ASSESSING THE FEASIBILITY OF DEVELOPING TECHNICAL STANDARDS TO EVALUATE REVEGETATION SUCCESS AT COAL MINES IN THE SOUTHERN POWDER RIVER BASIN OF WYOMING[1]

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Abstract. Interest in using technical standards to evaluate revegetation success, specifically for cover, production, and diversity parameters, at coal mines is increasing. To help evaluate the feasibility of developing such standards in Wyoming, a vegetation database was established for five mines in the Southern Powder River Basin. The baseline vegetation data for these mines comprised fifteen data sets (individual studies), and within these sets, the data were separated into five major and six minor standardized plant communities. Baseline data were collected during twelve years from 1978 through 1999, although not all standardized plant communities were sampled in each of those twelve years. In the two predominant plant communities, Mixed Grass Prairie (MGP) and Big Sagebrush Shrubland (BSS), statistical evaluations of the data sets revealed two important considerations. First, for cover data, the results are statistically different between quadrat and point-transect sampling methods. Second, herbaceous species production data can be correlated with precipitation over a relatively small area (e.g., an individual mine), but the influence of other factors, such as sampling methodology, preclude correlations over larger areas. Production data could not be correlated with Palmer Drought Indices, and cover data could not be correlated with either climate factor. The statistical evaluations also indicated significant differences between the data sets and between the mines. Based on all the evaluations of the available data, calculation of a regional data technical standard using detailed statistical methods may be difficult. While a simple approach, such as selection of a conservative number (e.g., the highest mean production value) might be considered, calculation of cover and production standards on an individual mine basis is considered feasible.

Additional Key Words: Database, ANOVA, Regression analysis, Non-parametric statistical evaluation, Baseline vegetation

Introduction

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1 Paper presented at the 2003 Joint Billings Land Reclamation Symposium and the National meeting of the American Society for Mining and Reclamation. Billings, MT, June 3-6, 2003. Pub. by ASMR 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2003 pp 1350-1380

DOI: 10.21000/JASMR03011350

https://doi.org/10.21000/JASMR03011350

The approved options currently available to Wyoming coal mine operators for evaluating revegetation success for cover and production depend upon comparison of contemporaneous data from a reclaimed area and a designated, undisturbed area. The Wyoming Department of Environmental Quality-Land Quality Division (WDEQ-LQD) Coal Rules and Regulations (R&R) define these undisturbed areas as control areas, comparison areas, reference areas, and/or extended reference areas. While the WDEQ-LQD R&R allow for the use of "...an alternative success standard approved by the Administrator..." (Chapter 4, Section 2.(d)(x))(2002(a)), the Federal Office of Surface Mining interpretation would require rule making to include technical standards as an option. The WDEQ-LQD has initiated this process.

Reliance on undisturbed areas for bond release comparisons can pose potential risks. Protection of these areas from energy development disturbance is becoming more difficult, due to rapidly changing mine plans and activities beyond many mine operators' control (e.g., installation of pipelines, transmission lines, and coal bed methane related activities). Grazing practices and rangeland fires can also affect these areas.

Selection of undisturbed areas can be complicated for rare or unique communities (e.g., playas), if undisturbed acreage is limited and/or located outside an operator's control. In addition, some broadly defined vegetation communities may vary significantly in terms of production, structure, or species diversity, from one corner of a permit area to another, especially considering coal mine permit areas may exceed 20,000 acres. If an operator uses a relatively small undisturbed area for revegetation bond release comparison, the resulting cover and production requirements may not represent the range in the cover and production in the vegetation communities disturbed by mining.

In addition to potential natural and human-caused impacts, many operators want to limit the level of uncertainty when attempting to meet vegetation bond release standards. Generally, reclaimed vegetation communities are more homogeneous and less structurally complex than native communities. Due to these differences, native and reclaimed communities may not respond similarly to environmental and climatological conditions, possibly making it more difficult for the reclaimed community vegetation to meet the bond release standards of the designated undisturbed community. The Introduction to Section 19.8 of the New Mexico Administrative Code (1999) discusses other difficulties associated with establishing reclamation standards in arid regions (e.g., slow development of climax vegetation communities).

To examine the differences in vegetation characteristics among mines and the feasibility of measuring revegetation success without direct comparison of reclaimed and undisturbed areas, the WDEQ-LQD began evaluation of two concepts:

- Creation of a comprehensive vegetation database using the mines' baseline vegetation data; and
- Assessment of the accumulated baseline vegetation data to determine the feasibility of developing technical standards for evaluating revegetation success for cover and production.

Methods

Database History

Impetus to examine the use of technical standards to evaluate cover and production data began in 1986 when the WDEQ-LQD initiated a project to summarize and standardize vegetation communities in the Powder River Basin, primarily for bentonite mines (WDEQ-LQD, 1987 and Keammerer, 1987). At the same time, the WDEQ-LQD began rule-making to allow the use of and identify methods to calculate technical standards for evaluating shrub density at coal mines during bond release (WDEQ-LQD R&R, Appendix A) (2002(a)). In 1998, the WDEQ-LQD provided a draft framework for the use of technical standards to quantitatively assess revegetated community species diversity and composition (Vincent, 1998(a), (b)).

In 1997, the WDEQ-LQD selected five coal mines in the Southern Powder River Basin (SPRB) to be used in the generation of a vegetation database. These mines were selected because: (1) the mines are in relatively close proximity and separated from other mines located further north in the basin; (2) some of the operators expressed an interest in technical standards; and (3) a number of data sets were available. The locations of the five coal mines in the SPRB are shown on Figure 1.

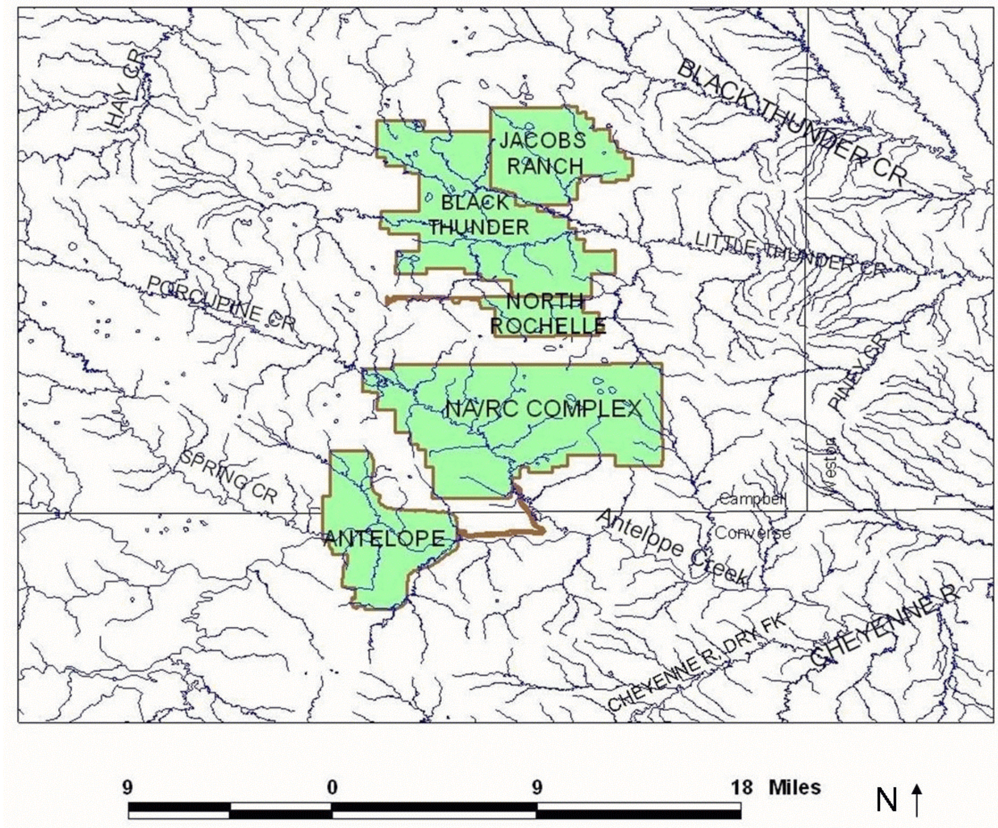

Figure 1. Location of the five Southern Powder River Basin mines in this study.

