.04	0.059	76
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.41	0.64	80
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.06	0.61	77

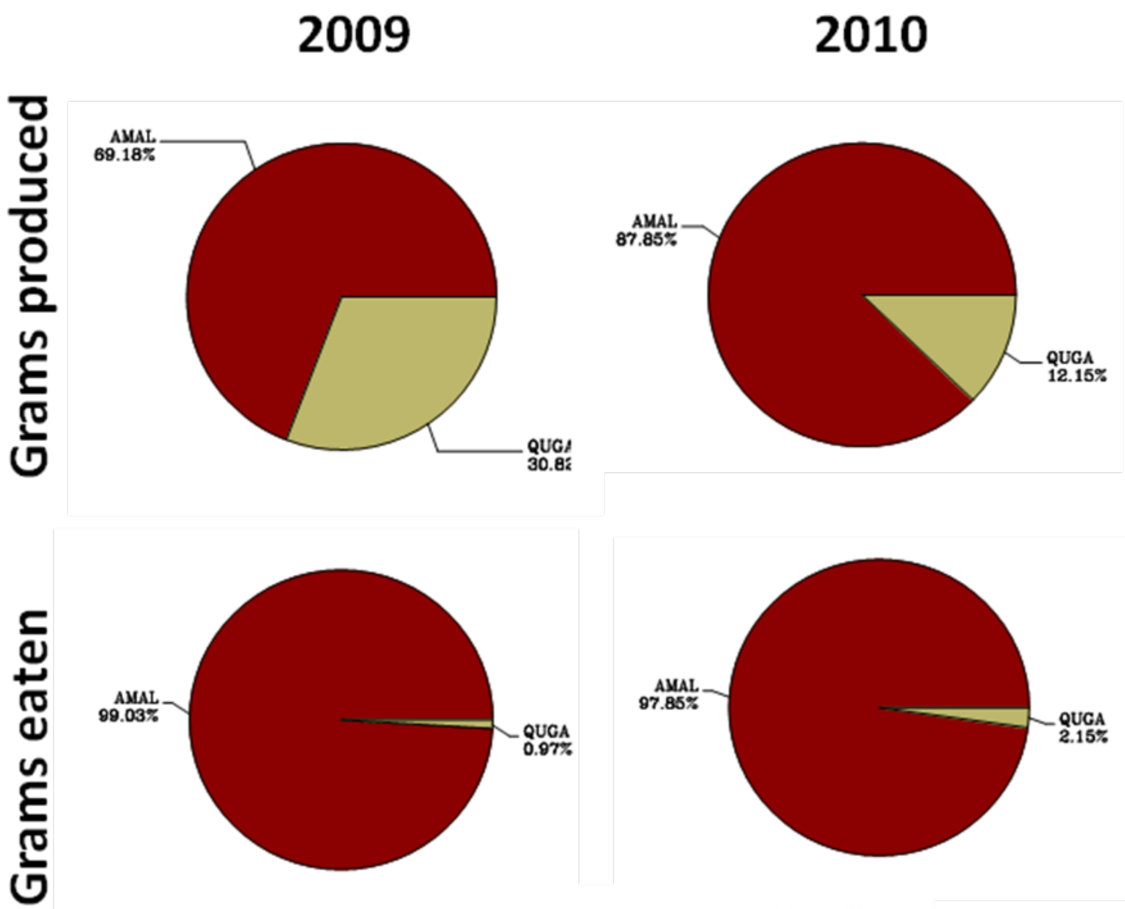
Table A1. Allometric equations for predicting browse consumed and utilized from shoot measurements.

