Effects from Long-Term Nongrazing After 75 Years

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Does removal of cattle grazing promote development of stable climax plant communities and preserve prairie grasslands in perpetuity?

The nonagricultural public of the United States have repeatedly been told that cattle grazing damages the nations public grasslands. Lacking conclusive scientific facts, these claims have been corroborated by locating and documenting areas of public rangelands that have deteriorated as a result of poor grazing management. With rhetoric spin, cattle grazing, not poor management, becomes the cause and effect for damage to rangeland areas. Furthermore, rather than following the rational evidence that indicates the need for implementation of better grazing management practices, this controversial argument concludes that cattle grazing should be removed from public rangelands. What are the consequences to grassland ecosystems if cattle grazing were successfully removed from public rangelands?

A long-term project for studying the effects from nongrazing compared to the effects from seasonlong grazing by large grass-eating herbivores (graminivores) on mixed grass prairie plant communities was initiated by Dr. Warren C. Whitman in 1936. This ongoing long-term project monitors changes in herbage biomass production, plant species composition, and soil characteristics on nongrazed areas inside of barbed wire exclosures and on grazed areas outside of the exclosures at four two-way rangeland ecological site reference areas.

This report quantitatively describes the effects from long-term nongrazing as determined by differences in plant community characteristics of the grazed area and ungrazed area at North Dakota's four oldest rangeland reference areas after 75 years of treatment.

Development of Study Areas

European settlement of western North Dakota was encouraged by the Homestead Act of 1862 and followed the construction of the first railroad across North Dakota. The Federal Railroad Land Grant Act of 1864 granted the Northern Pacific Railroad 39 million acres of land in a checkerboard pattern from Duluth, Minnesota to Puget Sound, Washington. Construction of the railroad started in 1870 at Superior, Wisconsin and reached Moorhead, Minnesota in December 1871. The tracks reached Bismarck, North Dakota in June 1873, Dickinson in 1880, and the Montana border in 1881. The human population of western North Dakota greatly increased during 1898 to 1915 with the peak period of activity between 1900 and 1910.

Title to 160 acres of surveyed public domain land west of the Mississippi River was transferred from the US Government to private citizens as a provision of the Homestead Act. Several attempts to adjust the law to meet the needs of the people and the natural resources were made. However, none of the many revisions of the Act met the needs of western United States. Failure of the lawmakers to address the requirements of the natural resources in semiarid regions caused numerous long-lasting management problems. In addition, the economic depression of 1929, the severe drought conditions of 1934 and 1936, and the low agricultural commodity prices received during the late 1920's and early 1930's created extreme hardships for homesteaders. The people living on lands declared to be submarginal were given the option to sell their land back to the federal government.

The Taylor Grazing Act of 1934 removed all unappropriated public domain lands from homestead, which included 68,442 acres in North Dakota. The Land Utilization Project was established in 1935 and a resettlement plan was completed that same year. Under these legislative acts, 1,104,789 homesteaded acres were purchased by the US Government in North Dakota (Hibbard 1965; Carstensen 1968; Manske 1994, 2008). The homestead acres repurchased under the Land Utilization Projects were designated for three specific purposes. The lands identified for grazing use and economic development from livestock agriculture became the Little Missouri National Grasslands, the lands identified for recreation use became the Theodore Roosevelt National Park, and the lands identified for wildlife use became Lostwood National Wildlife Refuge. The Bankhead-Jones Farm Tenant Act of 1937 provided for the implementation of followup conservation and utilization programs and for the development of improved practices of management for the repurchased lands.

Whitman (1953) reported that the United States Department of Agriculture Resettlement Administration authorized the establishment of experimental laboratory areas to conduct research on rangeland management practices for the Land Utilization Project's repurchased acres. Four rangeland reference areas were established in the Pyramid Park Region of the Little Missouri River Badlands in 1936 by an informal agreement. When the USDA Soil Conservation Service took over the administration of the Land Utilization Project, a formal lease agreement was signed in 1939 by the North Dakota Agricultural Experiment Station and the Soil Conservation Service. The lease agreement was for 50 years, and it was automatically renewable every eight years. When the USDA Forest Service took over the administration of the Little Missouri National Grasslands, the agency honored the previous lease agreement and issued an Occupancy Permit in 1955. This Terminable Permit was annually renewable as long as the requirements and conditions were met. To lengthen the term of the permit, the USDA Forest Service issued a Special Use Permit in 1987 to North Dakota State University Agricultural Experiment Station for collection of scientific data on the long term effects of grazing on four typical grassland ecosystems and for related livestock and range research. The permit was reissued in 2005 and requires renewal in 2025 and every twenty years thereafter.

Rangeland Reference Areas

Two-way rangeland reference areas that included a livestock exclosure area and a similar area exposed to livestock grazing were established on four major prairie grassland types based on the classification system developed by Hanson and Whitman (1938). These reference areas have been renamed according to current terminology. The four rangeland reference areas are the oldest scientifically documented reference areas in North Dakota and possibly in the Northern Plains. All four reference areas are located in Billings County, North Dakota, south of the city of Medora in the Pyramid Park Region on the eastern portion of the Little Missouri River Badlands.

The Sandy Ecological Site Reference Area was originally labeled Sandy Upland Rangeland Area and was classified as the Sandgrass Grassland Type, with prairie sandreed (*Calamovilfa longifolia*) as the dominant grass. The reference area is located in Section 15, T 138 N, R 102 W, has slopes of 2% east, northeast, and west, has an exclosure of 6.27 acres, and was constructed in 1937.

The Shallow Ecological Site Reference Area was originally labeled Badlands Upland Rangeland Area and was classified as the Grama-Needlegrass-Sedge Grassland Type, with blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*, *Hesperostipa comata*), and upland sedges (*Carex filifolia*, and *Carex heliophila*, *Carex inops heliophila*) as the dominant graminoids. The reference area is located in Section 5, T 138 N, R 101 W, has slopes of 3% north, has exclosures of 6.50 acres in two parts (west 4.90 acres, east 1.60 acres), and was constructed in 1937.

The Silty Ecological Site Reference Area was originally labeled Badlands Slope Rangeland Area and was classified as the Western wheatgrass-Grama-Sedge Grassland Type, with blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*, *Pascopyrum smithii*, *Elymus smithii*), and upland sedge (*Carex filifolia*) as the dominant graminoids. The reference area is located in Section 3, T 138 N, R 101 W, has a slope of 3% south, has an exclosure of 14.10 acres, and was constructed in 1938.

The Overflow Ecological Site Reference Area was originally labeled Sagebrush Flat Rangeland Area and was classified as the Sagebrush Type, with silver sagebrush (*Artemisa cana*) as the dominant shrub and western wheatgrass (*Agropyron smithii*, *Pascopyrum smithii*, *Elymus smithii*), blue grama (*Bouteloua gracilis*), and green needlegrass (*Stipa viridula*, *Nassella viridula*) as the dominant grasses. The reference area is located in Section 11, T 138 N, R 101 W, has a slope of less than 1%, has an exclosure of 2.90 acres, and was constructed in 1937.

The portions of the reference areas that are outside the exclosures have been annually exposed to grazing by livestock, primarily cow-calf pairs, and managed with moderately stocked, 7 to 8 month seasonlong grazing treatments. The grazing treatments are part of larger grazing units that are allotments in the Little Missouri National Grasslands, administered by USDA Forest Service and managed in cooperation with North Dakota Grazing Associations. Grazing permits for these allotments run from 1 May through 31 December, however, in most years the grazing season has been shortened because of inclement weather conditions.

Long-Term Regional Weather

The western North Dakota region has cold winters and hot summers typical of continental climates. Mean annual temperature is 40.9° F (4.9° C). January is the coldest month, with a mean temperature of 11.5° F (-11.4° C). July and August are the warmest months, with mean temperatures of 68.7° F (20.4° C) and 67.0° F (19.5° C), respectively. Long-term (1892-2010) mean annual precipitation is 16.03 inches (407.15 mm). The precipitation during the perennial plant growing season (April through October) is 13.54 inches (343.92 mm) and is 84.5% of the annual precipitation. June has the greatest monthly precipitation, at 3.55 inches (90.14 mm). The precipitation received in the three month period of May, June, and July is 8.13 inches (206.50 mm) and is 50.7% of the annual precipitation (table 1) (Manske 2011c).

Water stress develops in perennial plants during water deficiency periods when the amount of rainfall is less than evapotranspiration demand. Water deficiency months were identified from historical temperature and precipitation data by the ombrothermic diagram technique (Emberger et al. 1963). The long-term (1892-2010) ombrothermic diagram (figure 1) shows near water deficiency conditions during August, September, and October, and favorable water relations during April, May, June, and July. Reoccurrence of water deficiency conditions during April, May, June, and July is 16.9%, 13.6%, 10.2%, and 38.1%, respectively, and during August, September, and October water deficiency reoccurs 52.5%, 50.0%, and 46.6% of the years, respectively. Long-term occurrence of water deficiency conditions is 32.7% of the growing season months, for a mean of 2.0 water deficient months per growing season (Manske et al. 2010).

Table 1. Long-term (1892-2010) mean monthly temperature and monthly precipitation in western North Dakota.

	° F	° C	in.	mm
Jan	11.48	-11.40	0.41	10.39
Feb	15.25	-9.31	0.41	10.34
Mar	26.21	-3.22	0.74	18.71
Apr	41.56	5.31	1.41	35.76
May	52.77	11.54	2.34	59.39
Jun	61.96	16.65	3.55	90.14
Jul	68.74	20.41	2.24	56.92
Aug	67.01	19.45	1.71	43.38
Sep	56.09	13.38	1.34	33.97
Oct	43.74	6.52	0.95	24.20
Nov	28.44	-1.98	0.54	13.62
Dec	16.89	-8.39	0.41	10.33
	MEAN		**TOTAL**	
	40.85	**4.91**	**16.03**	**407.15**

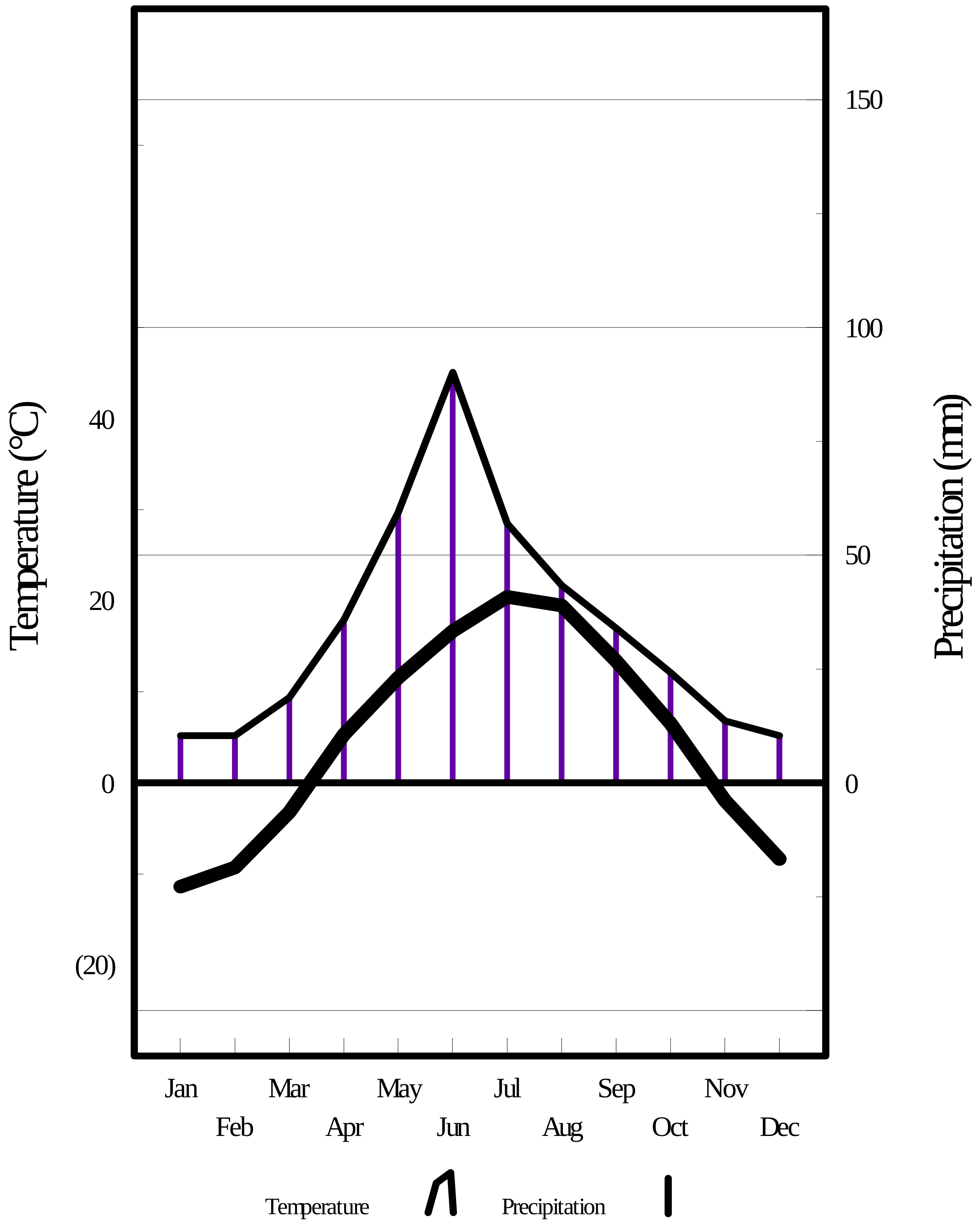

Figure 1. Ombrothermic diagram of long-term (1892-2010) mean monthly temperature and monthly precipitation in western North Dakota.

Procedures

The effects from long-term nongrazing after 75 years was compared to the effects from seasonlong grazing by large graminivores on four major plant communities of the mixed grass prairie at the two-way rangeland reference areas established by Dr. Warren C. Whitman in 1936. Vegetation changes in aboveground herbage biomass, grass basal cover, forb density, shrub density, belowground plant root biomass, rhizosphere biomass, and available soil mineral nitrogen were evaluated with data collected during the growing season from late June through mid September, 2011.

Aboveground herbage biomass was collected by the standard clipping method (Cook and Stubbendieck 1986). Vegetation on the grazed areas outside of the exclosures was protected from grazing during the growing season of 2011 by steel wire quonset type cages measuring 3 X 7 foot placed on the reference areas prior to livestock turnout. The herbage material from five 0.25 m^2 quadrats (frames) at each sample site both inside (ungrazed) and outside (grazed) each exclosure was hand clipped to ground level and sorted in the field by biotype categories: domesticated grasses, cool-season grasses, warm-season grasses, sedges, forbs, standing dead, and litter. The herbage of each biotype category from each frame was placed in labeled paper bags of known weight, oven dried at 140° F (60° C), and weighed. Herbage biomass in pounds per acre for each category were determined from the clipping data. Relative composition of herbage biomass biotype categories were determined.