The WDEQ-LQD entered into a contract with Keammerer Ecological Consultants, Inc. (KEC), in 1997 for the preliminary evaluation of the database feasibility and construction. Prior to inputting the data, decisions concerning standardization of the baseline vegetation communities were necessary, principally due to differences in naming conventions and field delineations between communities. Communities were standardized primarily by dominant species composition. Five major and six minor standardized plant communities were delineated for the five SPRB mines and are listed in Table 1. Major or minor community designation was based on areal extent of studied land. Once the standard plant community classification system was established, each baseline community data set was reviewed and assigned to one of the standardized community types.

The database structure was designed to allow for recovery of each of the original data sets, as well as enable computation of summary statistics across all or a portion of the data sets. The front-end software "Veg Manager," created for Microsoft Access 97, is a dynamic relational database that was used to simplify data input and retrieval.

Table 1. Standardized plant communities delineated for the Southern Powder River Basin mines (Keammerer, 1998).

MAJOR COMMUNITIES	MINOR COMMUNITIES
Mixed Grass Prairie	Playa Grassland
Big Sagebrush Shrubland	Lowland Grassland
Bunchgrass	Silver Sagebrush Shrubland
Rough Breaks/Badlands	Birdsfoot Sagebrush Shrubland
Bottomland Grassland	Alkali Shrubland
	Created Haylands

The original database included data for the following parameters: mine name; study name; standardized plant/vegetation community; sample number; sampling method; species name; species life form; individual species data (cover, production, and density, as applicable); litter cover; rock cover; total vegetation cover or total production for each sample location; total ground cover (vegetation, litter, and rock); and soil type. Precipitation and temperature data was compiled in a related section of the database. The database also contained relational "look-up" tables for life forms, soil types, species list, study design, study method, vegetation types, and vegetation sub-types.

For production data, the WDEQ-LQD R&R states "Full shrubs, succulents, annual grasses, annual forbs, *Yucca spp*., noxious weeds, cushion plants and trees should not be harvested." However, the R&R also states "If annual grasses and/or annual forbs are major community components, these life forms should be clipped" (2002(a)). Based on the WDEQ-LQD R&R, only herbaceous species production was included in the database.

KEC and the WDEQ-LQD entered into a second contract in 1999 to conduct additional ground work and analyses on the major standardized plant communities identified under the 1997 contract. The quality of each data set was evaluated in more detail, and the variations among the data sets, such as inclusion of plant species determined to be undesirable, were also evaluated. An undesirable species list was compiled by the WDEQ-LQD (after consulting with several outside sources) and then modified by KEC, based on the species recorded in the sampled sets of data. The final list of undesirable species for this project is presented in Table 2.

After the contract work was completed, the WDEQ-LQD added vegetation data, which had been submitted after 1999. The WDEQ-LQD then evaluated whether 'regional' technical standards could be developed for the major vegetation communities at the five mines, and if not, whether some other type of option for technical standards was workable, such as mine specific standards.

Data Assessment

Analyses in this paper focus on the two major plant communities encompassing the largest areal extent of the five SPRB mine permit areas: the Mixed Grass Prairie (MGP) and Big Sagebrush Shrubland (BSS) communities. The MGP community occurs on upland sites, in a variety of topographic settings and soils, and is dominated by several different native perennial grass species (Keammerer, 1998). The BSS community usually occurs in similar locations and overall species composition is similar to the MGP community, with the exception that Big sagebrush rather than perennial grasses occurs as the dominant species (Keammerer, 1998). The WDEQ-LQD (2002(a)) defines the difference between grasslands and shrublands by total relative cover of shrubs and sub-shrubs (i.e., shrublands $\geq$20%). Table 3 contains the baseline study dates and associated acreage for the MGP and BSS communities at the five SPRB mines. Combined, the MGP and BSS communities comprise almost 60% of the permit areas in the five SPRB mines.

Acceptable Species. We emphasized acceptable species, because they represent the stable and, usually, more desirable species in a community and to standardize the data. Acceptable species include any species not listed in Table 2. Acceptable species were not limited to perennials, but do encompass all native species and previously used non-native agricultural species, such as Intermediate wheatgrass or Sanfoin. Total vegetation cover of all species and total ground cover data patterns generally mirrored acceptable species cover data patterns. Because production collection methods were not consistent between studies, we could not accurately compare production of all

Table 2. List of unacceptable species which were found during baseline vegetation sampling at the Southern Powder River Basin mines (Keammerer, 1999).

Scientific Name	**Common Name**	**Scientific Name**	**Common Name**
ANNUAL GRASSES		ANNUAL FORBS	
Bromus commutatus	Annual bromegrass	*Alyssum alyssoides*	Pale alyssum
Bromus japonicus	Japanese brome	*Alyssum desertum*	Desert alyssum
Bromus tectorum	Cheatgrass brome	*Amaranthus albus*	White pigweed
Echinochloa crus-galli	Barnyardgrass	*Amaranthus blitoides*	Prostrate pigweed
Hordeum pusillum	Little barley	*Camelina microcarpa*	Littleseed falseflax
Panicum capillare	Witchgrass	*Camelina sativa*	Bigseed falseflax
Poa bulbosa	Bulbous bluegrass	*Chenopodium album*	Lambsquarters goosefoot
		Chenopodium leptophylum	Slimleaf goosefoot
PERENNIAL FORBS		*Chenopodium rubrum*	Red goosefoot
Ambrosia tomentosa	Skeleton bursage	*Chenopodium spp.*	Goosefoot species
Astragalus bisulcatus	Two-grooved Milkvetch	*Conyza canadensis*	Canadian horseweed
Cirsium arvense	Canada thistle	*Descurainia pinnata*[1]	Pinnate tansymustard
Cirsium ochrocentrum	Yellowspine thistle	*Descurainia richardsonii*	Richardson tansymustard
Convolvulus arvensis	Field bindweed	*Descurainia sophia*	Flixweed tansymustard
Lactuca tatarica	Blue (or Chicory) lettuce	*Filago arvensis*	Fluffweed
Taraxacum officinale	Common dandelion	*Kochia scoparia*	Kochia
		Lactuca serriola	Prickly lettuce
BIENNIAL FORBS		*Lappula redowskii*	Bluebur stickseed
Artemisia biennis	Biennial wormwood	*Polygonum aviculare*	Prostrate knotweed
Cirsium vulgare	Bull thistle	*Salsola iberica* (*S. kali*)	Russian thistle
Tragopogon dubius	Western salsify	*Sisymbrium altissimum*	Tumbling hedgemustard
		Sisymbrium loeselii	Tall hedgemustard
		Sonchus arvensis	Field sowthistle
		Sonchus spp.	Sowthistle species
		Thlaspi arvense	Field pennycress
		Verbena bracteata	Bigbract Verbena

[1]Two of the three *Descurainia* species listed consist of several sub-species or varieties. Some are classified as natives and others as introduced. It is often difficult to accurately identify the differences between these three species and thus they are generally lumped during field measurement and identification (Dittberner and Olson, 1983).

species with production of acceptable species, thus we decided to use only acceptable species production in all our analyses (WDEQ-LQD, 2002(b)).

Table 3. Mixed Grass Prairie and Big Sagebrush Shrubland acreage sampled for the Southern Powder River Basin mine permit areas.

	Mixed Grass Prairie	**Big Sagebrush Shrubland**
ANTELOPE	Permit Acreage Sampled	
Original Permit (1979)	1,453	122
Amendment (Horse Creek, 1998)	1,288	447
Amendment (Horse Creek, 1999)	*1998 and 1999 study areas were the same*	
Community Acreage in Permit (%)	2,741 (25%)	569 (5%)
BLACK THUNDER		
Original Permit (1979)	4,721	4,740
Amendment (West Black Thunder, 1991)	420	750
Amendment (Thundercloud, 1996)	1,618	1,907
Community Acreage in Permit (%)	6,759 (32%)	7,397 (35%)
JACOBS RANCH		
Original Permit (1978)	673	3,140
Amendment (1988)	763	903
Amendment (1989)	622	622
Community Acreage in Permit (%)	2,058 (22%)	4,665 (50%)
NORTH ANTELOPE/ROCHELLE		
Original Permit (1981)	2075	2652
Amendment (1990)	*Acreage not available because boundary revised*	
Amendment (1991)	1,957	1,337
Amendment (1997)	2,577	3,619
Community Acreage in Permit (%)	6,609 (24%)	7,608 (28%)
North Rochelle		
Original Permit (1980)	2,289	1,262
Amendment (North Roundup, 1999)	1,071	1,049
Community Acreage in Permit (%)	3,360 (48%)	2,311 (33%)
Total Community Acreage in SPRB	**21,527 (28%)**	**22,550 (30%)**

Comparisons of the Mines. Data was evaluated using three levels of classification: (1) INDIVIDUAL STUDY statistics (e.g., the mean of the Antelope 1998 MGP cover data); (2) MINE SUMMARY statistics (e.g., the mean of the three MGP cover means from each of the three Antelope studies); and (3) CUMULATIVE MINE statistics (e.g., the mean of all MPG cover samples in the three Antelope studies). We chose to emphasize the CUMULATIVE MINE statistical data for the majority of the analyses and comparisons in this paper, although INDIVIDUAL STUDY and MINE SUMMARY statistics are discussed briefly. The CUMULATIVE MINE data was chosen to analyze the potential differences between mines because the low sample numbers for each mine (from two to four), which precludes evaluation of normality and in turn selection of appropriate ANOVA methods (i.e., parametric versus non-parametric) for the MINE SUMMARY data.