Species	Mass fraction predicted (g)	Predictor variable: length (cm) or diameter (mm)	Equation	Linear parameters: slope	intercept	R^2
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.24	0.55	69
currant (n = 40)	Portion 3	top cut diameter	$\exp\left[m*\log(top\_cut\_diam)+b\right]$	-3.45	1.29	34
	Portion 2 + Portion3	shoot length	$\exp\left[m*(length)+b\right]-0.25$	-1.45	0.047	83
	Portion 2 + Portion3	bud scar diameter	$\exp\left[m*(bud\_scar\_diam)+b\right]-0.15$	-2.21	0.62	72
	Portion 1 + Portion 2 + Portion3	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2	0.56	70
	Portion 1 + Portion 2	old-wood diameter	$\exp\left[m*(old\_wood\_diam)+b\right]-0.15$	-2.14	0.53	65

APPENDIX B: SPECIES COMPOSITION OF BROWSE PRODUCED AND UTILIZED IN THE STUDY AREAS

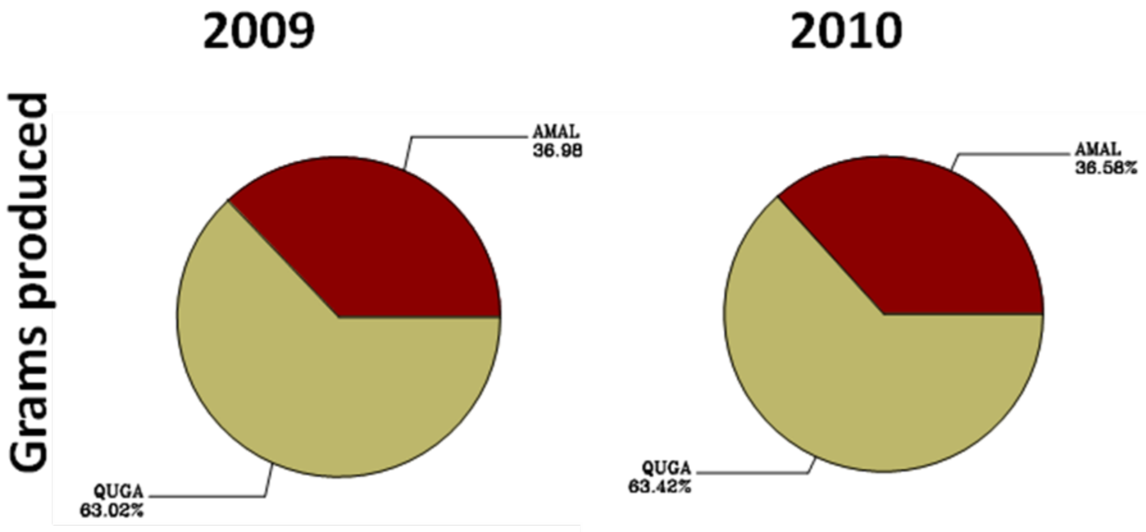


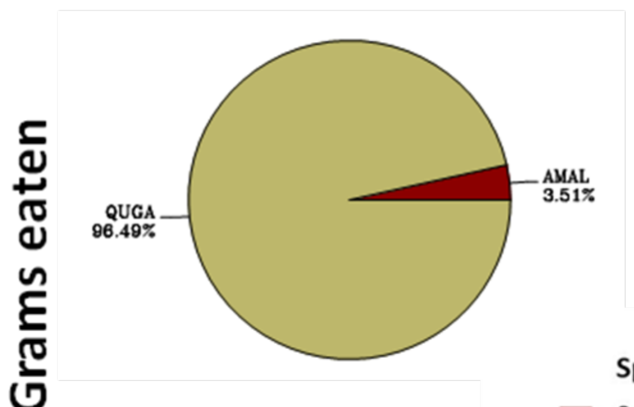
Muddy Creek hydro-ax control area



Species name	Species Code
Saskatoon serviceberry	AMAL
Gambel oak	QUGA
Mountain mahogany	CEMO
Currant	RIIN
Apsen	POTR
Rocky Mountain maple	AGCL