Plant species basal cover was determined by the ten-pin point frame method (Cook and Stubbendieck 1986), with 2000 points collected in the near vicinity of long-term transect lines both inside (ungrazed) and outside (grazed) each exclosure. The major transect lines were parallel to each other on opposite sides of the exclosure fence. The minor transect lines were perpendicular to the major transect lines and were parallel to each other. Basal cover plant species data were sorted into biotype categories: domesticated grasses, native grasses, sedges, forbs, woody species, and litter. Native grass species were categorized by three methods for analysis: 1) cool-season grasses, and warm-season grasses, 2) tall grasses, mid grasses, and short grasses, and 3) grasses with short shoots and basal leaves, and grasses with long shoots and stem leaves. Basal cover, relative basal cover, percent frequency, relative percent frequency, and importance value were determined from the ten-pin point frame data. Relative composition of basal cover biotype categories were determined.

Density of forbs were determined by counting individual stems of each forb species rooted inside twenty five 0.1 m^2 quadrats placed in the near vicinity of long-term transect lines both inside (ungrazed) and outside (grazed) each exclosure. The major transect lines were parallel to each other on opposite sides of the exclosure fence. The minor transect lines were perpendicular to the major transect lines and were parallel to each other. Forb species were categorized for analysis as: late succession forbs, mid succession forbs, and early succession forbs. Density per 0.1 m^2 quadrat, relatively density, percent frequency, relative percent frequency, and importance value were determined from the forb density data. Relative composition of forb categories were determined.

Density of shrubs were collected by counting individual plants of each shrub species rooted inside twenty five 1.0 m^2 quadrats placed in the near vicinity of long-term transect lines both inside (ungrazed) and outside (grazed) each exclosure. The major transect lines were parallel to each other on opposite sides of the exclosure fence. The minor transect lines were perpendicular to the major transect lines and were parallel to each other. Density per 1.0 m^2 quadrat, relatively density, percent frequency, relative percent frequency, and importance value were determined from the shrub density data. Relative composition of shrub species were determined. This procedure adequately represented the shrub component of the plant community at the sample sites outside (grazed) each exclosure, however, because of the great extent and high number of woody species growing inside the exclosures, this method greatly undersampled the woody plants located within each exclosure. A species present list of shrubs, cacti, and trees was compiled for inside and outside each exclosure.

Digital plant community maps of the four exclosures were developed. Shrub and tree infested plant communities were separated from grass plant communities into distinct map units on the long-term exclosure areas by ocular assessment of USDA National Agriculture Imagery Program 2009 orthoimages as displayed by Google Earth. Surface area of the woody shrub and tree infested map units and the nonwoody grass map units were determined in acres as digital data in ArcGIS. Technical mapping procedures were completed by student

ArcGIS technicians, with direction from Tobias L. Stroh, Assistant Professor, Department of Agriculture and Technical Studies, Dickinson State University, Dickinson, North Dakota.

Belowground plant root biomass was collected inside (ungrazed) and outside (grazed) each exclosure by two replicated soil cores 3 inches (7.6 cm) in diameter and 4 inches (10.2 cm) in depth. The proportion of live and dead roots in the total belowground plant biomass was not known because root material requires considerable time, one to four or more years, to decompose. Root material was separated from soil in a water bath assisted with gentle manual agitation, placed in labeled paper bags of known weight, oven dried at 140° F (60° C), and weighed. Root biomass per volume of soil at a one half foot depth was determined from the soil core root weight data and reported as pounds per acre and kilograms per cubic meter.

Rhizosphere biomass was collected inside (ungrazed) and outside (grazed) each exclosure by three replicated soil cores 3 inches (7.6 cm) in diameter and 4 inches (10.2 cm) in depth using a humane soil beastie catcher (Manske and Urban 2012). The fresh rhizosphere material, which included the rhizosphere organisms, the active plant roots, and the adhered soil particles, was separated from matrix soil by meticulous excavation with fine hand tools. Both wet and dry rhizosphere weights were collected. Rhizosphere biomass per volume of soil at a one half foot depth was determined from the soil core rhizosphere weight data and reported as pounds per acre and kilograms per cubic meter.

Soil mineral nitrogen, nitrate and ammonium, was sampled inside (ungrazed) and outside (grazed) each exclosure by three replicated soil cores with 6 inch (15.2 cm) increments to a 12 inch (30.5 cm) depth collected using a Veihmeyer soil tube with 1 inch (2.5 cm) diameter. Soil cores were placed on ice immediately and were frozen within 4 to 6 hours of collection. Analysis of soil core samples for available mineral nitrogen (NO_3-NH_4) was conducted by the North Dakota State University Soil Testing Laboratory. Total available mineral nitrogen at a one foot depth was determined from the soil core data and reported as pounds per acre and milligrams per kilogram.

Early exclosure studies were typically established without replication. Interpretation of treatment effects on plant community characteristics assumes only minor differences in the vegetation of the grazed area and ungrazed area at the time of exclosure constuction on each reference area.

Mathematical comparison of plant community vegetation between the grazed area and the ungrazed area of each reference area was determined by the index of similarity method (Mueller-Dombois and Ellenberg 1974). Similarity index of herbage biomass compared percent composition of biotype categories in common between the grazed area and the ungrazed area as related to the total percent composition of all biotype categories on both areas. Similarity index of basal cover compared importance value of grass species in common between the grazed area and the ungrazed area as related to the total importance value of all grass species on both areas. Similarity index of forb density compared importance value of forb species in common between the grazed area and the ungrazed area as related to the total importance value of all forb species on both areas. Similarity index of woody shrubs and trees compared the number of shrub and tree species present in common between the grazed area and the ungrazed area as related to the total shrub and tree species present on both areas. Similarity index of range condition compared percent herbage dry weight of plant species in the current plant community on the grazed area and on the ungrazed area as a percentage of the hypothetical historic ecological site plant community. Index values of 80% and greater are considered to be similar. Index values greater than 50% are degrees of similarity. Index values of less than 50% are degrees of dissimilarity. And index values of 20% and less are considered to be dissimilar.

A standard t-test was used to analyze differences among means (Mosteller and Rourke 1973). Nomenclature of plant species on the long-term rangeland reference areas follows Flora of the Great Plains (1986)

Results

Sandy Ecological Site

The Sandy Ecological Site (figures 2, 3, and 4) was classified by Hanson and Whitman (1938) as the Sandgrass Grassland Type with prairie sandreed, upland sedges, blue grama, needle and thread, and prairie Junegrass as the major vegetation. The loamy fine sand soil was the Blanchard series, mixed, frigid Typic Ustipsamments. The plant community and belowground characteristics data after 75 years of treatment are on tables 2 to 10 and figures 5 and 6.

Herbage biomass of native grasses was 1777.58 lbs/ac on the grazed area and 545.19 lbs/ac on the ungrazed area, with a 69.3% decrease on the ungrazed area. Herbage biomass of cool season grasses, warm season grasses, and sedges decreased 70.2%, 78.2%, and 59.8%, respectively, on the ungrazed area. Herbage biomass of domesticated grasses was 0.0 lbs/ac on the grazed area and 1158.89 lbs/ac on the ungrazed area, with a 100.0% increase on the ungrazed area. Herbage biomass of forbs was 147.72 lbs/ac on the grazed area and 156.99 lbs/ac on the ungrazed area, with a 6.3% increase on the ungrazed area. Native cool season grasses had the greatest herbage biomass on the grazed area and domesticated grasses had the greatest herbage biomass on the ungrazed area. Total live herbage biomass was 1925.29 lbs/ac on the grazed area and 1861.07 lbs/ac on the ungrazed area, with a 3.3% decrease on the ungrazed area. Standing dead biomass was 353.23 lbs/ac on the grazed area and 230.49 lbs/ac on the ungrazed area, with 34.8% decrease on the ungrazed area. Litter was 104.90 lbs/ac on the grazed area and 791.38 lbs/ac on the ungrazed area, with a 654.4% increase on the ungrazed area. Total dead biomass was 458.13 lbs/ac on the grazed area and 1021.87 lbs/ac on the ungrazed area, with a 123.1% increase on the ungrazed area. The total aboveground plant biomass was comprised of 35.5% dead biomass on the ungrazed area (table 2).

Relative composition of native grass biomass was 92.3% on the grazed area and 29.3% on the ungrazed area, with a 68.3% decrease on the ungrazed area. Composition of cool season grasses, warm season grasses, and sedges decreased 69.1%, 77.5%, and 58.4%, respectively, on the ungrazed area. Composition of domesticated grass biomass was 0.0 % on the grazed area and 62.3% on the ungrazed area, with a 100.0% increase on the ungrazed area. Composition of forb biomass was 7.7% on the grazed area and 8.4% on the ungrazed area, with a 10.0% increase on the ungrazed area. Composition of total live herbage biomass was 80.8% on the grazed area and 64.6% on the ungrazed area, with a 20.1% decrease on the ungrazed area. Composition of total dead biomass was 19.2% on the grazed area and 35.5% on the ungrazed area, with an 84.4% increase on the ungrazed area (table 2). Similarity index of herbage biomass was 18.9% indicating that the composition of biotype categories on the grazed area and on the ungrazed area were dissimilar (table 2).

Basal cover of native grasses was 29.1% on the grazed area and 10.9% on the ungrazed area, with a 62.5% decrease on the ungrazed area. Basal cover of cool season grasses, warm season grasses, and sedges decreased 49.2%, 84.6%, and 39.2%, respectively, on the ungrazed area. Basal cover of domesticated grasses was 0.2% on the grazed area and 5.7% on the ungrazed area, with a 3700.0% increase on the ungrazed area. Blue grama and upland sedges had the greatest basal covers on the grazed area and upland sedges and Kentucky bluegrass had the greatest basal covers on the ungrazed area. Total live basal cover was 30.2% on the grazed area and 17.0% on the ungrazed area, with a 43.8% decrease on the ungrazed area (table 3).

Basal cover of tall grasses, mid grasses, short grasses, and upland sedges were 0.6%, 1.3%, 15.7%, and 11.6%, respectively, on the grazed area and were 2.0%, 1.5%, 0.4%, and 7.1%, respectively, on the ungrazed area. Tall grass and mid grass basal cover increased 225.0% and 20.0%, respectively, and short grass and upland sedge basal cover decreased 97.4% and 39.2%, respectively, on the ungrazed area. Basal cover of short grasses and upland sedges were greater on the grazed area and basal cover of tall grasses, mid grasses, and domesticated grasses were greater on the ungrazed area.

Basal cover of native grasses with short shoots and basal leaves was 28.2% on the grazed area and 8.1% on the ungrazed area, with 71.4% decrease on the ungrazed area. Basal cover of native grasses with long shoots and stem leaves was 1.0% on the grazed area and 2.9% on the ungrazed area, with a 200.0% increase on the ungrazed area. Grasses with short shoots and basal leaves protect the soil and restrict invasion by undesirable plants. The high losses of grasses with short shoots and basal leaves provided the open spaces for the great increase of domesticated grasses on the ungrazed area.

Relative composition of native grass basal cover was 96.5% on the grazed area and 64.3% on the ungrazed area, with a 33.4% decrease on the ungrazed area. Composition of cool season grasses and warm season grasses decreased 9.7% and 72.5%, respectively, and composition of sedges increased 8.1% on the ungrazed area. Composition of domesticated grass basal cover was 0.5% on the grazed area and 33.6% on the ungrazed area, with a 6626.0% increase on the ungrazed area (table 3). Similarity index of basal cover was 49.0% indicating that the importance value of the grass species on the grazed area and on the ungrazed area were more dissimilar than similar (table 3).

Total forb density was 5.8 forbs/0.10 m^2 on the grazed area and 3.5 forbs/0.10 m^2 on the ungrazed area, with a 40.4% decrease on the ungrazed area. The forb component was composed mostly of native plants, 93.8% on the grazed area and 98.8% on the ungrazed area, and introduced forbs comprised 6.2% on the grazed area and 1.2% on the ungrazed area. Density of late and early succession forbs decreased 75.8% and 88.9%, respectively, and density of mid succession forbs increased 980.0% on the ungrazed area (table 4). Six late succession forbs grew only on the grazed area and were not present on the ungrazed area (table 42). The ungrazed area had a 53.9% decrease in the number of forb species present. Pussytoes, blazing star, and silverleaf scurfpea had the greatest densities on the grazed area and blue wild lettuce, blazing star, and silverleaf scurfpea had the greatest densites on the ungrazed area. Blue wild lettuce had the greatest increase of the forbs on the ungrazed area.

Relative composition of late, mid, and early succession forb density was 89.8%, 3.4%, and 6.1%, respectively, on the grazed area and 36.8%, 62.1%, and 1.2%, respectively, on the ungrazed area. Composition of late and early succession forbs decreased 59.0% and 81.2%, respectively, and composition of mid succession forbs increased 1725.6% on the ungrazed area (table 4). Relative composition of forbs was primarily late succession forbs on the grazed area and was mostly mid succession forbs on the ungrazed area. Similarity index of forb density was 42.8% indicating that the importance value of the forb species on the grazed area and on the ungrazed area were more dissimilar than similar (table 4).

Shrub density collected by the 1.0 m^2 quadrat method measured no shrubs on the grazed and ungrazed sample transect lines (table 5). This quantitative method greatly undersampled the woody plants located within the exclosure. Compilation of the woody species present list identified one shrub species and two cacti species on the grazed area and five shrub species, two cacti species, and one tree species on the ungrazed area (table 6). Similarity index of woody shrubs and trees present was 37.5% indicating that the number of woody species present on the grazed area and on the ungrazed area were more dissimilar than similar (table 6). A greater number of woody species and a greater number of individual woody plants were present on the ungrazed exclosure than were on the grazed area (figure 5). The ArcGIS mapping procedures identified 2.93 acres (46.7%) of nonwoody grass plant communities and 3.34 acres (53.3%) of woody shrub and tree infested plant communities on the 6.27 acre Sandy Ecological Site exclosure (figure 6 and table 7). The woody plant communities occupy a greater proportion of the ungrazed exclosure.

After 75 years of seasonlong grazing, the aboveground vegetation biomass on the grazed area consisted of 19.2% standing dead and litter and 80.8% live herbage. The live herbage was 0.0% domesticated grasses, 92.3% native grasses (41.7% cool season grasses, 26.2% upland sedges, and 24.4% warm season grasses), and 7.7% forbs. After 75 years of nongrazing, the aboveground vegetation biomass on the ungrazed exclosure consisted of 35.5% standing dead and litter and 64.5% live herbage. The live herbage was 62.3% domesticated grasses, 29.3% native grasses (12.9% cool season grasses, 10.9% upland sedges, and 5.5% warm season grasses), and 8.4% forbs (table 2).

Total belowground plant root biomass was 44,175.84 lbs/ac (32.48 kg/m^3) on the grazed area and 19,517.34 lbs/ac (14.35 kg/m^3) on the ungrazed area, with a 55.8% decrease on the ungrazed area (table 8). The 55.8% decrease of the total belowground plant root biomass on the ungrazed area coincided with the 43.8% decrease of the total aboveground live plant basal cover on the ungrazed area.