Manugistics Statgraphics Plus for Windows Version 4.1 software (1999) was used for all statistical analyses. As a preliminary step, the normality of the data was evaluated. Data was evaluated for normality with four tests: (1) Chi-squared; (2) Shapiro-Wilks; (3) Skewness; and (4) Kurtosis. For any of the tests, if the p-value is <0.1, the test indicates the rejection, with 90% confidence, that the data came from a normal distribution.

Analysis of variance (ANOVA) and multiple range tests were performed on two vegetation parameters: *Acceptable Species Total Vegetation Cover* and *Acceptable Species Total Production*. All comparisons of INDIVIDUAL STUDY, MINE SUMMARY, and CUMULATIVE MINE means were performed using the Bonferroni's multiple comparison method, at an alpha level of 0.1. The Bonferroni's method was selected because it is conservative and it can evaluate parameters with unequal sample sizes. The Kruskal-Wallis test was used to perform non-parametric ANOVA evaluations on the medians for non-normally distributed data. Notched Box-and-Whisker plots were used to visually evaluate median significant differences and 95% confidence level (the only level available within the Statgraphics software) (Manugistics, 1999).

Comparison of Cover Sampling Methods. Due to speculation that the cover methods (point-transect versus quadrats) may be a factor that affects values, the ANOVA, Bonferroni's method (alpha = 0.1), Kruskal-Wallis test, and notched Box-and-Whiskers plot were also used to evaluate sampling method affects.

Effect of Climate. To evaluate potential relationships between vegetation and climate data, we chose to use precipitation data collected by National Oceanic and Atmospheric Administration (NOAA) from the Rochelle 3E station because of its proximity to the SPRB mines (approximately 50 miles east) and the average from the Wyoming Region 7 (Cheyenne River Basin) stations (NOAA, 2002 and WRCC-DRI, 2002). Site specific data and data from the Dull Center station were not used because of concerns about consistency and data gaps. Several modified precipitation parameters were calculated for various time-frames, which consisted of totaling monthly values for the specified time-frame immediately prior to July of a sampling year. The "four-month" time-frame includes total precipitation from April-June. The "ten-month" includes total precipitation from September (of the previous year) through June of the sampling year. The "twelve-month" includes total precipitation from July (of the previous year) through June of the sampling year. Drought indices data came from Hayes (2002) and WRCC-DRI (2002). Several modified drought indices were also calculated for the same time-frames noted for the modified precipitation parameters. However, these drought index time-frame values consist of averaging monthly values for the specified time-frame.

Regression analyses were performed on *Acceptable Species Total Vegetation Cover* and *Acceptable Species Total Production*. Both the means and medians for the data sets were used to test correlations. These data parameters were evaluated at two levels of classification: (1) the INDIVIDUAL STUDY means (or medians) from all fifteen data sets; and (2) the MINE SUMMARY means (or medians) for North Antelope/Rochelle Mine (NARM). The NARM data was chosen because consistent sampling methods were used during each baseline sampling episode and NARM had the largest number of data sets. We also evaluated the relationships of cover data delineated by sampling method with the various climatic parameters. Both linear and non-linear regression analyses were performed. Statistical significance calculations were all performed at the alpha level of 0.1.

Results

Data Set Characteristics

Normal Distribution. The mean and median of most of the data sets were about the same, indicating an assumption of normality could not be automatically rejected (Tables 4 - 7). About half of the individual study cover and production data sets fit a normal distribution. There was little consistency among the groups as to which data sets were normally distributed, i.e., cover and production data within the same community and study were not always both normally distributed. There was also little consistency as to which of the four tests for normality indicated study data sets were not normally distributed. Fewer individual cover data sets were non-normally distributed than production data sets. The lack of normality in some of the data sets does not preclude the use of statistical tests developed for normally distributed data. Normality plots were used as a further check of whether an assumption of normality could adversely affect statistical comparison methods. The normality plots for cover and production data indicate the means plot along a straight line, thus statistical comparison methods developed for normally distributed data could be used with reasonable assurance (WDEQ-LQD, 2002(b)).

Comparison of Cover Sampling Methods. The MGP *Acceptable Species* quadrat mean was 34.2%, and the point-transect mean was 50.5%. The BSS *Acceptable Species* quadrat mean was 40.6% and the point-transect mean was 52.6%. While the ANOVA and Bonferroni comparison results indicate significant differences between the cover sampling methods, the standardized skewness and kurtosis indicated some significant non-normality for both communities. Therefore, the Kruskal-Wallis test and Box-and-Whiskers plots were also used to compare the cover sampling methods. Both the Kruskal-Wallis test and Box-and-Whiskers plot indicated the point-transect method results in significantly higher cover values than the quadrat method (WDEQ-LQD, 2002(b)). The results for *All Species* cover mirrored the *Acceptable Species* cover with the differences (for all tests) being even more pronounced for the *All Species* cover data.

Table 4. Summary: Cover Data - Mixed Grass Prairie community (acceptable species).

Study Year		Sample #	Cover (%)				Normal Distribution [1]
			Range	Mean	Standard Deviation	Median	
Antelope	1979	66	8 - 45	26	9	27	Yes
	1998	53	19 - 75	48	17	48	No (K)
	1999	66	7 -79	50	16	51	No (CS)
	Mine Summary	3	26 - 50	41	14	NA	No (CS) [2]
	Cumulative Mine	185	7 -79	41	18	37	No (SW, CS)
Black Thunder	1979	10	35-50	44	5	44	Yes [2]
	1991	60	6 - 40	26	8	27	No (CS)
	1996	20	38 - 74	55	10	55	Yes
	Mine Summary	3	26 - 55	41	14	NA	Yes [2]
	Cumulative Mine	90	6 - 74	34	15	31	No (SW, CS)
Jacobs Ranch	1978	41	14 - 29	20	4	20	No (CS)
	1988	16	15 - 33	25	5	25	Yes [2]
	1989	15	17 - 45	30	8	30	Yes [2]
	Mine Summary	3	20 - 30	25	5	NA	Yes [2]
	Cumulative Mine	72	14 - 45	23	6	23	No (SW, S)
NARM	1981	27	19 - 70	53	13	58	No (SW)
	1990	28	42 - 60	42	11	45	Yes
	1991	27	40 - 74	55	10	54	Yes
	1997	42	12 - 74	49	13	49	Yes
	Mine Summary	4	42 - 55	50	5	NA	Yes [2]
	Cumulative Mine	124	12 - 74	50	13	50	No (CS, SW)
North Rochelle	1980	31	19 - 55	33	7	33	No (K)
	1999	21	36 - 64	52	7	54	No (CS)
	Mine Summary	2	33 - 52	43	14	NA	– [3]
	Cumulative Mine	52	19 - 64	41	12	36	No (SW, K, CS)

[1] If data set not normally distributed, the test(s) which so indicated are listed in parentheses: skewness (S); kurtosis (K); Chi-square goodness-of-fit (CS); and Shapiro-Wilks (SW).
[2] The kurtosis and/or skewness tests were not computed due to low sample size.
[3] Normality tests could not be calculated because of small sample size.

Table 5. Summary: Production Data - Mixed Grass Prairie community (acceptable species).