Muddy Creek hydro-ax treatment area

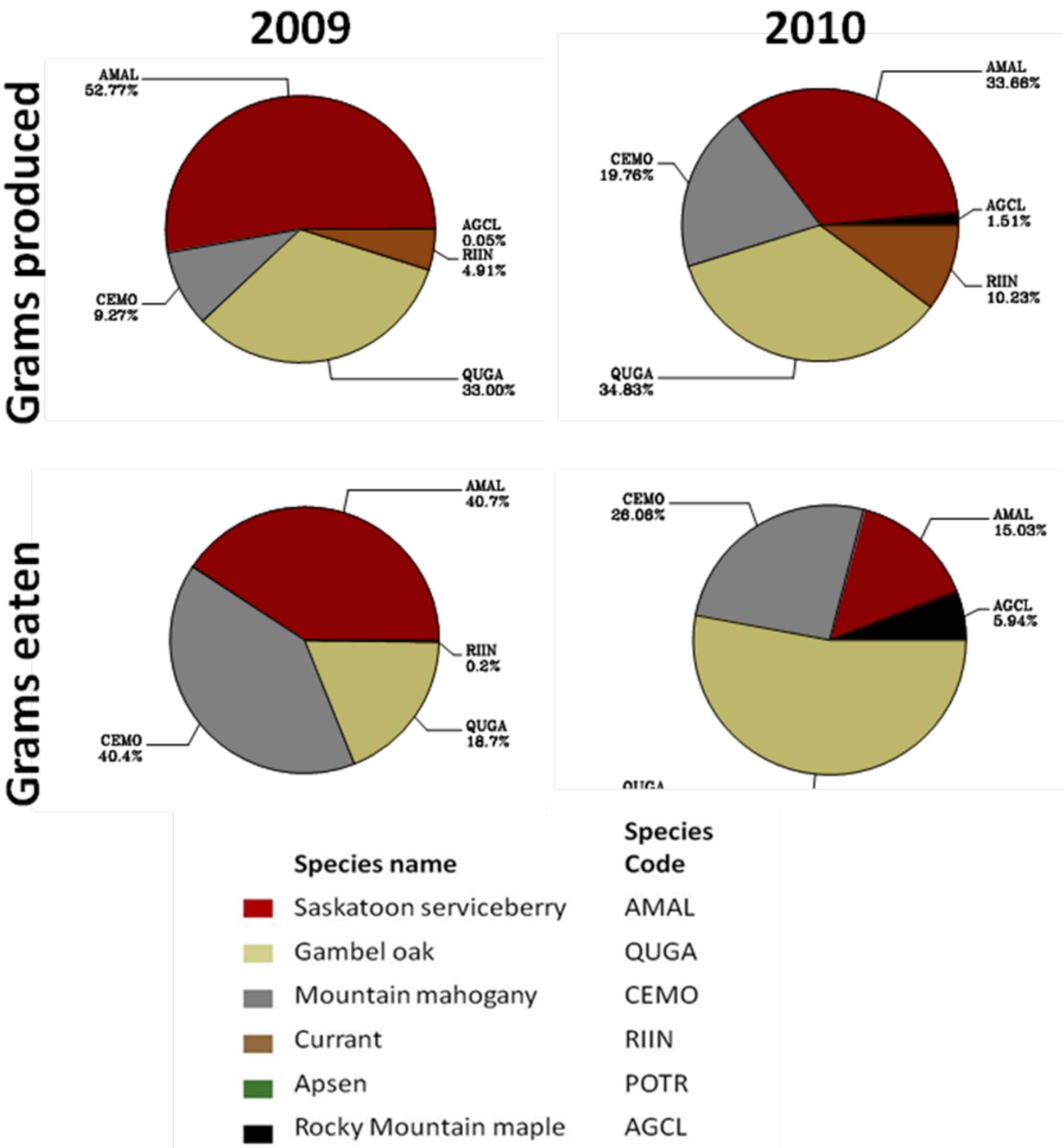




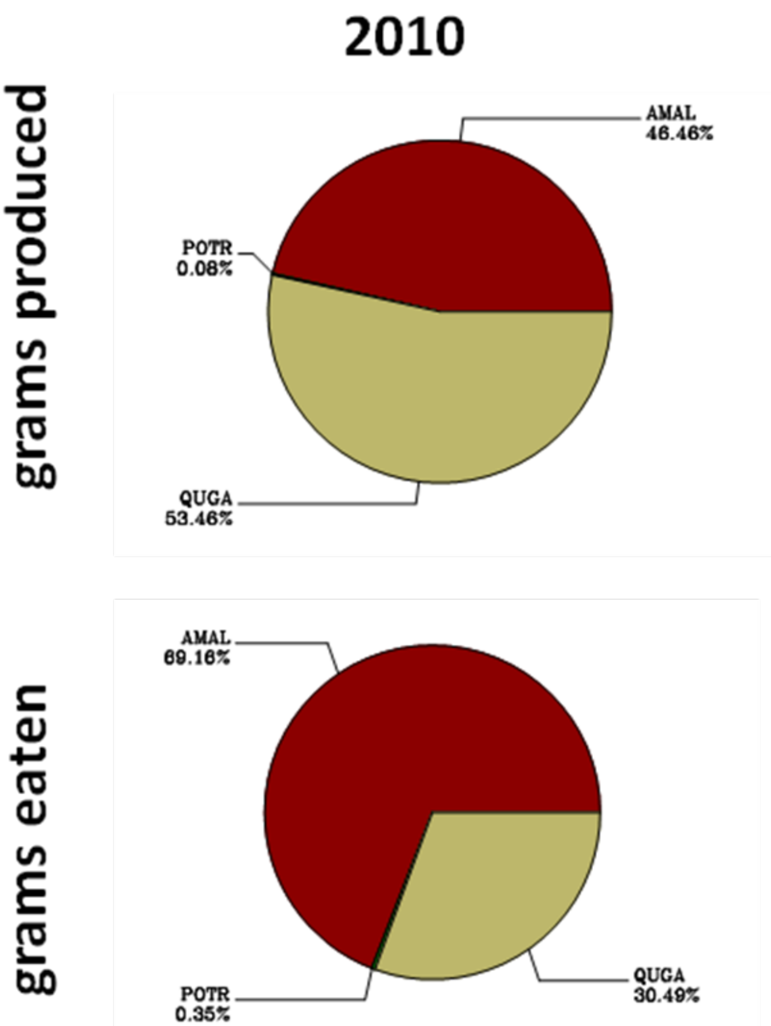
* No plots received any utilization in 2010

Species name	Species Code
Saskatoon serviceberry	AMAL
Gambel oak	QUGA
Mountain mahogany	CEMO
Currant	RIIN
Apsen	POTR
Rocky Mountain maple	AGCL

Pipeline winter range, north end



Divide Creek burn area

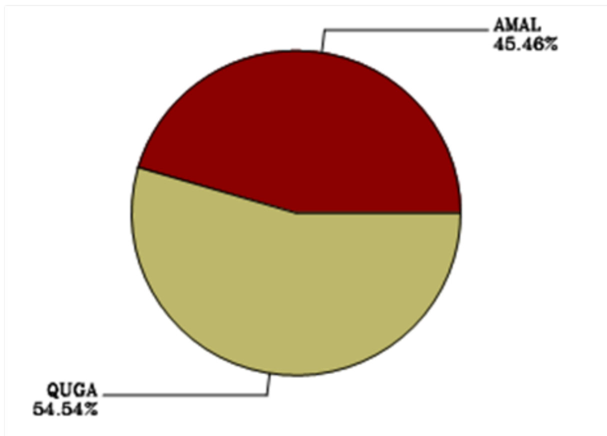


Species name	Species Code
Saskatoon serviceberry	AMAL
Gambel oak	QUGA
Mountain mahogany	CEMO
Currant	RIIN
Apsen	POTR
Rocky Mountain maple	AGCL

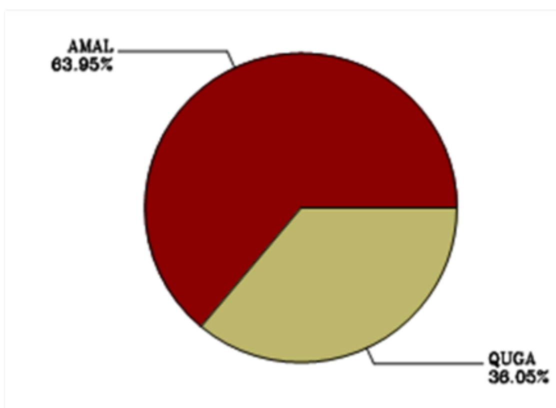
Divide Creek control area

2010

Grams produced



Grams eaten



	Species name	Species Code
■	Saskatoon serviceberry	AMAL
■	Gambel oak	QUGA
■	Mountain mahogany	CEMO
■	Currant	RIIN
■	Apsen	POTR
■	Rocky Mountain maple	AGCL