Rhizosphere biomass was 232,589.59 lbs/ac (171.01 kg/m^3) on the grazed area and 141,196.10 lbs/ac (103.74 kg/m^3) on the ungrazed area, with a 39.3% decrease on the ungrazed area (table 8). Basal cover of native grasses was 29.1% on the grazed area and 10.9% on the ungrazed area. Basal cover of domesticated grasses was 0.2% on the grazed area and 5.7% on the ungrazed area. The 39.3% decrease of rhizosphere biomass on the ungrazed area preceded the 62.5% decrease in native grass basal cover, that was followed by the large increase in domesticated grass basal cover on the ungrazed area.

The total available soil mineral nitrogen of nitrate and ammonium was 31.52 lbs/ac on the grazed area and 23.52 lbs/ac on the exclosure, with a decrease of 25.4% on the exclosure. The quantity of total mineral nitrogen was greater on the grazed area than on the ungrazed exclosure. The quantities of mineral nitrogen were not significantly different on the grazed area and the exclosure. The quantity of nitrate was 6.33 lbs/ac on the grazed area and 7.33

lbs/ac on the exclosure, with an increase of 15.8% on the ungrazed exclosure. The quantity of ammonium was 25.19 lbs/ac on the grazed area and 16.19 lbs/ac on the exclosure, with a decrease of 35.7% on the ungrazed exclosure (table 9). The exclosure had greater nitrate and lower ammonium and the grazed area had lower nitrate and greater ammonium. The greater quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

Similarity index of range condition on the grazed area was 59.8%, low good condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was a little more similar than dissimilar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 10). Similarity index of range condition on the ungrazed area was 36.8%, low fair condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was more dissimilar than similar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 10). The current plant community of the ungrazed area had degraded from the hypothetical historical sandy ecological site plant community 38.4% greater than the degradation of the current plant community on the grazed area after 75 years (table 10).

The effects from long-term nongrazing on the sandy ecological site were great after 75 years. Native grass herbage biomass decreased 69.3% and basal cover decreased 62.5% on the ungrazed area. Cool season grass, warm season grass, and sedge herbage biomass decreased 70.2%, 78.2%, and 59.8%, respectively, and basal cover decreased 49.2%, 84.6%, and 39.2%, respectively, on the ungrazed area. Domesticated grass herbage biomass increased 100.0% and basal cover increased 3700.0% on the ungrazed area. Forb herbage biomass increased 6.3%, forb density decreased 40.8%, and the number of forb species present decreased 53.9% on the ungrazed area. The number of shrub and tree species present increased 166.7% of the ungrazed data. Woody plants infested 53.3% of the area on the ungrazed exclosure. Total live plant basal cover decreased 43.8% on the ungrazed area. Total live herbage biomass decreased only 3.3% because the decrease in native grasses was a little greater than the increase in domesticated grasses on the ungrazed area. Total dead biomass increased 123.1% on the ungrazed area (tables 2, 3, 4, 5, 6, and 7). Belowground plant root biomass decreased 55.8% on the ungrazed area (table 8). Rhizosphere biomass decreased 39.3% on the ungrazed area (table 8). Mineral nitrogen decreased 25.4% on the ungrazed area (table 9).

Similarity indices of herbage biomass, basal cover, forb density, and shrubs present were 18.9%, 49.0%, 42.8%, and 37.5%, respectively. Similarity index of herbage biomass indicated that the plant communities on the grazed area and on the ungrazed area were dissimilar. Similarity indices of basal cover, forb density, and shrubs present all indicated that the plant communities on the grazed area and on the ungrazed area were more dissimilar than similar. Similarity index of range condition indicated that the current plant community on the ungrazed area had degraded 38.4% greater than the current plant community on the grazed area.

Figure 2. Sandy Ecological Site, located in Sec. 15, T 138 N, R 102 W, exclosure of 6.27 acres, built in 1937, looking North.

Figure 3. Sandy Ecological Site, located in Sec. 15, T 138 N, R 102 W, exclosure of 6.27 acres, built in 1937, looking East.

Figure 4. Sandy Ecological Site, located in Sec. 15, T 138 N, R 102 W, exclosure of 6.27 acres, built in 1937, looking South.

Table 2. Herbage biomass (lbs/ac) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Herbage Biomass			Relative Composition		
Site: Sandy	lbs/ac Grazed	lbs/ac Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	0.00	1158.89	+100.00	0.00	62.27	+100.00
Native Cool Season	803.51	239.77	-70.16	41.73	12.88	-69.13
Native Warm Season	468.84	102.04	-78.24	24.35	5.48	-77.49
Sedges	505.23	203.38	-59.75	26.24	10.93	-58.35
Native Grass	1777.58	545.19	-69.33	92.33	29.29	-68.28
Total Grass	1777.58	1704.08	-4.13	92.33	91.56	-0.83
Forbs	147.72	156.99	+6.28	7.67	8.44	+10.04
Total Live	1925.29	1861.07	-3.34	80.78	64.55	-20.09
Standing Dead	353.23	230.49	-34.75	14.82	7.99	-46.09
Litter	104.90	791.38	+654.41	4.40	27.45	+523.86
Total Dead	458.13	1021.87	+123.05	19.22	35.45	+84.44
Total Live & Dead	2383.42	2882.94	+20.96			

		Similarity Index of Herbage Biomass
Similarity Index	18.9%	(Dissimilar)

Table 3. Basal cover (%) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Basal Cover			Relative Composition		
Site: Sandy	% Grazed	% Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	0.15	5.70	+3700.00	0.50	33.63	+6626.00
Native Cool Season	3.25	1.65	-49.23	10.78	9.73	-9.74
Native Warm Season	14.25	2.20	-84.56	47.26	12.98	-72.53
Sedges	11.60	7.05	-39.22	38.47	41.59	+8.11
Native Grass	29.10	10.90	-62.54	96.52	64.31	-33.37
Total Grass	29.25	16.60	-43.25	97.01	97.94	+0.96
Forbs	0.85	0.35	-58.82	2.82	2.06	-26.95
Woody Species	0.05	0.00	-	0.17	0.00	-
Total Live	30.15	16.95	-43.78	30.15	16.95	-43.78
Litter	69.85	83.05	+18.90	69.85	83.05	+18.90
Total Live & Dead	100.00	100.00				

Similarity Index of Basal Cover

Similarity Index	49.0%	(More dissimilar than similar)

Table 4. Forb density (#/0.10 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Sandy	#/0.10 m^2 Grazed	#/0.10 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Late Succession Forbs	5.28	1.28	-75.76	89.80	36.78	-59.04
Mid Succession Forbs	0.20	2.16	+980.00	3.40	62.07	+1725.59
Early Succession Forbs	0.36	0.04	-88.89	6.12	1.15	-81.21
Woody Species	0.04	0.00	-	0.68	0.00	-
Total Live	5.88	3.48	-40.82			
	Similarity Index of Forb Density					
Similarity Index	42.8%	(More dissimilar than similar)				

Table 5. Shrub density (#/1.0 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Sandy	#/1.0 m^2 Grazed	#/1.0 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Artemisia cana	0.00	0.00	-	0.00	0.00	-
Rosa arkansana	0.00	0.00	-	0.00	0.00	-
Symphoricarpos occidentalis	0.00	0.00	-	0.00	0.00	-
Total Live	0.00	0.00	-			

Table 6. Shrubs, cacti, and trees present on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Sandy	
	Grazed	Exclosure
Prunus virginiana		X
Rhus trilobata		X
Rosa arkansana	X	X
Symphoricarpos occidentalis		X
Yucca glauca		X
Escobaria vivipara	X	X
Opuntia polyacantha	X	X
Juniperus scopulorum		X
Similarity Index of Shrubs Present		
Similarity Index	37.5% (More dissimilar than similar)	

Figure 5. Sandy Ecological Site, exclosure with increased woody vegetation

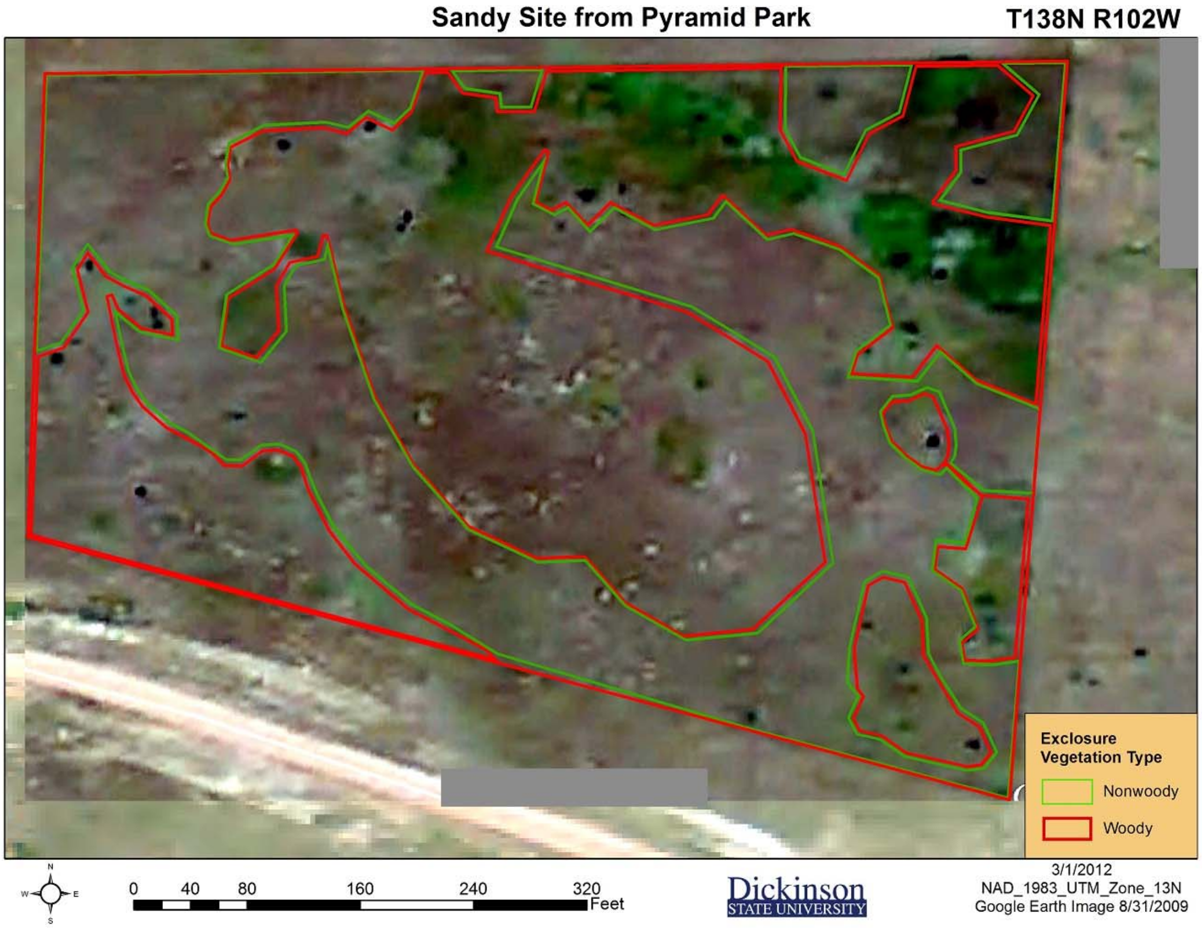

Figure 6. Sandy Ecological Site exclosure with Woody shrub and tree infested plant communities and Nonwoody grass plant communities in the Little Missouri River Badlands, 1936-2011.

Table 7. Woody shrub and tree infested plant communities and Nonwoody grass plant communites in the Little Missouri River Badlands, 1936-2011.

Site: Sandy	Total Exclosure Area	Major Plant Communities: Nonwoody Grass	Major Plant Communities: Woody Shrub and Tree Infested
Acres	6.27	2.93	3.34
Percentage		46.67	53.33

Determined by ArcGIS mapping procedures.

Table 8. Belowground biomass for plant root weight (lbs/ac and kg/m^3) and rhizosphere weight (lbs/ac and kg/m^3) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Belowground Biomass				
Site: Sandy	lb/ac Grazed	kg/m^3 Grazed	lbs/ac Exclosure	kg/m^3 Exclosure	% Difference
Root Biomass	44,175.84	32.48	19,517.34	14.35	-55.82
Rhizosphere Biomass	232,589.59	171.01	141,096.10	103.74	-39.34

Table 9. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Site: Sandy	lbs/ac Grazed	mg/kg Grazed	lbs/ac Exclosure	mg/kg Exclosure	% Difference
Mineral Nitrogen	31.52	9.66	23.52	7.21	-25.38
Nitrate	6.33	1.94	7.33	2.25	15.80
Ammonium	25.19	7.72	16.19	4.96	-35.73

Table 10. Similarity index of range condition for the grazed area and ungrazed area on the reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	Similarity Index of Range Condition		
	Grazed Area	Ungrazed Area	% Difference
Sandy	59.8	36.8	-38.4
	Low Good	Low Fair	

Shallow Ecological Site

The Shallow Ecological Site (figures 7, 8, and 9) was classified by Hanson and Whitman (1938) as the Grama-Needlegrass-Sedge Grassland Type with blue grama, needle and thread, upland sedges, western wheatgrass, and prairie Junegrass as the major vegetation. The loamy fine sand soil was the Telfer-Lihen complex, sandy, mixed, frigid Entic Haploborolls. The plant community and belowground characteristics data after 75 years of treatment are on tables 11 to 19 and figures 10 and 11.

Herbage biomass of native grasses was 1086.10 lbs/ac on the grazed area and 181.26 lbs/ac on the ungrazed area, with an 83.3% decrease on the ungrazed area. Herbage biomass of cool season grasses, warm season grasses, and sedges decreased 96.1%, 98.3%, and 46.2%, respectively, on the ungrazed area. Herbage biomass of domesticated grasses was 0.0 lbs/ac on the grazed area and 1299.47 lbs/ac on the ungrazed area, with a 100.0% increase on the ungrazed area. Herbage biomass of forbs was 183.40 lbs/ac on the grazed area and 316.12 lbs/ac on the ungrazed area, with a 72.4% increase on the ungrazed area. Native cool season grasses had the greatest herbage biomass on the grazed area and domesticated grasses had the greatest herbage biomass on the ungrazed area. Total live herbage biomass was 1269.49 lbs/ac on the grazed area and 1796.84 lbs/ac on the ungrazed area, with a 41.5% increase on the ungrazed area. The total live herbage biomass produced on the grazed area was low and around 30% less than the quantity that would have been expected. The quantity of standing dead biomass on the grazed area was almost nonexistent at 3.57 lbs/ac. Standing dead biomass on the ungrazed area was 376.07 lbs/ac, with a 10434.2% increase on the ungrazed area. Litter was 70.65 lbs/ac on the grazed area and 643.67 lbs/ac on the ungrazed area, with an 811.1% increase on the ungrazed area. Total dead biomass was 74.22 lbs/ac on the grazed area and 1019.74 lbs/ac on the ungrazed area, with a 1273.9% increase on the ungrazed area. The total aboveground plant biomass was comprised of 36.2% dead biomass on the ungrazed area (table 11).