Study Year		Sample #	Production (grams/square meter)				Normal Distribution [1]
			Range	Mean	Standard Deviation	Median	
Antelope	1979	66	11 - 104	40	22	35	No (SW)
	1998	53	0 - 156	86	28	86	Yes
	1999	66	23 - 177	77	38	72	No (SW)
	Mine Summary	3	40 - 86	68	24	NA	No (CS) [2]
	Cumulative Mine	185	0 - 177	66	36	64	No (SW, S, CS)
Black Thunder	1979	10	32 - 75	53	14	50	Yes [2]
	1991	60	56 - 182	105	30	100	No (SW)
	1996	50	11 - 84	37	16	33	No (SW)
	Mine Summary	3	37 - 105	65	35	NA	No (CS) [2]
	Cumulative Mine	120	11 - 182	72	41	70	No (SW, CS, S)
Jacobs Ranch	1978	53	53 - 305	106	42	98	No (SW, K, S)
	1988	26	28 - 62	41	9	41	Yes
	1989	27	33 - 94	60	16	61	Yes
	Mine Summary	3	41 - 106	69	33	NA	Yes [2]
	Cumulative Mine	106	28 - 305	78	42	70	No (SW, K, S, CS)
NARM	1981	54	9 - 132	47	22	41	No (SW)
	1990	50	27 - 297	97	55	83	No (SW, K, S, CS)
	1991	50	33 - 222	99	43	97	No (CS, SW)
	1997	130	7 - 224	64	30	60	Yes
	Mine Summary	4	47 - 99	76	25	NA	Yes [2]
	Cumulative Mine	284	7 - 297	72	41	64	No (SW, CS, S, K)
North Rochelle	1980	31	39 - 125	72	21	68	Yes
	1999	41	41 - 153	87	26	86	Yes
	Mine Summary	2	72 - 87	80	11	NA	– [3]
	Cumulative Mine	72	39 - 153	81	25	81	Yes

(1) If data set not normally distributed, the test(s) which so indicated are listed in parentheses: skewness (S); kurtosis (K); Chi-square goodness-of-fit (CS); and Shapiro-Wilks (SW).
(2) The kurtosis and/or skewness tests were not computed due to low sample size.
(3) Normality tests could not be calculated because of small sample size.

Table 6. Summary: Cover Data - Big Sagebrush Shrubland community (acceptable species).

Study Year		Sample #	Cover (%)				Normal Distribution[1]
			Range	Mean	Standard Deviation	Median	
Antelope	1979	38	18 - 51	32	9	28	No (SW)
	1998	62	28 - 82	56	12	56	Yes
	1999	66	15 - 85	54	15	58	Yes
	Mine Summary	3	32 - 56	47	14	NA	No (CS, SW)[2]
	Cumulative Mine	166	15 -85	49	16	50	No (K, SW, CS)
Black Thunder	1979	10	35 - 51	46	5	46	Yes[2]
	1991	63	16 - 54	31	8	30	No (SW)
	1996	20	28 - 70	52	12	56	Yes
	Mine Summary	3	31 - 52	43	11	NA	No (CS)[2]
	Cumulative Mine	93	16 - 70	37	13	34	No (SW, CS, S)
Jacobs Ranch	1978	16	13 - 32	25	4	25	Yes[2]
	1988	18	21 - 42	29	6	29	Yes[2]
	1989	18	13 - 41	29	7	30	Yes[2]
	Mine Summary	3	25 - 29	28	3	NA	No (CS)[2]
	Cumulative Mine	52	13 - 42	28	6	27	Yes
NARM	1981	25	36 - 78	58	10	60	Yes
	1990	33	16 - 62	41	11	40	Yes
	1991	31	42 - 76	60	10	60	No (K)
	1997	44	34 - 76	53	11	54	No (CS)
	Mine Summary	4	41 - 60	53	9	NA	Yes[2]
	Cumulative Mine	133	16 - 78	52	13	54	No (CS)
North Rochelle	1980	26	19 - 56	33	8	31	No (CS)
	1999	21	44 - 62	54	6	54	Yes
	Mine Summary	2	33 - 54	43	15	NA	–[3]
	Cumulative Mine	47	19 - 62	42	13	43	No (K, SW, CS)

[1] If data set not normally distributed, the test(s) which so indicated are listed in parentheses: skewness (S); kurtosis (K); Chi-square goodness-of-fit (CS); and Shapiro-Wilks (SW).
[2] The kurtosis and/or skewness tests were not computed due to low sample size.
[3] Normality tests could not be calculated because of small sample size.

Table 7. Summary: Production Data - Big Sagebrush Shrubland community (acceptable species).

Study Year		Sample #	Production (grams/square meter)				Normal Distribution[1]
			Range	Mean	Standard Deviation	Median	
Antelope	1979	31	18 - 309	85	56	72	No (SW, K, S, CS)
	1998	62	0 - 200	95	32	90	No (K)
	1999	67	20 - 183	66	29	62	No (SW, K, S, CS)
	Mine Summary	3	66 - 95	82	15	NA	Yes [2]
	Cumulative Mine	160	0 - 309	81	39	78	No (SW, K, S)
Black Thunder	1979	10	24 - 46	35	7	36	Yes [2]
	1991	63	26 - 121	61	23	58	No (SW)
	1996	20	14 - 52	33	10	32	Yes
	Mine Summary	3	33 - 61	43	16	NA	No (CS) [2]
	Cumulative Mine	93	14 - 121	52	23	46	No (SW, CS, S)
Jacobs Ranch	1978	16	16 - 128	63	30	66	Yes [2]
	1988	16	15 - 50	32	10	31	Yes [2]
	1989	15	7 - 43	25	13	24	Yes [2]
	Mine Summary	3	25 - 63	40	20	NA	No (CS) [2]
	Cumulative Mine	47	7 - 128	40	26	34	No (SW, S, K, CS)
NARM	1981	51	12 - 201	65	30	58	No (SW, K, S)
	1990	32	23 - 245	82	44	69	No (SW, K, S)
	1991	36	27 - 129	67	22	67	Yes
	1997	65	2 - 163	49	24	47	No (K, SW, S)
	Mine Summary	4	49 - 82	66	14	NA	Yes [2]
	Cumulative Mine	184	2 - 245	62	32	58	No (SW, K)
North Rochelle	1980	25	21 - 75	48	16	47	No (K)
	1999	21	32 - 104	68	18	67	Yes
Mine Summary		2	48 - 68	58	15	NA	– [3]
Cumulative Mine		46	21 - 104	57	20	57	Yes

[1] If data set not normally distributed, the test(s) which so indicated are listed in parentheses: skewness (S); kurtosis (K); Chi-square goodness-of-fit (CS); and Shapiro-Wilks (SW).
[2] The kurtosis and/or skewness tests were not computed due to low sample size.
[3] Normality tests could not be calculated because of small sample size.

Results of Mixed Grass Prairie Analyses

INDIVIDUAL STUDY Analyses. For vegetation cover, the ANOVA and Kruskal-Wallis test indicated several studies were significantly different. The Bonferroni multiple comparison test revealed five homogeneous groups of significance among the fifteen studies. Figure 2 shows the Box-and-Whisker plot of the cover data, which revealed seven homogeneous groups and two very distinct separations of the data sets. Because normality tests indicated the data were not normally distributed and variance comparisons indicated a statistically significant difference among the standard deviations at the 95% confidence level, the non-parametric comparisons (Kruskal-Wallis test and Box-and-Whisker plot) were considered more appropriate.

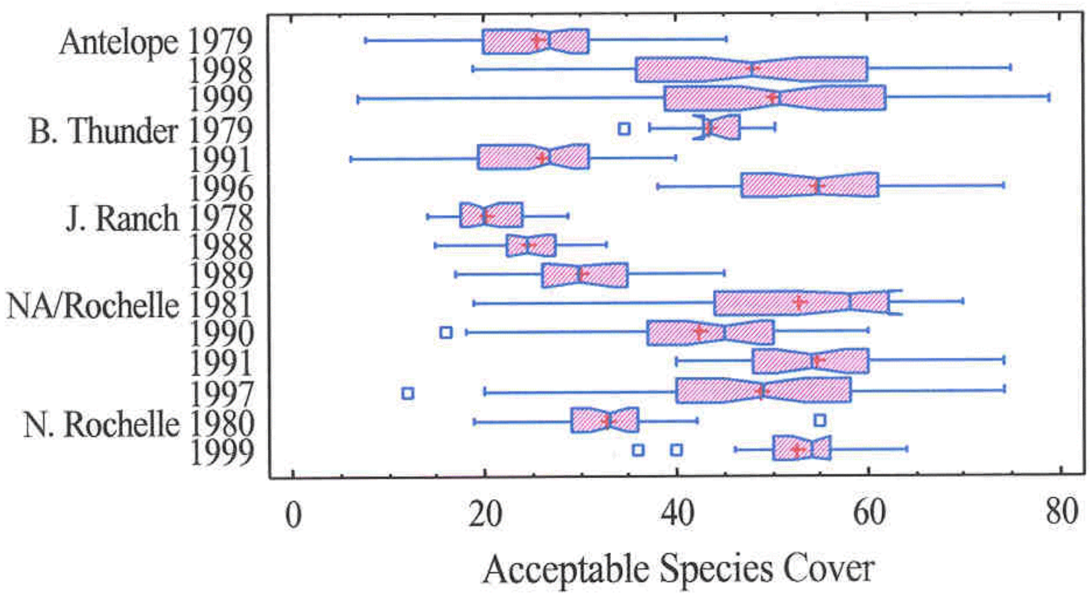

Figure 2. Box-and-Whisker plot of cover data from individual baseline vegetation studies, Mixed Grass Prairie community.