Relative composition of native grass biomass was 85.6% on the grazed area and 10.1% on the ungrazed area, with an 88.2% decrease on the ungrazed area. Composition of cool season grasses, warm season grasses, and sedges decreased 97.2%, 98.8%, and 61.9%, respectively, on the ungrazed area. Composition of domesticated grass biomass was 0.0 % on the grazed area and 72.3% on the ungrazed area, with a 100.0% increase on the ungrazed area. Composition of forb biomass was 14.5% on the grazed area and 17.6% on the ungrazed area, with a 21.7% increase on the ungrazed area. Composition of total live herbage biomass was 94.5% on the grazed area and 63.8% on the ungrazed area, with a 32.5% decrease on the ungrazed area. Composition of total dead biomass was 5.5% on the grazed area and 36.2% on the ungrazed area, with a 555.8% increase on the ungrazed area (table 11). Similarity index of herbage biomass was 12.3% indicating that the composition of biotype categories on the grazed area and on the ungrazed area were dissimilar (table 11).

Basal cover of native grasses was 32.2% on the grazed area and 11.7% on the ungrazed area, with a 63.8% decrease on the ungrazed area. Basal cover of cool season grasses and warm season grasses decreased 88.7% and 98.2%, respectively, and basal cover of sedges increased 1.9% on the ungrazed area. Basal cover of domesticated grasses was 0.0% on the grazed area and 5.8% on the ungrazed area, with a 100.0% increase on the ungrazed area. Blue grama, upland sedges, and prairie Junegrass had the greatest basal covers on the grazed area and upland sedges and Kentucky bluegrass had the greatest basal covers on the ungrazed area. Total live basal cover was 34.9% on the grazed area and 19.1% on the ungrazed area, with a 45.3% decrease on the ungrazed area (table 12).

Basal cover of mid grasses, short grasses, and upland sedges were 3.2%, 18.7%, and 10.3%, respectively, on the grazed area and were 0.5%, 0.7%, and 10.5%, respectively, on the ungrazed area. Mid grass and short grass basal cover decreased 84.4% and 96.5%, respectively, and upland sedge basal cover increased 1.9% on the ungrazed area. Basal cover of mid grasses and short grasses were greater on the grazed area and basal cover of upland sedges and domesticated grasses were greater on the ungrazed area.

Basal cover of native grasses with short shoots and basal leaves was 31.5% on the grazed area and 11.6% on the ungrazed area, with 63.5% decrease on the ungrazed area. Basal cover of native grasses with long shoots and stem leaves was 0.7% on the grazed area and 0.1% on the ungrazed area, with a 84.6% decrease on the ungrazed area. Grasses with short shoots and basal leaves protect the soil and restrict invasion by undesirable plants. The high losses of grasses with short shoots and basal leaves provided the open spaces for the great increase of domesticated grasses on the ungrazed area.

Relative composition of native grass basal cover was 92.3% on the grazed area and 61.2% on the ungrazed area, with a 33.7% decrease on the ungrazed area. Composition of cool season grasses and warm season grasses decreased 79.3% and 96.7%, respectively, and composition of sedges increased 86.5% on the ungrazed area. Composition of domesticated grass basal cover was 0.0% on the grazed area and 30.5% on the ungrazed area, with a 100.0% increase on the ungrazed area (table 12). Similarity index of basal cover was 34.2% indicating that the importance value of the grass species on the grazed area and on the ungrazed area were more dissimilar than similar (table 12).

Total forb density was 23.8 forbs/0.10 m^2 on the grazed area and 9.9 forbs/0.10 m^2 on the ungrazed area, with a 58.5% decrease on the ungrazed area. The total forb density on the grazed area was high and around double the quantity that would have been expected. The forb component was composed mostly of native plants, 96.3% on the grazed area and 99.2% on the ungrazed area, and introduced forbs comprised 3.7% on the grazed area and 0.8% on the ungrazed area. Density of late and early succession forbs decreased 82.6% and 90.9%, respectively, and density of mid succession forbs increased 1533.3% on the ungrazed area (table 13). Nine late succession forbs grew only on the grazed area and were not present on the ungrazed area (table 42). The ungrazed area had a 50.0% decrease in the number of forb species present. Pussytoes, fringed sage, and white sage had the greatest densities on the grazed area and blue wild lettuce, blazing star, and wavy leaf thistle had the greatest densities on the ungrazed area. Blue wild lettuce had the greatest increase of the forbs on the ungrazed area.

Relative composition of late, mid, and early succession forb density was 94.6%, 1.5%, and 3.7%, respectively, on the grazed area and 39.7%, 59.5%, and 0.8%, respectively, on the ungrazed area. Composition of late and early succession forbs decreased 58.1% and 78.1%, respectively, and composition of mid succession forbs increased 3841.1% on the ungrazed area (table 13). Relative composition of forbs was primarily late succession forbs on the grazed area and was mostly mid succession forbs on the ungrazed area. Similarity index of forb density was 10.8% indicating that the importance value of the forb species on the grazed area and on the ungrazed area were dissimilar (table 13).

Shrub density was 0.24 shrubs/1.0 m^2 on the grazed area and 3.0 shrubs/1.0 m^2 on the ungrazed area, with a 1150.0% increase on the ungrazed area (table 14). This quantitative method greatly undersampled the woody plants located within the exclosure. Compilation of the woody species present list identified two shrub species on the grazed area and five shrub species and two tree species on the ungrazed area (table 15). Similarity index of woody shrubs and trees present was 28.6% indicating that the number of woody species present on the grazed area and on the ungrazed area were more dissimilar than similar (table 15). A greater number of woody species and a greater number of individual woody plants were present on the ungrazed exclosure than were on the grazed area (figure 10). The ArcGIS mapping procedures identified 2.15 acres (43.9%) of nonwoody grass plant communities and 2.75 acres (56.1%) of woody shrub and tree infested plant communities on the west 4.90 acre Shallow Ecological Site exclosure (figure 11 and table 16). The woody plant communities occupy a greater proportion of the ungrazed exclosure.

After 75 years of seasonlong grazing, the aboveground vegetation biomass on the grazed area consisted of 5.5% standing dead and litter and 94.5% live herbage. The live herbage was 0.0% domesticated grasses, 85.6% native grasses (45.9% cool season grasses, 22.7% upland sedges, and 17.0% warm season grasses), and 14.5% forbs. After 75 years of nongrazing, the aboveground vegetation biomass on the ungrazed exclosure consisted of 36.2% standing dead and litter and 63.8% live herbage. The live herbage was 72.3% domesticated grasses, 10.1% native grasses (8.6% upland sedges, 1.3% cool season grasses, 0.2% warm season grasses), and 17.6% forbs (table 11).

Total belowground plant root biomass was 46,964.03 lbs/ac (34.53 kg/m^3) on the grazed area and 36,545.71 lbs/ac (26.87 kg/m^3) on the ungrazed area, with a 22.2% decrease on the ungrazed area (table 17). The 22.2% decrease of the total belowground plant root biomass on the ungrazed area coincided with the 45.3% decrease of the total aboveground live plant basal cover on the ungrazed area.

Rhizosphere biomass was 207,536.67 lbs/ac (152.59 kg/m^3) on the grazed area and 222,892.13 lbs/ac (163.88 kg/m^3) on the ungrazed area, with a 7.4% increase on the ungrazed area (table 17). Basal cover of native grasses was 32.2% on the grazed area and 11.7% on the ungrazed area. Basal cover of domesticated grasses was 0.0% on the grazed area and 5.8% on the ungrazed area. The rhizosphere biomass on the ungrazed area was greater than the rhizosphere biomass on the grazed area which was different than the other ecological sites that had greater rhizosphere biomass on the grazed area. The decrease in rhizosphere biomass on the grazed area had occurred at an accelerated rate in the recent past. The degradation of the belowground rhizosphere community occurred before the degradation of the aboveground plant community. The aboveground native plant herbage biomass had decreased below expected quantities and forb density was greater than expected. However, the basal cover and relative composition of native grasses and of domesticated grasses, and the range condition on the grazed area had not yet had similar unexpected changes. In the near future, basal cover and relative composition of native grasses and range condition on the grazed area will decrease greatly and basal cover and relative composition of domesticated grasses on the grazed area will increase greatly. The rhizosphere biomass on the ungrazed area will continue to decrease at the long-term rate and precede future decreases in native grass basal cover, that will be followed by future increases in domesticated grass basal cover on the ungrazed area.

The total available soil mineral nitrogen of nitrate and ammonium was 33.12 lbs/ac on the grazed area and 41.26 lbs/ac on the exclosure, with an increase of 24.6% on the exclosure. The quantity of nitrate was 6.00 lbs/ac on both the grazed area and the exclosure. The quantity of ammonium was 27.12 lbs/ac on the grazed area and 35.26 lbs/ac on the exclosure, with an increase of 30.0% on the ungrazed exclosure (table 18). The quantities of mineral nitrogen were not significantly different on the grazed area and the ungrazed exclosure. The quantities of nitrate were low. The grazed area had extremely low amounts of total mineral nitrogen and ammonium; these values were much lower than would have been expected. The exclosure had slightly more total mineral nitrogen and ammonium. The belowground ecosystem biogeochemical processes on the grazed area have degraded at an accelerated rate in the recent past. The aboveground basal cover and relative composition of native grasses and domesticated grasses on the grazed area have not yet degraded, but will soon follow the degraded belowground processes.

Similarity index of range condition on the grazed area was 68.4%, good condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was more similar than dissimilar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 19). Similarity index of range condition on the ungrazed area was 20.1%, poor condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was dissimilar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 19). The current plant community of the ungrazed area had degraded from the hypothetical historical shallow ecological site plant community 70.6% greater than the degradation of the current plant community on the grazed area after 75 years (table 19).

The effects from long-term nongrazing on the shallow ecological site were great after 75 years. Native grass herbage biomass decreased 83.3% and basal cover decreased 63.8% on the ungrazed area. Cool season grass, warm season grass, and sedge herbage biomass decreased 96.1%, 98.3%, and 46.2%, respectively, on the ungrazed area. Cool season grass and warm season grass basal cover decreased 88.7% and 98.2%, respectively, on the ungrazed area. Sedge basal cover increased 1.9% on the ungrazed area. Domesticated grass herbage biomass increased 100.0% and basal cover increased 100.0% on the ungrazed area. Forb herbage biomass increased 72.4%, forb density decreased 58.5%, and the number of forb species present decreased 50.0% on the ungrazed area. The number of shrub and tree species present increased 250.0% on the ungrazed area. Woody plants infested 56.1% of the area on the ungrazed exclosure. Total live plant basal cover decreased 45.3% on the ungrazed area. Total live herbage biomass increased 41.5% because the increase in domesticated grasses was greater than the decrease in native grasses on the ungrazed area. Total dead biomass increased 1273.9% on the ungrazed area (tables 11, 12, 13, 14, 15, and 16). Belowground plant root biomass decreased 22.2% on the ungrazed area (table 17). Rhizosphere biomass increased 7.4% on the ungrazed area because the recent rate of decrease in rhizosphere biomass was greatly accelerated on the grazed area (table 17). Mineral nitrogen increased 24.6% on the ungrazed area because of the recent decrease of the biogeochemical processes on the grazed area (table 18).

Similarity indices of herbage biomass, basal cover, forb density, and shrubs present were 12.3%, 34.2%, 10.8%, and 28.6%, respectively. Similarity indices of herbage biomass and forb density indicated that the plant communities on the grazed area and on the ungrazed area were dissimilar. Similarity indices of basal cover and shrubs and trees present indicated that the plant communities on the grazed area and on the ungrazed area were more dissimilar than similar. Similarity index of range condition indicated that the current plant community on the ungrazed area had degraded 70.6% greater than the current plant community on the grazed area.

Figure 7. Shallow Ecological Site, located in Sec. 5, T 138 N, R 101 W, exclosure of 6.50 acres, built in 1937, looking North.

Figure 8. Shallow Ecological Site, located in Sec. 5, T 138 N, R 101 W, exclosure of 6.50 acres, built in 1937, looking East.

Figure 9. Shallow Ecological Site, located in Sec. 5, T 138 N, R 101 W, exclosure of 6.50 acres, built in 1937, looking South.

Table 11. Herbage biomass (lbs/ac) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Herbage Biomass			Relative Composition		
Site: Shallow	lbs/ac Grazed	lbs/ac Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	0.00	1299.47	+100.00	0.00	72.32	+100.00
Native Cool Season	583.01	22.84	-96.08	45.92	1.27	-97.23
Native Warm Season	215.51	3.57	-98.34	16.98	0.20	-98.82
Sedges	287.58	154.85	-46.15	22.65	8.62	-61.94
Native Grass	1086.10	181.26	-83.31	85.55	10.09	-88.21
Total Grass	1086.10	1480.72	+36.33	85.55	82.41	-3.67
Forbs	183.40	316.12	+72.37	14.45	17.59	+21.73
Total Live	1269.49	1796.84	+41.54	94.48	63.80	-32.47
Standing Dead	3.57	376.07	+10434.17	0.27	13.35	+4844.44
Litter	70.65	643.67	+811.07	5.26	22.85	+334.41
Total Dead	74.22	1019.74	+1273.94	5.52	36.20	+555.80
Total Live & Dead	1343.71	2816.58	+109.61			
		Similarity Index of Herbage Biomass				
Similarity Index	12.3%	(Dissimilar)				

Table 12. Basal cover (%) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Basal Cover			Relative Composition		
Site: Shallow	% Grazed	% Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	0.00	5.80	+100.00	0.00	30.45	+100.00
Native Cool Season	7.95	0.90	-88.68	22.81	4.72	-79.31
Native Warm Season	13.90	0.25	-98.20	39.89	1.31	-96.72
Sedges	10.30	10.50	+1.94	29.56	55.12	+86.47
Native Grass	32.15	11.65	-63.76	92.25	61.15	-33.71
Total Grass	32.15	17.45	-45.72	92.25	91.60	-0.70
Forbs	2.70	1.55	-42.59	7.75	8.14	+5.03
Woody Species	0.00	0.05	-	0.00	0.26	-
Total Live	34.85	19.05	-45.34	35.74	20.06	-43.87
Litter	62.65	75.90	+21.15	64.26	79.94	+24.40
Total Live & Dead	97.50	94.95				

Similarity Index of Basal Cover

Similarity Index	34.2%	(More dissimilar than similar)

Table 13. Forb density (#/0.10 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Shallow	#/0.10 m^2 Grazed	#/0.10 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Late Succession Forbs	22.52	3.92	-82.59	94.62	39.68	-58.06
Mid Succession Forbs	0.36	5.88	+1533.33	1.51	59.51	+3841.06
Early Succession Forbs	0.88	0.08	-90.91	3.70	0.81	-78.11
Woody Species	0.04	0.00	-	0.17	0.00	-
Total Live	23.80	9.88	-58.49			
	Similarity Index of Forb Density					
Similarity Index	10.8%	(Dissimilar)				

Table 14. Shrub density (#/1.0 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Shallow	#/1.0 m^2 Grazed	#/1.0 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Artemisia cana	0.00	0.00	-	0.00	0.00	-
Rosa arkansana	0.24	3.00	+1150.00	100.00	100.00	-
Symphoricarpos occidentalis	0.00	0.00	-	0.00	0.00	-
Total Live	0.24	3.00	+1150.00			

Table 15. Shrubs, cacti, and trees present on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Shallow	
	Grazed	Exclosure
Artemisia cana		X
Prunus virginiana		X
Rhus trilobata		X
Rosa arkansana	X	X
Symphoricarpos occidentalis	X	X
Fraxinus pennsylvanica		X
Juniperus scopulorum		X
	Similarity Index of Shrubs Present	
Similarity Index	28.6% (More dissimilar than similiar)	

Figure 10. Shallow Ecological Site, exclosure with increased woody vegetation.

Figure 11. Shallow Ecological Site exclosure with Woody shrub and tree infested plant communities and Nonwoody grass plant communities in the Little Missouri River Badlands, 1936-2011.

Table 16. Woody shrub and tree infested plant communities and Nonwoody grass plant communites in the Little Missouri River Badlands, 1936-2011.

		Major Plant Communities	
Site: Shallow			
	Total Exclosure Area	Nonwoody Grass	Woody Shrub and Tree Infested
Acres	4.90	2.15	2.75
Percentage		43.90	56.10

Determined by ArcGIS mapping procedures.

Table 17. Belowground biomass for plant root weight (lbs/ac and kg/m^3) and rhizosphere weight (lbs/ac and kg/m^3) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Belowground Biomass				
Site: Shallow	lb/ac Grazed	kg/m^3 Grazed	lbs/ac Exclosure	kg/m^3 Exclosure	% Difference
Root Biomass	46,964.03	34.53	36,545.71	26.87	-22.18
Rhizosphere Biomass	207,536.67	152.59	222,892.13	163.88	7.40

Table 18. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Site: Shallow	lbs/ac Grazed	mg/kg Grazed	lbs/ac Exclosure	mg/kg Exclosure	% Difference
Mineral Nitrogen	33.12	10.15	41.26	12.64	24.58
Nitrate	6.00	1.84	6.00	1.84	0.0
Ammonium	27.12	8.31	35.26	10.80	30.01

Table 19. Similarity index of range condition for the grazed area and ungrazed area on the reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	Similarity Index of Range Condition		
	Grazed Area	Ungrazed Area	% Difference
Shallow	68.4	20.1	-70.6
	Good	Poor	

Silty Ecological Site

The Silty Ecological Site (figures 12, 13, and 14) was classified by Hanson and Whitman (1938) as the Wheatgrass-Grama-Sedge Grassland Type with western wheatgrass, blue grama, upland sedge, needle and thread, and prairie Junegrass as the major vegetation. The silt loam soil was a Farland-like series, fine-silty, mixed, superactive, Typic Argiborolls. The plant community and belowground characteristics data after 75 years of treatment are on tables 20 to 28 and figures 15 and 16.

Herbage biomass of native grasses was 857.04 lbs/ac on the grazed area and 215.50 lbs/ac on the ungrazed area, with a 74.9% decrease on the ungrazed area. Herbage biomass of cool season grasses, warm season grasses, and sedges decreased 80.0%, 99.7%, and 23.9%, respectively, on the ungrazed area. Herbage biomass of domesticated grasses was 692.91 lbs/ac on the grazed area and 1427.91 lbs/ac on the ungrazed area, with a 106.1% increase on the ungrazed area. Herbage biomass of forbs was 124.88 lbs/ac on the grazed area and 149.86 lbs/ac on the ungrazed area, with a 20.0% increase on the ungrazed area. Domesticated grasses had the greatest herbage biomass on both the grazed area and the ungrazed area. Total live herbage biomass was 1674.82 lbs/ac on the grazed area and 1793.28 lbs/ac on the ungrazed area, with a 7.1% increase on the ungrazed area. Standing dead biomass was 112.04 lbs/ac on the grazed area and 494.52 lbs/ac on the ungrazed area, with a 341.4% increase on the ungrazed area. Litter was 563.03 lbs/ac on the grazed area and 2162.21 lbs/ac on the ungrazed area, with a 284.0% increase on the ungrazed area. Total dead biomass was 675.07 lbs/ac on the grazed area and 2656.73 lbs/ac on the ungrazed area, with a 293.6% increase on the ungrazed area (table 20). The total aboveground plant biomass was comprised of 59.7% dead biomass on the ungrazed area. The ungrazed area had 48.2% greater total dead biomass than total live herbage biomass.

Relative composition of native grass biomass was 51.2% on the grazed area and 12.0% on the ungrazed area, with a 76.5% decrease on the ungrazed area. Composition of cool season grasses, warm season grasses, and sedges decreased 81.3%, 99.7%, and 28.9%, respectively, on the ungrazed area. Composition of domesticated grass biomass was 41.4% on the grazed area and 79.6% on the ungrazed area, with a 92.5% increase on the ungrazed area. Composition of forb biomass was 7.5% on the grazed area and 8.4% on the ungrazed area, with a 12.1% increase on the ungrazed area. Composition of total live herbage biomass was 71.3% on the grazed area and 40.3% on the ungrazed area, with a 43.5% decrease on the ungrazed area. Composition of total dead biomass was 28.7% on the grazed area and 59.7% on the ungrazed area, with a 107.8% increase on the ungrazed area (table 20). Similarity index of herbage biomass was 30.4% indicating that the composition of biotype categories on the grazed area and on the ungrazed area were more dissimilar than similar (table 20).

Basal cover of native grasses was 11.7% on the grazed area and 1.2% on the ungrazed area, with a 90.2% decrease on the ungrazed area. Basal cover of cool season grasses, warm season grasses, and sedges decreased 100.0%, 100.0%, and 79.8%, respectively, on the ungrazed area. Basal cover of domesticated grasses was 17.5% on the grazed area and 11.7% on the ungrazed area, with a 33.2% decrease on the ungrazed area. The domesticated grass basal cover on the grazed area was 49.6% greater than the basal cover on the ungrazed area, however, the domesticated grass herbage biomass on the grazed area was 51.5% less than the herbage biomass on the ungrazed area, indicating that the domesticated grass tillers on the grazed area were numerous but small compared to the large and robust domesticated grass tillers on the ungrazed area. Kentucky bluegrass and upland sedges had the greatest basal covers on both the grazed area and the ungrazed area. Total live basal cover was 30.1% on the grazed area and 15.2% on the ungrazed area, with a 49.4% decrease on the ungrazed area (table 21). The decrease in basal cover of the native grasses and the increase in basal cover of domesticated grasses on both the grazed area and ungrazed area on the silty ecological site was greater than the respective changes in basal cover on the sandy, shallow, and overflow ecological sites.

Basal cover of mid grasses, short grasses, and upland sedges were 2.3%, 3.8%, and 5.7%, respectively, on the grazed area and were 0.0%, 0.0%, and 1.2%, respectively, on the ungrazed area. Mid grass, short grass, and upland sedge basal cover decreased 100.0%, 100.0%, and 79.8%, respectively, on the ungrazed area. Basal cover of mid grasses, short grasses, upland sedges, and domesticated grasses were greater on the grazed area.

Basal cover of native grasses with short shoots and basal leaves was 10.7% on the grazed area and 1.2% on the ungrazed area, with 89.2% decrease on the ungrazed area. Basal cover of native grasses with long shoots and stem leaves was 1.1% on the grazed area and 0.0% on the ungrazed area, with a 100.0% decrease on the ungrazed area. Grasses with short shoots and basal leaves protect the soil and restrict invasion by undesirable plants. The high losses of grasses with short shoots and basal leaves provided the open spaces for the great increase of domesticated grasses on the ungrazed area.

Relative composition of native grass basal cover was 38.9% on the grazed area and 7.6% on the ungrazed area, with an 80.6% decrease on the ungrazed area. Composition of cool season grasses, warm season grasses and sedges decreased 100.0%, 100.0%, and 60.1%, respectively, on the ungrazed area. Composition of domesticated grass basal cover was 58.1% on the grazed area and 76.6% on the ungrazed area, with a 32.0% increase on the ungrazed area (table 21). Similarity index of basal cover was 59.7% indicating that the importance value of the grass species on the grazed area and on the ungrazed area were more similar than dissimilar (table 21). The high similarity index of basal cover of the plant communities on the silty ecological site was a result of the similar high relative composition of domesticated grasses on both the grazed area and the ungrazed area.

Total forb density was 10.5 forbs/0.10 m^2 on the grazed area and 12.8 forbs/0.10 m^2 on the ungrazed area, with a 22.1% increase on the ungrazed area. The forb component was composed mostly of native plants, 77.5% on the grazed area and 100.0% on the ungrazed area, and introduced forbs comprised 22.5% on the grazed area and 0.0% on the ungrazed area. However, the ungrazed area had a large patch of leafy spurge that did not extend to the sample site and a small patch of leafy spurge was present on the grazed area that extended into the sample site. Density of late succession forbs increased 145.3% and density of mid and early succession forbs decreased 92.5% and 100.0%, respectively, on the ungrazed area (table 22). Five late succession forbs grew only on the grazed area and were not present on the ungrazed area (table 42). The ungrazed area had a 56.3% decrease in the number of forb species present. The density of late succession forbs was less than expected, the density of mid and early succession forbs was greater than expected, and the composition of introduced forbs was greater than expected on the grazed area. Blue wild lettuce, white sage, and dandelion had the greatest densities on the grazed area and white sage, wavy leaf thistle, and blue wild lettuce had the greatest densities on the ungrazed area. White sage and wavy leaf thistle had the greatest increases of the forbs on the ungrazed area.

Relative composition of late, mid, and early succession forb density was 48.9%, 30.5%, and 20.6%, respectively, on the grazed area and 98.1%, 1.9%, and 0.0%, respectively, on the ungrazed area. Composition of late succession forbs increased 100.9% and composition of mid and early succession forbs decreased 93.8% and 100.1%, respectively, on the ungrazed area (table 22). Relative composition of forbs was mostly late and mid succession forbs on the grazed area and was primarily late succession forbs on the ungrazed area. Similarity index of forb density was 31.8% indicating that the importance value of the forb species on the grazed area and on the ungrazed area were more dissimilar than similar (table 22).

Shrub density collected by the 1.0 m^2 quadrat method measured no shrubs on the grazed and ungrazed sample transect lines (table 23). This quantitative method greatly undersampled the woody plants located within the exclosure. Compilation of the woody species present list identified two shrub species on the grazed area and nine shrub species, one cactus species, and two tree species on the ungrazed area (table 24). Similarity index of woody shrubs and trees present was 16.7% indicating that the number of woody species present on the grazed area and on the ungrazed area were dissimilar (table 24). A greater number of woody species and a greater number of individual woody plants were present on the ungrazed exclosure than were on the grazed area (figure 15). The ArcGIS mapping procedures identified 6.52 acres (46.2%) of nonwoody grass plant communities and 7.58 acres (53.8%) of woody shrub and tree infested plant communities on the 14.10 acre Silty Ecological Site exclosure (figure 16 and table 25). The woody plant communities occupy a greater proportion of the ungrazed exclosure.

After 75 years of seasonlong grazing, the aboveground vegetation biomass on the grazed area consisted of 28.7% standing dead and litter and 71.3% live herbage. The live herbage was 41.4% domesticated grasses, 51.2% native grasses (30.3% cool season grasses, 12.0% warm season grasses, and 8.9% upland sedges), and 7.5% forbs. After 75 years of nongrazing, the aboveground vegetation biomass on the ungrazed exclosure consisted of 59.7% standing dead and litter and 40.3% live herbage. The live herbage was 79.6% domesticated grasses, 12.0% native grasses (6.3% upland sedges, 5.7% cool season grasses, and less than 0.1% warm season grasses), and 8.4% forbs (table 20).

Total belowground plant root biomass was 33,757.52 lbs/ac (24.82 kg/m^3) on the grazed area and 22,754.37 lbs/ac (16.73 kg/m^3) on the ungrazed area, with a 32.6% decrease on the ungrazed area (table 26). The 32.6% decrease of the total belowground plant root biomass on the ungrazed area coincided with the 49.4% decrease of the total aboveground live plant basal cover on the ungrazed area.

Rhizosphere biomass was 188,549.76 lbs/ac (138.63 kg/m^3) on the grazed area and 179,641.15 lbs/ac (132.08 kg/m^3) on the ungrazed area, with a 4.7% decrease on the ungrazed area (table 26). Composition of native grasses was 38.9% on the grazed area and 7.6% on the ungrazed area. Composition of domesticated grasses was 58.1% on the grazed area and 76.6% on the ungrazed area. The rhizosphere biomass on the ungrazed area was only slightly less than the rhizosphere biomass on the grazed area. The greater than expected decrease in rhizosphere biomass on the grazed area had occurred over a long period of time. The degradation of the belowground rhizosphere community occurred before the degradation of the aboveground plant community. The rhizosphere biomass on the grazed area of the silty ecological site was less than the rhizosphere biomass on the grazed areas of the sandy, shallow, and overflow ecological sites. The aboveground native grass herbage biomass and basal cover had decreased below expected quantities on the grazed area. The density of late succession forbs had decreased below expected quantities on the grazed area. The domesticated grass herbage biomass and basal cover had increased well above expected quantities on the grazed area. Both the belowground rhizosphere community and the aboveground plant community had deteriorated on the grazed area over a long time period. The decrease in rhizosphere biomass on both the grazed area and ungrazed area preceded the decrease in native grass composition on both the grazed area and ungrazed area, that was followed by the increase in domesticated grass composition on both the grazed area and ungrazed area. The degradation of the belowground rhizosphere community and the aboveground plant community on the ungrazed area was greater than that of the belowground and aboveground communities on the grazed area.

The total available soil mineral nitrogen of nitrate and ammonium was 46.62 lbs/ac on the grazed area and 42.02 lbs/ac on the exclosure, with a decrease of 9.9% on the ungrazed exclosure. The quantity of total mineral nitrogen was greater on the grazed area than on the exclosure. The quantities of mineral nitrogen were not significantly different on the grazed area and the exclosure. The quantity of nitrate was 11.00 lbs/ac on the grazed area and 10.00 lbs/ac on the exclosure, with a decrease of 9.1% on the ungrazed exclosure. The quantity of ammonium was 35.62 lbs/ac on the grazed area and 32.02 lbs/ac on the exclosure, with a decrease of 10.1% on the ungrazed exclosure (table 27). The amount of nitrate was slightly elevated on both the grazed area and the exclosure. The greater quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. Both the grazed area and the exclosure had high domesticated grass basal cover. The grazed area had greater ammonium. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

Similarity index of range condition on the grazed area was 53.6%, low good condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was slightly more similar than dissimilar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 28). Similarity index of range condition on the ungrazed area was 19.1%, poor condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was dissimilar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 28). The current plant community of the ungrazed area had degraded from the hypothetical historical silty ecological site plant community 64.4% greater than the degradation of the current plant community on the grazed area after 75 years (table 28).