For vegetation production, the ANOVA and Kruskal-Wallis test also indicated several studies were significantly different. The Bonferroni multiple comparison test revealed five homogeneous groups of significance among the fifteen studies. Figure 3 displays the Box-and-Whisker plot of the production data, which revealed several homogeneous groups of data. While the study separations were not as pronounced as the cover data, there again appeared to be two distinct separations of data set values. Because the normality tests indicated the data were not normally distributed and variance comparisons indicated a statistically significant difference among the standard deviations at the 95% confidence level, non-parametric evaluations were considered more appropriate.

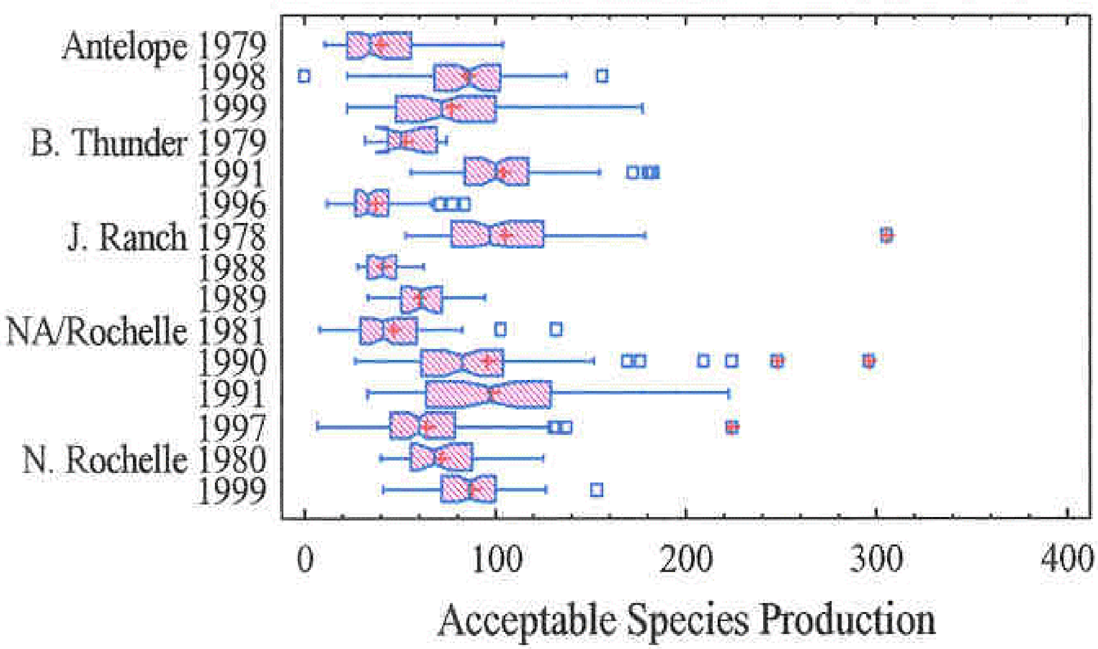

Figure 3. Box-and-Whisker plot of production data from individual baseline vegetation studies, Mixed Grass Prairie community.

M I N E

SUMMARY Analyses. ANOVAs of the cover and production data did not reveal any significant differences between means. However, the total number of samples was very low for each mine (from two to four), precluding adequate evaluation of normality and in turn selection of appropriate ANOVA methods and comparison tests (i.e., parametric versus non-parametric).

CUMULATIVE MINE Analyses. Table 8 displays the statistically significant groups for the MGP cover and production data, based on the Bonferroni tests of the cumulative data from each mine. The results of the Kruskal-Wallis test and Box-and-Whiskers plots indicated that the medians followed the same significance pattern as the means, even though the cover data from all five mines and production data from four of the five mines were not normally distributed. The Box-and-Whiskers plots for the cover and production data are shown on Figures 4 and 5, respectively.

Table 8. Results of multiple comparison tests of the cumulative mine data from the Mixed Grass Prairie community (acceptable species).

	Group with Lowest Mean → Group with Highest Mean[1]			
	Group I	Group II	Group III	Group IV
Cover	JR[2]	BT, NR	NR, A	NARM
Production	A, BT, NARM, JR	BT, NARM, JR, NR		

[1] The groups are significantly different based on the Bonferroni's multiple comparison test at an alpha = 0.10. Within each group, the mines are listed from lowest to highest cumulative mean (Tables 4 and 5).
[2] A - Antelope Mine; BT - Black Thunder Mine; JR - Jacobs Ranch Mine; NARM - North Antelope/Rochelle Mine; NR - North Rochelle Mine

Effect of Climate. Table 9 lists the highest correlations of MGP cover and production data with precipitation and drought indices. For cover, the correlations of all the individual study means (or medians) with precipitation or drought indices were weak, i.e., all the correlation coefficients (r^2) were <0.30. For production, the highest correlation between production and precipitation yielded an r^2 value of 0.54, indicating only a moderate correlation. Correlations between all the drought indices and production were very low (r^2 <0.14).

The highest correlations using the data from NARM's individual studies are also displayed in Table 9. For cover, the correlations of means with precipitation or drought indices was weak (r^2 <0.15). Correlation between cover medians and the Palmer Drought Severity Index 10-month averages resulted in a moderately strong relationship, however based on the p-values (model probability), they were not statistically significant. For production, correlation between production means and precipitation (Rochelle 10-month) were strong, and the p-values indicated the relationships between the parameters were statistically significant (WDEQ-LQD, 2002(b)).

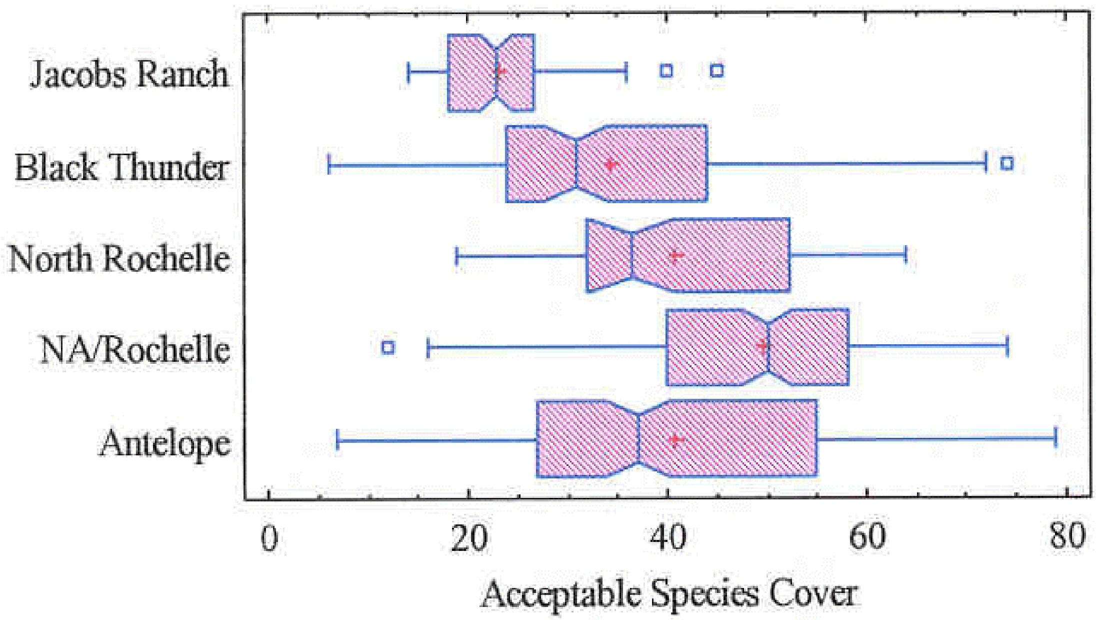

Figure 4. Box-and-Whisker plot of all baseline cover data cumulated for each the five Southern Powder River Basin mines within the Mixed Grass Prairie community.