The effects from long-term nongrazing on the silty ecological site were great after 75 years. Native grass herbage biomass decreased 74.9% and basal cover decreased 90.2% on the ungrazed area. Cool season grass, warm season grass, and sedge herbage biomass decreased 80.0%, 99.7%, and 23.9%, respectively, and basal cover decreased 100.0%, 100.0%, and 79.8%, respectively, on the ungrazed area. Domesticated grass herbage biomass increased 106.1% and basal cover decreased 33.2% on the ungrazed area. The silty ecological site had the greatest domesticated grass basal cover on both the grazed area and the ungrazed area. Forb herbage biomass increased 20.0%, forb density increased

22.1%, and the number of forb species present decreased 56.3% on the ungrazed area. The number of shrub and tree species present increased 500.0% on the ungrazed area. Woody plants infested 53.8% of the area on the ungrazed exclosure. Total live plant basal cover decreased 49.4% on the ungrazed area. Total live herbage biomass increased 7.1% because the increase in domesticated grasses was greater than the decrease in native grasses on the ungrazed area. Total dead biomass increased 293.6% on the ungrazed area (tables 20, 21, 22, 23, 24, and 25). Belowground plant root biomass decreased 32.6% on the ungrazed area (table 26). Rhizosphere biomass decreased 4.7% on the ungrazed area because the rate of rhizosphere biomass decrease on the ungrazed area was only slightly greater than the rate of rhizosphere biomass decrease on the grazed
area (table 26). Mineral nitrogen decreased 9.9% on the ungrazed area (table 27).

Similarity indices of herbage biomass, basal cover, forb density, and shrubs present were 30.4%, 59.7%, 31.8%, and 16.7%, respectively. Similarity indices of shrubs and trees present indicated that the plant communities on the grazed area and on the ungrazed area were dissimilar. Similarity indices of herbage biomass and forb density indicated that the plant communities on the grazed area and on the ungrazed area were more dissimilar than similar. Similarity index of basal cover indicated that the plant comminities on the grazed area and on the ungrazed area were more similar than dissimilar because both the grazed area and ungrazed area had greatly decreased native grass basal cover and had greatly increased domesticated grass basal cover. Similarity index of range condition indicated that the current plant community on the ungrazed area had degraded 64.4% greater than the current plant community on the grazed area.

Figure 12. Silty Ecological Site, located in Sec. 3, T 138 N, R 101 W, exclosure of 14.10 acres, built in 1938, looking North.

Figure 13. Silty Ecological Site, located in Sec. 3, T 138 N, R 101 W, exclosure of 14.10 acres, built in 1938, looking East.

Figure 14. Silty Ecological Site, located in Sec. 3, T 138 N, R 101 W, exclosure of 14.10 acres, built in 1938, looking South.

Table 20. Herbage biomass (lbs/ac) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Herbage Biomass			Relative Composition		
Site: Silty	lbs/ac Grazed	lbs/ac Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	692.91	1427.91	+106.07	41.37	79.63	+92.48
Native Cool Season	506.66	101.33	-80.00	30.25	5.65	-81.32
Native Warm Season	201.24	0.71	-99.65	12.02	0.04	-99.67
Sedges	149.14	113.46	-23.93	8.90	6.33	-28.88
Native Grass	857.04	215.50	-74.86	51.17	12.02	-76.51
Total Grass	1549.94	1643.42	+6.03	92.54	91.64	-0.97
Forbs	124.88	149.86	+20.00	7.46	8.36	+12.06
Total Live	1674.82	1793.28	+7.07	71.27	40.30	-43.45
Standing Dead	112.04	494.52	+341.38	4.77	11.11	+132.91
Litter	563.03	2162.21	+284.03	23.96	48.59	+102.80
Total Dead	675.07	2656.73	+293.55	28.73	59.70	+107.80
Total Live & Dead	2349.89	4450.01	+89.37			
		Similarity Index of Herbage Biomass				
Similarity Index	30.4%	(More dissimilar than similar)				

Table 21. Basal cover (%) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Basal Cover			Relative Composition		
Site: Silty	% Grazed	% Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	17.45	11.65	-33.24	58.07	76.64	+31.98
Native Cool Season	3.25	0.00	-100.00	10.82	0.00	-100.00
Native Warm Season	2.75	0.00	-100.00	9.15	0.00	-100.00
Sedges	5.70	1.15	-79.82	18.97	7.57	-60.09
Native Grass	11.70	1.15	-90.17	38.94	7.57	-80.56
Total Grass	29.15	12.80	-56.09	97.00	84.21	-13.19
Forbs	0.90	2.40	+166.67	2.99	15.79	+428.09
Woody Species	0.00	0.00	-	0.00	0.00	-
Total Live	30.05	15.20	-49.42	31.87	15.20	-52.31
Litter	64.25	84.80	+31.98	68.13	84.80	+24.47
Total Live & Dead	94.30	100.00				

Similarity Index of Basal Cover		
Similarity Index	59.7%	(More similar than dissimilar)

Table 22. Forb density (#/0.10 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Silty	#/0.10 m^2 Grazed	#/0.10 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Late Succession Forbs	5.12	12.56	+145.31	48.85	98.13	+100.88
Mid Succession Forbs	3.20	0.24	-92.50	30.53	1.88	-93.84
Early Succession Forbs	2.16	0.00	-100.00	20.61	0.00	-100.00
Woody Species	0.00	0.00	-	0.00	0.00	-
Total Live	10.48	12.80	+22.14			
	Similarity Index of Forb Density					
Similarity Index	31.8%	(More dissimilar than similar)				

Table 23. Shrub density (#/1.0 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Silty	#/1.0 m^2 Grazed	#/1.0 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Artemisia cana	0.00	0.00	-	0.00	0.00	-
Rosa arkansana	0.00	0.00	-	0.00	0.00	-
Symphoricarpos occidentalis	0.00	0.00	-	0.00	0.00	-
Total Live	0.00	0.00	-			

Table 24. Shrubs, cacti, and trees present on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Silty	
	Grazed	Exclosure
Artemisia cana		X
Juniperus communis		X
Juniperus horizontalis		X
Prunus virginiana		X
Rhus trilobata		X
Rosa arkansana	X	X
Shepherdia argentea		X
Symphoricarpos occidentalis	X	X
Yucca glauca		X
Opuntia polyacantha		X
Fraxinus pennsylvanica		X
Juniperus scopulorum		X
Similarity Index of Shrubs Present		
Similarity Index	16.7% (Dissimilar)	

Figure 15. Silty Ecological Site, exclosure with increased woody vegetation.

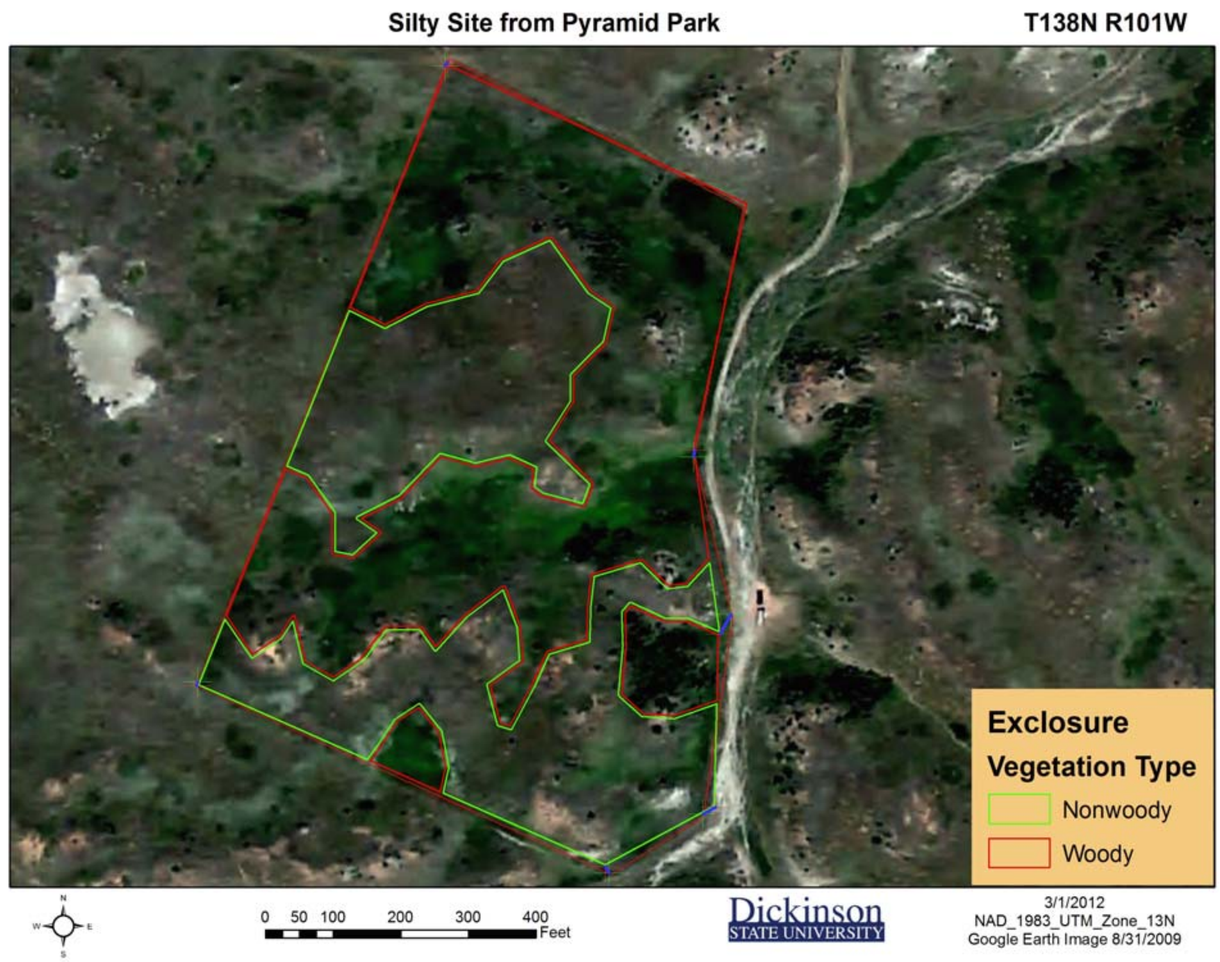

Figure 16. Silty Ecological Site exclosure with Woody shrub and tree infested plant communities and Nonwoody grass plant communities in the Little Missouri River Badlands, 1936-2011.

Table 25. Woody shrub and tree infested plant communities and Nonwoody grass plant communites in the Little Missouri River Badlands, 1936-2011.

Site: Silty	Total Exclosure Area	Major Plant Communities Nonwoody Grass	Woody Shrub and Tree Infested
Acres	14.10	6.52	7.58
Percentage		46.23	53.77

Determined by ArcGIS mapping procedures.

Table 26. Belowground biomass for plant root weight (lbs/ac and kg/m^3) and rhizosphere weight (lbs/ac and b kg/m^3) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Belowground Biomass				
Site: Silty	lb/ac Grazed	kg/m^3 Grazed	lbs/ac Exclosure	kg/m^3 Exclosure	% Difference
Root Biomass	33,757.52	24.82	22,754.37	16.73	-32.59
Rhizosphere Biomass	188,549.76	138.63	179,641.15	132.08	-4.72

Table 27. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Site: Silty	lbs/ac Grazed	mg/kg Grazed	lbs/ac Exclosure	mg/kg Exclosure	% Difference
Mineral Nitrogen	46.62	14.29	42.02	12.88	-9.87
Nitrate	11.00	3.37	10.00	3.07	-9.09
Ammonium	35.62	10.92	32.02	9.81	-10.11

Table 28. Similarity index of range condition for the grazed area and ungrazed area on the reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	Similarity Index of Range Condition		
	Grazed Area	Ungrazed Area	% Difference
Silty	53.6	19.1	-64.4
	Low Good	Poor	

Overflow Ecological Site

The Overflow Ecological Site (figures 17, 18, and 19) was classified by Hanson and Whitman (1938) as the Sagebrush Type with silver sage, western wheatgrass, blue grama, needle and thread, and green needlegrass as the major vegetation. The silt loam soil was the Havrelon series, fine-loamy, mixed (calcareous), frigid Typic Ustifluvents. The plant community and belowground characteristics data after 75 years of treatment are on tables 29 to 37 and figures 20 and 21.

Herbage biomass of native grasses was 1753.31 lbs/ac on the grazed area and 1090.39 lbs/ac on the ungrazed area, with a 37.8% decrease on the ungrazed area. Herbage biomass of cool season grasses, warm season grasses, and sedges decreased 31.9%, 63.0%, and 94.7%, respectively, on the ungrazed area. Herbage biomass of domesticated grasses was 12.13 lbs/ac on the grazed area and 211.94 lbs/ac on the ungrazed area, with a 1647.2% increase on the ungrazed area. Herbage biomass of forbs was 239.06 lbs/ac on the grazed area and 99.90 lbs/ac on the ungrazed area, with a 58.2% decrease on the ungrazed area. Native cool season grasses had the greatest herbage biomass on both the grazed area and the ungrazed area. Total live herbage biomass was 2004.50 lbs/ac on the grazed area and 1402.22 lbs/ac on the ungrazed area, with a 30.1% decrease on the ungrazed area. Standing dead biomass was 300.43 lbs/ac on the grazed area and 1351.56 lbs/ac on the ungrazed area, with a 349.9% increase on the ungrazed area. Litter was 648.66 lbs/ac on the grazed area and 1497.85 lbs/ac on the ungrazed area, with a 130.9% increase on the ungrazed area. Total dead biomass was 949.09 lbs/ac on the grazed area and 2849.41 lbs/ac on the ungrazed area, with a 200.2% increase on the ungrazed area (table 29). The total aboveground plant biomass was comprised of 67.0% dead biomass on the ungrazed area. The ungrazed area has 103.2% greater total dead biomass than total live herbage biomass.

Relative composition of native grass biomass was 87.5% on the grazed area and 77.8% on the ungrazed area, with an 11.1% decrease on the ungrazed area. Composition of cool season grasses, warm season grasses, and sedges decreased 2.7%, 46.9%, and 92.5%, respectively, on the ungrazed area. Composition of domesticated grass biomass was 0.6 % on the grazed area and 15.1% on the ungrazed area, with a 2377.1% increase on the ungrazed area. Composition of forb biomass was 11.9% on the grazed area and 7.1% on the ungrazed area, with a 40.3% decrease on the ungrazed area. Composition of total live herbage biomass was 67.9% on the grazed area and 33.0% on the ungrazed area, with a 51.4% decrease on the ungrazed area. Composition of total dead biomass was 32.1% on the grazed area and 67.0% on the ungrazed area, with a 108.6% increase on the ungrazed area (table 29). Similarity index of herbage biomass was 42.8% indicating that the composition of biotype categories on the grazed area and on the ungrazed area were more dissimilar than similar (table 29).

Basal cover of native grasses was 23.7% on the grazed area and 4.2% on the ungrazed area, with an 82.3% decrease on the ungrazed area. Basal cover of cool season grasses, warm season grasses, and sedges decreased 78.5%, 96.7%, and 91.7%, respectively, on the ungrazed area. Basal cover of domesticated grasses was 0.2% on the grazed area and 4.7% on the ungrazed area, with a 2225.0% increase on the ungrazed area. Western wheatgrass, needle and thread, and blue grama had the greatest basal covers on the grazed area and Kentucky bluegrass and western wheatgrass had the greatest basal covers on the ungrazed area. Total live basal cover was 25.1% on the grazed area and 9.5% on the ungrazed area, with a 62.2% decrease on the ungrazed area (table 30).

Basal cover of mid grasses, short grasses, and upland sedges were 18.4%, 4.7%, and 0.6%, respectively, on the grazed area and were 4.0%, 0.2%, and 0.1%, respectively, on the ungrazed area. Mid grass, short grass, and upland sedge basal cover decreased 78.3%, 96.8%, and 91.7%, respectively, on the ungrazed area. Basal cover of mid grasses, short grasses, and upland sedges were greater on the grazed area and basal cover of domesticated grasses was greater on the ungrazed area.

Basal cover of native grasses with short shoots and basal leaves was 11.8% on the grazed area and 0.3% on the ungrazed area, with 97.5% decrease on the ungrazed area. Basal cover of native grasses with long shoots and stem leaves was 12.0% on the grazed area and 3.9% on the ungrazed area, with a 67.4% decrease on the ungrazed area. Grasses with short shoots and basal leaves protect the soil and restrict invasion by undesirable plants. The high losses of grasses with short shoots and basal leaves provided the open spaces for the great increase of domesticated grasses on the ungrazed area.

Relative composition of native grass basal cover was 94.4% on the grazed area and 44.2% on the ungrazed area, with a 53.2% decrease on the ungrazed area. Composition of cool season grasses, warm season grasses, and sedges decreased 43.2%, 91.2%, and 77.8%, respectively, on the ungrazed area. Composition of domesticated grass basal cover was 0.8% on the grazed area and 49.0% on the ungrazed area, with a 6018.8% increase on the ungrazed area (table 30). Similarity index of basal cover was 46.2% indicating that the importance value of the grass species on the grazed area and on the ungrazed area were more dissimilar than similar (table 30).

Total forb density was 11.9 forbs/0.10 m^2 on the grazed area and 5.2 forbs/0.10 m^2 on the ungrazed area, with a 56.7% decrease on the ungrazed area. The forb component was composed mostly of native plants, 87.2% on the grazed area and 64.3% on the ungrazed area, and introduced forbs comprised 12.8% on the grazed area and 35.7% on the ungrazed area. Leafy spurge comprised 5.4% of the forb component on the ungrazed area. Density of late and mid succession forbs decreased 82.1% and 44.9%, respectively, and density of early succession forbs increased 21.1% on the ungrazed area (table 31). Eight late succession forbs grew only on the grazed area and were not present on the ungrazed area (table 42). The ungrazed area had a 52.9% decrease in the number of forb species present. Black medic, american vetch, and dandelion had the greatest densities on the grazed area and blue wild lettuce, collomia, and western yarrow had the greatest densities on the ungrazed area. Blue wild lettuce had the greatest increase of the forbs on the ungrazed area.

Relative composition of late, mid, and early succession forb density was 54.4%, 32.9%, and 12.8%, respectively, on the grazed area and 22.5%, 41.9%, and 35.7%, respectively, on the ungrazed area. Composition of late succession forbs decreased 58.7% and composition of mid and early succession forbs increased 27.3% and 179.7%, respectively, on the ungrazed area (table 31). Relative composition of forbs was mostly late succession forbs on the grazed area and was mostly mid and early succession forbs on the ungrazed area. Similarity index of forb density was 23.8% indicating that the importance value of the forb species on the grazed area and on the ungrazed area were nearly dissimilar (table 31).

Shrub density was 0.16 shrubs/1.0 m^2 on the grazed area and 3.16 shrubs/1.0 m^2 on the ungrazed area, with a 1875.0% increase on the ungrazed area (table 32). This quantitative method greatly undersampled the woody plants located within the exclosure and on the grazed area. Compilation of the woody species present list identified two shrub species on the grazed area and two shrub species and two tree species on the ungrazed area (table 33). Similarity index of woody shrubs and trees present was 50.0% indicating that the number of woody species present on the grazed area and on the ungrazed area were half similar (table 33). A greater number of woody species and a vastly greater number of individual woody plants were present on the ungrazed exclosure than were on the grazed area (figure 20). The ArcGIS mapping procedures identified 0.40 acres (13.8%) of nonwoody grass plant communities and 2.50 acres (86.2%) of woody shrub and tree infested plant communities on the 2.90 acre Overflow Ecological Site exclosure (figure 21 and table 34). The woody plant communities occupy a greater proportion of the ungrazed exclosure.

After 75 years of seasonlong grazing, the aboveground vegetation biomass on the grazed area consisted of 32.1% standing dead and litter and 67.9% live herbage. The live herbage was 0.6% domesticated grasses, 87.5% native grasses (77.8% cool season grasses, 6.8% upland sedges, and 2.9% warm season grasses), and 11.9% forbs. After 75 years of nongrazing, the aboveground vegetation biomass on the ungrazed exclosure consisted of 67.0% standing dead and litter and 33.0% live herbage. The live herbage was 15.1% domesticated grasses, 77.8% native grasses (75.7% cool season grasses, 1.5% warm season grasses, and 0.5% upland sedges), and 7.1% forbs (table 29).

Total belowground plant root biomass was 19,517.34 lbs/ac (14.35 kg/m^3) on the grazed area and 15,124.24 lbs/ac (11.12 kg/m^3) on the ungrazed area, with a 22.5% decrease on the ungrazed area (table 35). The 22.5% decrease of the total belowground plant root biomass on the ungrazed area coincided with the 62.2% decrease of the total aboveground live plant basal cover on the ungrazed area.

Rhizosphere biomass was 212,922.64 lbs/ac (156.55 kg/m^3) on the grazed area and 148,535.81 lbs/ac (109.21 kg/m^3) on the ungrazed area, with a 30.2% decrease on the ungrazed area (table 35). Basal cover of native grasses was 23.7% on the grazed area and 4.2% on the ungrazed area. Basal cover of domesticated grasses was 0.2% on the grazed area and 4.7% on the ungrazed area. The 30.2% decrease of rhizosphere biomass on the ungrazed area preceded the 82.3% decrease in native grass basal cover, that was followed by the large increase in domesticated grass basal cover on the ungrazed area.

The total available soil mineral nitrogen of nitrate and ammonium was 58.23 lbs/ac on the grazed area and 51.03 lbs/ac on the exclosure, with a decrease of 12.4% on the ungrazed exclosure. The quantity of total mineral nitrogen was greater on the grazed area than on the exclosure. The quantities of mineral nitrogen were not significantly different on the grazed area and the exclosure. The quantity of nitrate was 9.67 lbs/ac on the grazed area and 14.33 lbs/ac on the exclosure, with an increase of 48.2% on the ungrazed exclosure. The quantity of ammonium was 48.56 lbs/ac on the grazed area and 36.70 lbs/ac on the exclosure, with a decrease of 24.4% on the ungrazed exclosure (table 36). The exclosure had greater nitrate and lower ammonium and the grazed area had lower nitrate and greater ammonium. The greater quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. The exclosure had greater domesticated grass basal cover. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

Similarity index of range condition on the grazed area was 52.7%, low good condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was slightly more similar than dissimilar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 37). Similarity index of range condition on the ungrazed area was 36.1%, low fair condition, indicating that the relative percent herbage dry weight of plant species of the current plant community was more dissimilar than similar to the relative percent herbage dry weight of plant species of the hypothetical historical plant community (table 37). The current plant community of the ungrazed area had degraded from the hypothetical historical overflow ecological site plant community 31.6% greater than the degradation of the current plant community on the grazed area after 75 years (table 37).

The effects from long-term nongrazing on the overflow ecological site were great after 75 years. Native grass herbage biomass decreased 37.8% and basal cover decreased 82.3% on the ungrazed area. Cool season grass, warm season grass, and sedge herbage biomass decreased 31.9%, 63.0%, and 94.7%, respectively, and basal cover decreased 78.5%, 96.70%, and 91.7%, respectively, on the ungrazed area. Domesticated grass herbage biomass increased 1647.2% and basal cover increased 2225.0% on the ungrazed area. Forb herbage biomass decreased 58.2%, forb density decreased 56.7%, and the number of forb species present decreased 52.9% on the ungrazed area. The number of shrub and tree species present increased 100.0% on the ungrazed area. Woody plants infested 86.2% of the area on the ungrazed exclosure. Total live plant basal cover decreased 62.2% on the ungrazed area. Total live herbage biomass decreased 30.1% because the decrease in native grasses was greater than the increase in domesticated grasses on the ungrazed area. Total dead biomass increased 200.2% on the ungrazed area (tables 29, 30, 31, 32, 33, and 34). Belowground plant root biomass decreased 22.5% on the ungrazed area (table 35). Rhizosphere biomass decreased 30.2% on the ungrazed area (table 35). Mineral nitrogen decreased 12.4% on the ungrazed area (table 36).

Similarity indices of herbage biomass, basal cover, forb density, and shrubs present were 42.8%, 46.2%, 23.8%, and 50.0%, respectively. Similarity index of forb density indicated that the plant communities on the grazed area and on the ungrazed area were nearly dissimilar. Similarity indices of herbage biomass and basal cover indicated that the plant communities on the grazed area and on the ungrazed area were more dissimilar than similar. Similarity index of woody shrubs and trees present indicated that the plant communities on the grazed area and on the ungrazed area were half similar. Similarity index of range condition indicated that the current plant community on the ungrazed area had degraded 31.6% greater than the current plant community on the grazed area.

Figure 17. Overflow Ecological Site, located in Sec. 11, T 138 N, R 101 W, exclosure of 2.90 acres, built in 1937, looking North.

Figure 18. Overflow Ecological Site, located in Sec. 11, T 138 N, R 101 W, exclosure of 2.90 acres, built in 1937, looking East.

Figure 19. Overflow Ecological Site, located in Sec. 11, T 138 N, R 101 W, exclosure of 2.90 acres, built in 1937, looking South.

Table 29. Herbage biomass (lbs/ac) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Herbage Biomass			Relative Composition		
Site: Overflow	lbs/ac Grazed	lbs/ac Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	12.13	211.94	+1647.24	0.61	15.11	+2377.05
Native Cool Season	1559.93	1061.84	-31.93	77.82	75.73	-2.69
Native Warm Season	57.80	21.41	-62.96	2.88	1.53	-46.88
Sedges	135.58	7.14	-94.73	6.76	0.51	-92.46
Native Grass	1753.31	1090.39	-37.81	87.47	77.76	-11.10
Total Grass	1765.45	1302.32	-26.23	88.07	92.88	+5.46
Forbs	239.06	99.90	-58.21	11.93	7.12	-40.32
Total Live	2004.50	1402.22	-30.05	67.87	32.98	-51.41
Standing Dead	300.43	1351.56	+349.88	10.17	31.79	+212.59
Litter	648.66	1497.85	+130.91	21.96	35.23	+60.43
Total Dead	949.09	2849.41	+200.23	32.13	67.02	+108.59
Total Live & Dead	2953.59	4251.63	+43.95			

		Similarity Index of Herbage Biomass
Similarity Index	42.8%	(More dissimilar than similar)

Table 30. Basal cover (%) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Basal Cover			Relative Composition		
Site: Overflow	% Grazed	% Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	0.20	4.65	+2225.00	0.80	48.95	+6018.75
Native Cool Season	18.60	4.00	-78.49	74.10	42.11	-43.17
Native Warm Season	4.50	0.15	-96.67	17.93	1.58	-91.19
Sedges	0.60	0.05	-91.67	2.39	0.53	-77.82
Native Grass	23.70	4.20	-82.28	94.42	44.21	-53.18
Total Grass	23.90	8.85	-62.97	95.22	93.16	-2.16
Forbs	1.20	0.65	-45.83	4.78	6.84	+43.10
Woody Species	0.00	0.00	-	0.00	0.00	-
Total Live	25.10	9.50	-62.15	25.10	9.50	-62.15
Litter	74.90	90.50	+20.83	74.90	90.50	+20.83
Total Live & Dead	100.00	100.00				

Similarity Index of Basal Cover

Similarity Index	46.2%	(More dissimilar than similar)

Table 31. Forb density (#/0.10 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Overflow	#/0.10 m^2 Grazed	#/0.10 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Late Succession Forbs	6.48	1.16	-82.10	54.36	22.48	-58.65
Mid Succession Forbs	3.92	2.16	-44.90	32.89	41.86	+27.27
Early Succession Forbs	1.52	1.84	+21.05	12.75	35.66	+179.69
Woody Species	0.00	0.00	-	0.00	0.00	-
Total Live	11.92	5.16	-56.71			
	Similarity Index of Forb Density					
Similarity Index	23.8%	(Nearly dissimilar)				

Table 32. Shrub density (#/1.0 m^2) and relative composition (%) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Density			Relative Composition		
Site: Overflow	#/1.0 m^2 Grazed	#/1.0 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Artemisia cana	0.16	3.16	+1875.00	100.00	100.00	-
Rosa arkansana	0.00	0.00	-	0.00	0.00	-
Symphoricarpos occidentalis	0.00	0.00	-	0.00	0.00	-
Total Live	0.16	3.16	+1875.00			

Table 33. Shrubs, cacti, and trees present on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Overflow	
	Grazed	Exclosure
Artemisia cana	X	X
Symphoricarpos occidentalis	X	X
Fraxinus pennsylvanica		X
Populus deltoides		X
	Similarity Index of Shrub Present	
Similarity Index	50.0% (Half similar)	

Figure 20. Overflow Ecological Site, exclosure with increased woody vegetation.

Figure 21. Overflow Ecological Site exclosure with Woody shrub and tree infested plant communities and Nonwoody grass plant communities in the Little Missouri River Badlands, 1936-2011.

Table 34. Woody shrub and tree infested plant communities and Nonwoody grass plant communites in the Little Missouri River Badlands, 1936-2011.

		Major Plant Communities	
Site: Overflow			
	Total Exclosure Area	Nonwoody Grass	Woody Shrub and Tree Infested
Acres	2.90	0.40	2.50
Percentage		13.80	86.20

Determined by ArcGIS mapping procedures.

Table 35. Belowground biomass for plant root weight (lbs/ac and kg/m^3) and rhizosphere weight (lbs/ac and kg/m^3) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Belowground Biomass				
Site: Overflow	lb/ac Grazed	kg/m^3 Grazed	lbs/ac Exclosure	kg/m^3 Exclosure	% Difference
Root Biomass	19,517.34	14.35	15,124.24	11.12	-22.51
Rhizosphere Biomass	212,922.64	156.55	148,535.81	109.21	-30.24

Table 36. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) for native rangeland on the reference areas in the Little Missouri River Badlands, 1936-2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Site: Overflow	lbs/ac Grazed	mg/kg Grazed	lbs/ac Exclosure	mg/kg Exclosure	% Difference
Mineral Nitrogen	58.23	17.84	51.03	15.64	-12.36
Nitrate	9.67	2.96	14.33	4.39	48.19
Ammonium	48.56	14.88	36.70	11.25	-24.42

Table 37. Similarity index of range condition for the grazed area and ungrazed area on the reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	Similarity Index of Range Condition		
	Grazed Area	Ungrazed Area	% Difference
Overflow	52.7	36.1	-31.6
	Low Good	Low Fair	

Mean of Four Ecological Sites

The mean effects from long-term nongrazing on the mixed grass prairie plant communities of the four reference area exclosures established by Dr. Warren C. Whitman in 1936 were great after 75 years. Data from the respective sample categories were combined to determine the means of four ecological sites. The mean plant community and belowground characteristics data after 75 years of treatment are on tables 38 to 50 and figure 22.