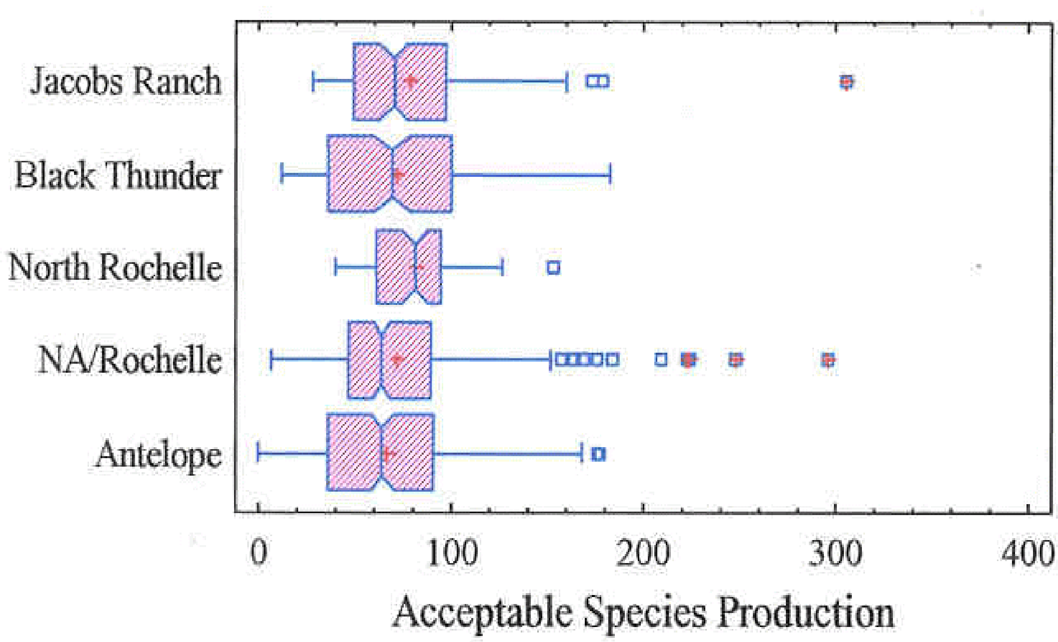

Figure 5. Box-and-Whisker plot of all baseline production data cumulated for each of the five Southern Powder River Basin mines, within the Mixed Grass Prairie community.

Table 9. Highest correlation results between vegetation and climatic parameters using individual study data, Mixed Grass Prairie community (acceptable species).

	Model	Vegetation Parameter	Climatic Parameter[(1)]	r^2	Model p-Value[(2)]	Lack-of-Fit p-Value[(3)]
All Mines	Precipitation					
	Logrithmic-x (Means)	Cover	Roch 10	0.28	0.04	>0.10
	Linear (Means)	Production	Roch 4	0.54	<0.01	0.06
	Drought Indices					
	Linear (Means)	Cover	PDSI 10	0.28	0.04	>0.10
	Exponential (Means)	Production	PDSI 4	0.13	0.19	0.04
NARM	Precipitation					
	Reciprocal-x (Means)	Production	Roch 10	1.00	<0.01	NA[(4)]
	Reciprocal-x	Cover	Region 10	0.37	0.39	NA
	Drought Indices					
	Linear (Medians)	Cover	PDSI 10	0.44	0.34	NA
	Reciprocal-y	Production	MPDSI 4	0.35	0.77	NA

(1) Roch 4 = Rochelle 3E station four-month (April-June) precipitation total.
Roch 10 = Rochelle 3E station ten-month (September-June) precipitation total.
Region 10 = Mean of Region 7 stations ten-month (September-June) precipitation total.
MPDSI 4 = Modified Palmer Drought Severity Index four-month (April-June) average.
PDSI 4 = Palmer Drought Severity Index four-month (April-June) average.
PDSI 10 = Palmer Drought Severity Index ten-month (September-June) average.

(2) A Model p-Value < 0.10 indicates a statistically significant relationship between the specified vegetation and climatic parameters at a 90% confidence level.

(3) A Lack-of-Fit p-Value < 0.10 indicates a statistically significant lack of fit between observed data and the model at a 90% confidence level.

(4) NA = Not analyzed, because no replicate observations for the same climatic factor values.

Because of the influence of cover sampling method on the results, the correlations of cover data, collected using a specific method, with climatic factors were tested. These correlations were not tabulated, but are discussed briefly. The linear correlation between the quadrat cover medians and the Palmer Hydrologic Drought Index 10-month averages resulted in the highest correlation (r^2 = 0.56). Quadrat cover correlations with precipitation data (Rochelle 10-month) were not as strong

($r^2 = 0.40$). The p-values indicated that the correlations were statistically significant. In contrast, the correlation between transect cover data with climatic factors was very poor ($r^2 < 0.18$).

Results of Big Sagebrush Shrubland Analyses

INDIVIDUAL STUDY Analyses. For vegetation cover, the ANOVA and Kruskal-Wallis test indicated several studies were significantly different. The Bonferroni multiple comparison test and the Box-and-Whisker plot (Figure 6) revealed five homogeneous groups of significance for the fifteen studies. The Box-and-Whisker plot also displays two distinct separations of study data, although these separations are not as clearly dissimilar as the groups identified for the MGP community cover data. Because normality tests indicated the data were not normally distributed and variance comparisons indicated a statistically significant difference amongst the standard deviations at the 95% confidence level, the non-parametric comparisons were considered more appropriate.

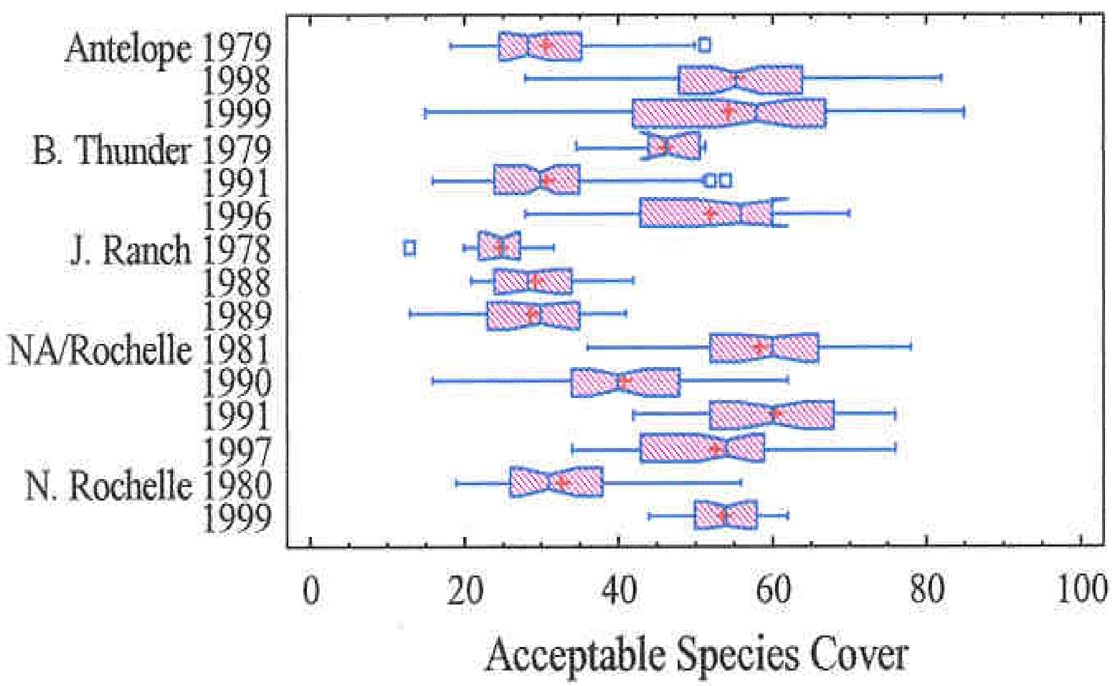

Figure 6. Box-and-Whisker plot of cover data from individual baseline studies, Big Sagebrush Shrubland community.

For production data, the ANOVA and Kruskal-Wallis test indicated several studies were

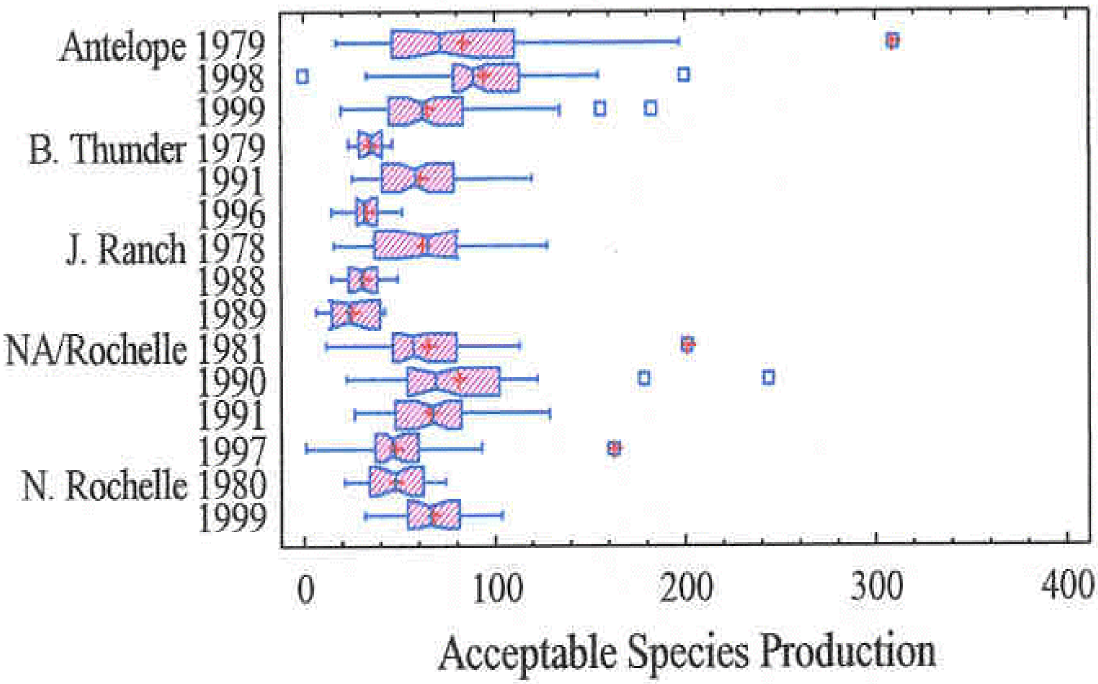

Figure 7. Box-and-Whisker plot of production data from individual baseline studies, Big Sagebrush Shrubland community.

significantly different. The Bonferroni multiple comparison test and the Box-and-Whisker plot (Figure 7) revealed seven and four homogeneous groups of significance, respectively, for the production data of the fifteen studies. The Box-and-Whisker plot indicate that study separations are not as pronounced as for the cover data.

<u>MINE SUMMARY Analyses</u>. ANOVAs of the data for cover and production revealed only one significant difference, specifically between the production at the Antelope and North Rochelle mines. As with the data from the MGP Community, caution should be exercised when making decisions using the MINE SUMMARY analyses because of the low number of studies per mine.

<u>CUMULATIVE MINE Analyses</u>. Bonferroni analyses of the cover and production data indicate three homogeneous groups for each parameter (Table 10). The Jacobs Ranch mine cover mean was significantly lower than the other four mines, and their production mean was significantly lower than

both the NARM and Antelope mines as well. The cover data Box-and-Whiskers plot (Figure 8) revealed four homogeneous groups of significance. The production data Box-and-Whiskers plot (Figure 9) displayed a similar data separation as the cover data, and revealed four homogeneous groups of significance. While the production data was more variable than cover, normality measurements of both parameter data indicated four of the five mine's data sets displayed non-normal distributions. Since normality tests indicated the data were not normally distributed and variance comparisons indicated a statistically significant difference amongst the standard deviations at the 95% confidence level, non-parametric evaluations were considered more appropriate.

Table 10. Results of multiple comparison tests of the cumulative mine data from the Big Sagebrush Shrubland community (acceptable species)

	Group with Lowest Mean → Group with Highest Mean[1]		
	Group I	Group II	Group III
Cover	JR[2]	BT, NR	A, NARM
Production	JR, BT, NR	BT, NR, NARM	A

[1] The groups are significantly different based on the Bonferroni's multiple comparison test at an alpha = 0.10. Within each group, the mines are listed from lowest to highest cumulative mean (Tables 6 and 7).
[2] A - Antelope Mine; BT - Black Thunder Mine; JR - Jacobs Ranch Mine; NARM - North Antelope/Rochelle Mine; NR - North Rochelle Mine

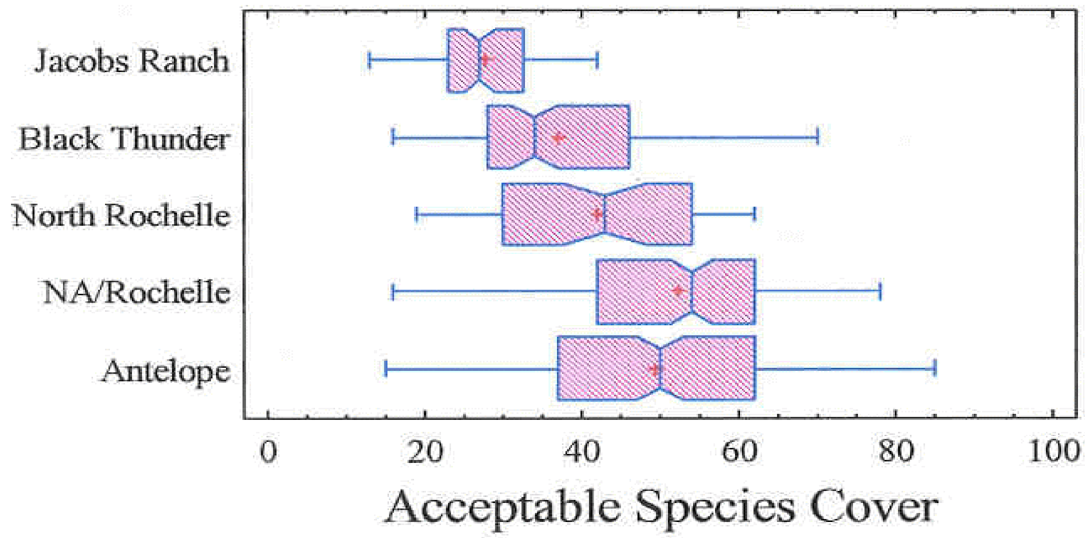

Figure 8. Box-and-Whisker plot of all baseline cover data cumulated for each of the five Southern Powder River Basin mines, within the Big Sagebrush Shrubland community.

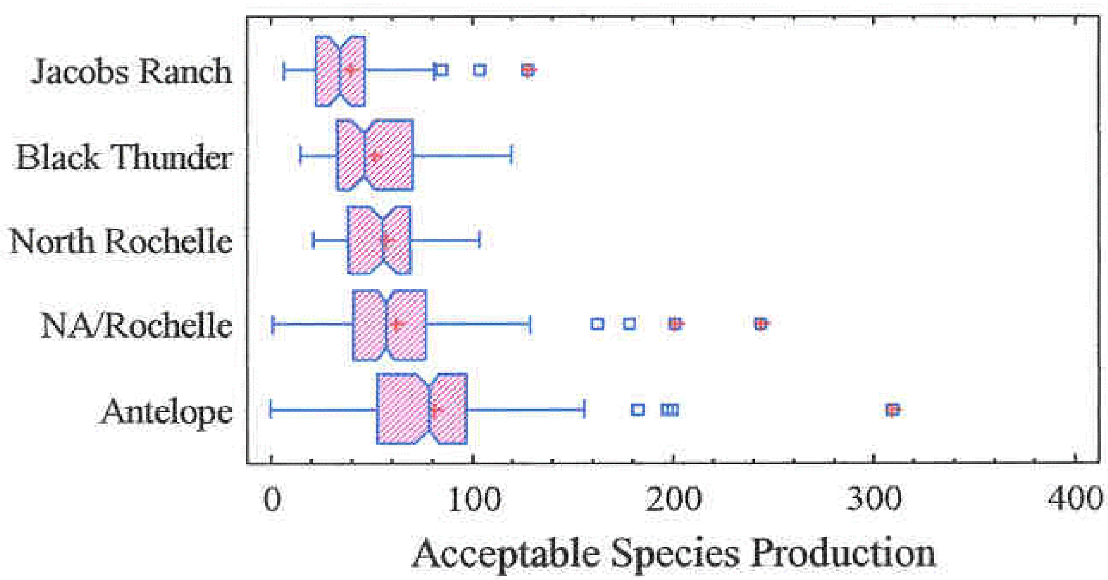

Figure 9. Box-and-Whisker plot of all baseline production data cumulated for each of the five Southern Powder River Basin mines, within the Big Sagebrush Shrubland community.

Effect of Climate. Similar to the MGP community, regression analyses for the BSS community, using all the SPRB mine studies, revealed only weak correlations between cover data and all climatic parameters (Table 11). All correlations between cover and climatic parameters resulted in r^2 values of ≤ 0.30. Again, regression analyses within the BSS community indicated precipitation correlations were stronger for production data than cover data; however, the correlations were still considered weak to moderate, although p-values indicate the relationships were significant. All regression analyses with drought parameters yielded r^2 values <0.20.

For the NARM, the correlation between cover data and all climatic parameters was very weak (<0.20). Regressions between the production medians and the Rochelle 12-month precipitation resulted in strong correlations for both the linear ($r^2 = 0.91$) and non-linear (reciprocal-x) models ($r^2 = 0.96$). Regressions of the production means yielded lower r^2 values, but both the linear and non-linear regression models displayed moderately strong and statistically significant relationships between the two parameters. Both linear and non-linear analyses between production and the Palmer Hydrologic Drought Index 10-month averages indicated moderately strong relationships. The p-values again, indicated statistically significant relationships between the parameters.

Although cover method correlation results were not tabulated, the linear correlation between both quadrat cover means and medians and all the drought indices 10-month averages resulted in equivalent correlations ($r^2 \approx 0.66$). Quadrat cover median correlation with precipitation data (Rochelle 12 month) was moderate ($r^2 = 0.47$). The p-values indicated that the relationships and models involving quadrat cover data were statistically significant. The correlation between transect cover medians and means with all climatic factors was very poor ($r^2 <0.08$).

Table 11. Highest correlation results between vegetation and climatic parameters using individual study data, Big Sagebrush Shrubland community (acceptable species).

	Model	Vegetation Parameter	Climatic Parameter(1)	r^2	Model p-Value(2)	Lack-of-Fit p-Value(3)
All Mines	Precipitation					
	Sq Root-x (Median)	Cover	Roch 10	0.27	0.05	>0.10
	Multiplicative (Median)	Production	Roch 12	0.43	<0.01	>0.10
	Drought Indices					
	Exponential (Median)	Cover	MPDSI 10	0.30	0.04	>0.10
	Multiplicative (Median)	Production	PHDI 4	0.19	0.10	>0.10
NARM	Precipitation					
	Double Reciprocal (Median)	Cover	Roch 10	0.19	0.56	NA(4)
	Linear (Mean)	Cover	PDSI 10	0.11	0.67	NA
	Drought Indices					
	Reciprocal-x (Median)	Production	Roch 12	0.96	0.01	NA
	Reciprocal-y (Mean)	Production	PHDI 10	0.75	<0.01	NA
	Precipitation and Drought Indices					
	Multiple (Median)	Production	Roch 10 + PHDI 10	1.00	0.03	NA

(1) Roch 10 = Rochelle 3E station ten-month (September-June) precipitation total.
Roch 12 = Rochelle 3E station twelve-month (July-June) precipitation total.
MPDSI 10 = Modified Palmer Drought Severity Index ten-month (September-June) average.
PHDI 4 = Palmer Hydrologic Drought Index four-month (April-June) average.
PHDI 10 = Palmer Hydrologic Drought Index ten-month (September-June) average.
PDSI 10 = Palmer Drought Severity Index ten-month (September-June) average.

(2) A Model p-Value < 0.10 indicates a statistically significant relationship between the specified vegetation and climatic parameters at a 90% confidence level.

(3) A Lack-of-Fit p-Value < 0.10 indicates a statistically significant lack of fit between observed data and the model at a 90% confidence level.

(4) NA = Not analyzed, because no replicate observations for the same climatic factor values.

Discussion and Conclusions

This paper does not present the full scope of either the data within the database or the various analyses performed for the two major plant communities (Mixed Grass Prairie and Big Sagebrush Shrubland). However, it is intended to present an overview of the results of WDEQ-LQD efforts to compile a comprehensive baseline vegetation database and to develop technical standards. Identification of standardized plant communities for the database was relatively straightforward. However, within in each of the major communities the variations in cover and production were significant, due to factors such as sampling method and climate. From a statistical standpoint, calculation of regional cover and production standards using the current database information may be difficult. Analyses reveled the possibility of using selective regional data to calculate cover technical standards based on methodology and time of sampling. Development and use of any technical standard will require prescriptions by the WDEQ-LQD. As additional data sets are collected, statistical analyses may provide more insight for evaluating the mine similarities and/or differences. Since this report was completed, one new baseline data set has been submitted and another new baseline data set collected, but not yet submitted. Inclusion of this data may provide additional insight into the intra- and inter-mine data relationships and factors controlling cover and production. Evaluating mines from different parts of the Powder River Basin may also provide additional insight into data relationships and controlling factors.

Data Set Characteristics

Based on available information, data can be analyzed based on the assumption that the baseline data sets are normally distributed. All new baseline data sets should be checked for normality prior to incorporating them into statistical analyses. Production data were more variable and fewer INDIVIDUAL STUDY data sets normally distributed than cover data sets, for both vegetation communities analyzed. This was generally expected, since production data sets usually contain a higher number of samples and because cover values are constrained by upper limits (i.e., values are $\leq$100), while production is not constrained by an upper value limit. In addition, more BSS production data sets were normally distributed than MGP production data sets. This is likely because a greater percent of the production of the BSS was not collected (i.e., shrubs were not clipped), relative to MGP, which by definition does not contain as large a percent of shrubs.

Comparison of Mines

Results from the ANOVA, Bonferroni multiple comparison method, and Kruskal-Wallis tests, as well as the Box-and-Whisker plots, indicate that evaluation of the cumulative mine data does not result in the consistent grouping of mines. More than one group of mines was identified by each test, indicating that calculation of one cover or one production technical standard for each of the major vegetation communities in the SPRB mines may be difficult. The data collected to date imply a general trend of lower cover and production, within the BSS community, for the northern mines that increases as you move south in the SPRB.

Factors for which data was available and which were incorporated into the database, including precipitation and cover sampling method, contribute to the variability among the mines. It is also likely that several factors not incorporated into the database (e.g., elevation, aspect, soil characteristics, site specific moisture conditions, plant phenological status) make it difficult to statistically group the data. In addition, incorporation of new data sets into the analyses impact the variability among the mines. However, incorporation of additional baseline data may help identify consistent patterns in the data. Alternately, selection of the “highest” cover and production values of the available studies from the SPRB may provide an opportunity to use technical standards while still meeting the WDEQ-LQD R&R requirement of "equal to or greater than" (Chapter 4, Section 2(d)(x)) (2002a).

Effect of Climate

Correlation of vegetation cover data with climatic data is difficult whether the data is combined from all five mines or evaluated just from a single mine. Regression analyses were conducted to determine if a climatic factor (or factors) contributing to differences in cover and production values among the various data sets could be identified and to determine if there were any correlation between cover and production values. Both the means and medians for the data sets were used to test correlations. This was done to help reduce the impact of non-normally distributed data sets and to evaluate if the means and medians displayed the same general relationships or levels of correlation. As noted in the method section, we chose to look at two different compilations of the data sets: (1) the means (or medians) from all fifteen data sets; and (2) from the NARM data sets. These data delineations were used to determine the relative importance covering a broad range of circumstances (e.g., different sampling methods and times at the different mines) versus limiting the circumstances (e.g., consistent sampling methods in a smaller area). As an extension to the analyses described in the methods and above, we also attempted to investigate if cover sampling method were correlated with the various climatic factors.

With respect to the SPRB mines and the individual mine, correlation between cover and all climatic parameters resulted in r^2 values <0.50. Use of medians, rather than means, seemed to improve the correlation using data from an individual mine, as did use of the Palmer Drought Index. With respect to production, use of precipitation and means from an individual mine (NARM), explained much of the variability in the data for the MGP community, and use of precipitation and medians from an individual mine (NARM) explained much of the variability in the data for the BSS community. The p-values also indicate these relationships were statistically significant. The best precipitation correlations resulted from using the Rochelle 3E station data. Only the cover data collected with the quadrat method resulted in moderate, although statistically significant correlations with either drought or precipitation parameters. Quadrat cover data for both the MGP and BSS appeared to have their best relationships with ten month drought parameters.

Acknowledgments

This study would not have been possible with the valuable data collected and reported by the Antelope, Black Thunder, Jacobs Ranch, North Antelope-Rochelle, and North Rochelle Mines, and the additional help of BKS Environmental Associates, Inc. and Keammerer Ecological Consultants, Inc. Assistance from the staff of the Land Quality Division and the Office of Surface Mining was invaluable, and the support of the authors by the Wyoming Department of Environmental Quality for preparation of the paper is gratefully acknowledged.

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