Mean herbage biomass of native grasses was 1368.51 lbs/ac on the grazed areas and 508.09 lbs/ac on the ungrazed areas, with a 62.9% decrease on the ungrazed areas. Herbage biomass of cool season grasses, warm season grasses, and sedges decreased 58.7%, 86.5%, and 55.6%, respectively, on the ungrazed areas. Herbage biomass of domesticated grasses was 176.26 lbs/ac on the grazed areas and 1024.55 lbs/ac on the ungrazed areas, with a 481.3% increase on the ungrazed areas. Herbage biomass of forbs was 173.77 lbs/ac on the grazed areas and 180.72 lbs/ac on the ungrazed areas, with a 4.0% increase on the ungrazed areas. Native cool season grasses had the greatest herbage biomass on the grazed areas and domesticated grasses had the greatest herbage biomass on the ungrazed areas. Total live herbage biomass was 1718.53 lbs/ac on the grazed areas and 1713.35 lbs/ac on the ungrazed areas, with a 0.3% decrease on the ungrazed areas. The mean decrease in native grasses and the mean increase in domesticated grasses were about the same on the ungrazed areas. Standing dead biomass was 192.32 lbs/ac on the grazed areas and 613.16 lbs/ac on the ungrazed areas, with a 218.8% increase on the ungrazed areas. Litter was 346.81 lbs/ac on the grazed areas and 1273.78 lbs/ac on the ungrazed areas, with a 267.3% increase on the ungrazed areas. Total dead biomass was 539.13 lbs/ac on the grazed areas and 1886.94 lbs/ac on the ungrazed areas, with a 250.0% increase on the ungrazed areas. The total aboveground plant biomass was comprised of 52.4% dead biomass on the ungrazed areas (table 38).

Mean relative composition of native grass biomass was 79.6% on the grazed areas and 29.7% on the ungrazed areas, with a 62.8% decrease on the ungrazed areas. Composition of cool season grasses, warm season grasses, and sedges decreased 58.6%, 86.4%, and 55.4%, respectively, on the ungrazed areas. Composition of domesticated grass biomass was 10.3% on the grazed areas and 59.8% on the ungrazed areas, with a 482.9% increase on the ungrazed areas. Composition of forb biomass was 10.1% on the grazed areas and 10.6% on the ungrazed areas, with a 4.4% increase on the ungrazed areas. Composition of total live herbage biomass was 76.1% on the grazed areas and 47.6% on the ungrazed areas, with a 37.5% decrease on the ungrazed areas. Composition of total dead biomass was 23.9% on the grazed areas and 52.4% on the ungrazed areas, with a 119.5% increase on the ungrazed areas (table 38). Mean similarity index of herbage biomass was 26.1% indicating that the composition of biotype categories on the grazed areas and on the ungrazed areas were more dissimilar than similar (table 38).

Mean basal cover of native grasses was 24.2% on the grazed areas and 7.0% on the ungrazed areas, with a 77.2% decrease on the ungrazed areas. Basal cover of cool season grasses, warm season grasses, and sedges decreased 80.2%, 92.7%, and 33.5%, respectively, on the ungrazed areas. Basal cover of domesticated grasses was 4.5% on the grazed areas and 7.0% on the ungrazed areas, with a 56.2% increase on the ungrazed areas. Native warm season grasses and cool season grasses had the greatest basal covers on the grazed area and domesticated grasses had the greatest basal cover on the ungrazed area. Total live basal cover was 30.0% on the grazed areas and 15.2% on the ungrazed areas, with a 49.5% decrease on the ungrazed areas (table 39).

Mean relative composition of native grass basal cover was 80.6% on the grazed areas and 46.0% on the ungrazed areas, with a 42.9% decrease on the ungrazed areas. Composition of cool season grasses and warm season grasses decreased 60.7% and 85.5%, respectively, and composition of sedges increased 31.7% on the ungrazed areas. Composition of domesticated grass basal cover was 14.8% on the grazed areas and 45.8% on the ungrazed areas, with a 209.1% increase on the ungrazed areas (table 39). Mean similarity index of basal cover was 47.3% indicating that the importance value of the grass species on the grazed areas and on the ungrazed areas were more dissimilar than similar (table 39).

Mean basal cover of native grasses with short shoots and basal leaves was 20.5% on the grazed areas and 5.3% on the ungrazed areas, with a 74.4% decrease on the ungrazed areas. Mean relative composition of grasses with short shoots and basal leaves decreased 47.3% on the ungrazed areas. Mean basal cover of native grasses with long shoots and stem leaves was 3.7% on the grazed areas and 1.7% on the ungrazed areas, with a 53.2% decrease on the ungrazed areas. Mean relative composition of grasses with long shoots and stem leaves decreased 3.8% on the ungrazed areas. Grasses with short shoots and basal leaves protect the soil from erosion and high levels of solar radiation and maintain a closed community that restricts invasion by undesirable plants. High losses of grasses with short shoots and basal leaves on the ungrazed areas created large areas of open spaces available for invasion by domesticated cool season grasses. Mean basal cover and mean relative composition of domesticated grasses increased 56.2% and 221.1%, respectively, on the ungrazed areas (table 40).

Mean total forb density was 13.0 forbs/0.10 m^2 on the grazed areas and 7.8 forbs/0.10 m^2 on the ungrazed areas, with a 39.8% decrease on the ungrazed areas. The forb component was composed mostly of native plants, 90.5% on the grazed area and 93.7% on the ungrazed area, and introduced forbs composed 9.5% on the grazed area and 6.3% on the ungrazed area. Density of late and early succession forbs decreased 52.0% and 60.2%, respectively, and density of mid succession forbs increased 35.9% on the ungrazed areas (table 41). Twenty late succession forbs grew only on the grazed areas and were not present on the ungrazed areas (table 42). The ungrazed areas had a 53.1% decrease in the number of forb species present.

Mean relative composition of late, mid, and early succession forb density was 75.7%, 14.8%, and 9.5%, respectively, on the grazed areas and 60.4%, 33.3%, and 6.3%, respectively, on the ungrazed areas. Composition of late and early succession forbs decreased 20.2% and 33.8%, respectively, and composition of mid succession forbs increased 126.0% on the ungrazed areas (table 41). Relative composition of forbs was mostly late succession forbs on the grazed area and mostly late and mid succession forbs on the ungrazed areas. Mean similarity index of forb density was 27.3% indicating that the importance value of the forb species on the grazed areas and on the ungrazed areas were more dissimilar than similar (table 41).

Shrub density was greatly undersampled by the 1.0 m^2 quadrat method within the four exclosures. Compilation of the woody species present list identified three shrub species and two cacti species on the four grazed areas and nine shrub species, two cacti species, and three tree species on the four ungrazed areas (table 43). Mean similarity index of woody shrubs and trees present was 33.2% indicating that the number of woody species present on the grazed areas and on the ungrazed areas were more dissimilar than similar (table 43). A greater number of woody species and a greater number of individual woody plants were present on the ungrazed exclosures than were on the grazed areas. The woody shrub and tree infested plant communities composed 54.4% and the nonwoody grass plant communities composed 45.6% of the sandy, shallow, and silty ecological site exclosures. The woody shrub and tree infested plant communities composed 86.2% and the nonwoody grass plant communities composed 13.8% of the overflow ecological site exclosure. The woody plant communities occupy an extraordinary quantity of the four reference area ungrazed exclosures (table 44).

The quantity of woody shrubs and trees growing on the Little Missouri National Grasslands in 1936 is not known. However, the aerial photographic record of shrub occupancy of Lostwood National Wildlife Refuge was compiled by Smith (1988) and reported that in the mid to late 1930's, only about 5% of the upland landscape area was occupied by shrubs. Assuming a similar 5% shrub cover in 1936, the shrub infestation on the sandy, shallow, and silty ecological site ungrazed exclosures expanded a mean of 988.0% during 75 years.

Mean total belowground plant root biomass was 36,103.68 lbs/ac (26.54 kg/m^3) on the grazed areas and 23,485.42 lbs/ac (17.27 kg/m^3) on the ungrazed areas, with a 35.0% decrease on the ungrazed areas (table 45). The 35.0% decrease of the total belowground plant root biomass on the ungrazed areas coincided with the 49.5% decrease of the total aboveground live plant basal cover on the ungrazed areas. The percent decrease in total live plant basal cover was greater than the percent decrease in total root biomass on the ungrazed areas because the root biomass samples included an unknown proportion of dead material that required several years to decompose.

Mean rhizosphere biomass was 210,399.67 lbs/ac (154.69 kg/m^3) on the grazed areas and 173,041.30 lbs/ac (127.23 kg/m^3) on the ungrazed areas, with a 17.8% decrease in the ungrazed areas (table 46). The 17.8% decrease of rhizosphere biomass on the ungrazed areas preceded the 77.2% decrease in native grass basal cover, that was followed by the 56.2% increase in domesticated grass basal cover on the ungrazed areas. The sandy and overflow ecological sites showed standard responses of rhizosphere organisms to seasonlong grazing with mean rhizosphere biomass of 222,756.12 lbs/ac

(163.78 kg/m^3) on the grazed areas and showed antagonistic responses to nongrazing with mean rhizosphere biomass of 144,815.96 lbs/ac (106.48 kg/m^3) on the ungrazed area, with a 35.0% decrease on the ungrazed areas (table 46 and figure 22). The silty ecological site showed a long-term degradation on the grazed area, with only a 4.7% decrease in rhizosphere biomass on the ungrazed area. The shallow ecological site showed an accelerated decrease in rhizosphere biomass due to degradation of the grazed area in the recent past, with a 6.9% decrease in rhizosphere biomass on the grazed area (table 46 and figure 22).

The mean quantity of mineral nitrogen on the four ecological sites was 42.37 lbs/ac on the grazed areas and 39.46 lbs/ac on the ungrazed areas, with a 6.9% decrease on the ungrazed exclosures (table 47). The quantity of mineral nitrogen was greater on the grazed areas of the sandy, silty, and overflow ecological sites. Rangeland ecosystem biogeochemical processes with rhizosphere organisms that cycle nitrogen need to function at rates that provide 100 lbs/ac to 165 lbs/ac of mineral nitrogen to produce the potential quantity of herbage biomass (Wight and Black 1972, 1979). Nitrogen deficiency exists in mix grass prairie ecosystems when quantities of soil mineral nitrogen are available at less than 100 lbs/ac.

The effects from long-term nongrazing on the four ecological sites were great after 75 years (table 48). Native grass mean herbage biomass decreased 62.9% and mean basal cover decreased 77.2% on the ungrazed areas. Cool season grass, warm season grass, and sedge mean herbage biomass decreased 58.7%, 86.5%, and 55.6%, respectively, and mean basal cover decreased 80.2%, 92.7%, and 33.5%, respectively, on the ungrazed areas. Domesticated grass mean herbage biomass increased 481.3% and mean basal cover increased 56.2% on the ungrazed areas. Forb mean herbage biomass increased 4.0%, forb mean total density decreased 39.8%, and the number of forb species present decreased 53.1% on the ungrazed areas. Late and early succession forb mean density decreased 52.0% and 60.2%, respectively, and mid succession forb mean density increased 35.9% on the ungrazed areas. The total number of woody shrub and tree species present increased 180.0% and the number of individual woody plants greatly increased on the ungrazed areas. The woody shrub and tree infested plant communities occupied 54.4% of the area on the sandy, shallow, and silty ecological site exclosures and occupied 86.2% of the area on the overflow ecological site exclosure. Mean total live plant basal cover decreased 49.5% on the ungrazed areas. However, mean total live herbage biomass decreased only 0.3% as a result of the mean decrease on native grass herbage biomass and the mean increase in domesticated grass herbage biomass were about the same on the ungrazed areas. Mean total dead biomass increased 250.0% on the ungrazed areas (table 48). Mean belowground plant root biomass decreased 35.0% on the ungrazed areas (table 45). Mean rhizosphere biomass decreased 17.8% on the ungrazed areas (table 46). Mean mineral nitrogen decreased 6.9% on the ungrazed areas (table 47).

Mean similarity indices of herbage biomass, basal cover, forb density, and shrubs present were 26.1%, 47.3%, 27.3%, and 33.2%, respectively (table 49). All mean similarity indices indicated that the plant communities on the grazed areas and on the ungrazed areas were more dissimilar than similar.

Mean similarity index of range condition on the grazed areas was 58.6%, low good condition, indicating that the current grazed plant communities were slightly more similar than dissimilar to the hypothetical historical plant communities (table 50). Mean similarity index of range condition on the ungrazed areas was 28.0%, low fair condition, indicating that the current ungrazed plant communities were much more dissimilar than similar to the hypothetical historical plant communities (table 50). The current plant communities on the ungrazed areas had degraded from the hypothetical historical plant communities 51.3% greater than the degradation of the current plant communities on the grazed areas after 75 years (table 50).

Table 38. Mean herbage biomass (lbs/ac) and mean relative composition (%) for native rangeland on the four reference areas in the Little Missouri River Badlands, 1936-2011.

	Mean Herbage Biomass			Mean Relative Composition		
Site: Mean of Four	lbs/ac Grazed	lbs/ac Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	176.26	1024.55	+481.27	10.26	59.80	+482.85
Native Cool Season	863.28	356.45	-58.71	50.23	20.80	-58.59
Native Warm Season	235.85	31.93	-86.46	13.72	1.86	-86.44
Sedges	269.38	119.71	-55.56	15.68	6.99	-55.42
Native Grass	1368.51	508.09	-62.87	79.63	29.65	-62.77
Total Grass	1544.77	1532.64	-0.79	89.89	89.45	-0.49
Forbs	173.77	180.72	+4.00	10.11	10.55	+4.35
Total Live	1718.53	1713.35	-0.30	76.12	47.59	-37.48
Standing Dead	192.32	613.16	+218.82	8.52	17.03	+100.00
Litter	346.81	1273.78	+267.28	15.36	35.38	+130.34
Total Dead	539.13	1886.94	+250.00	23.88	52.41	+119.47
Total Live & Dead	2257.65	3600.29	+59.47			
Mean Similarity Index of Herbage Biomass						
Similarity Index	26.1%	(More dissimilar than similar)				

Table 39. Mean basal cover (%) and mean relative composition (%) for native rangeland on the four reference areas in the Little Missouri River Badlands, 1936-2011.

	Mean Basal Cover			Mean Relative Composition		
Site: Mean of Four	% Grazed	% Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Domesticated Cool Season	4.45	6.95	+56.18	14.81	45.78	+209.12
Native Cool Season	8.26	1.64	-80.15	27.50	10.80	-60.73
Native Warm Season	8.85	0.65	-92.66	29.46	4.28	-85.47
Sedges	7.05	4.69	-33.48	23.47	30.90	+31.66
Native Grass	24.20	6.98	-77.16	80.56	45.98	-42.92
Total Grass	28.56	13.93	-51.23	95.07	91.77	-3.47
Forbs	1.41	1.24	-12.06	4.69	8.17	+74.20
Woody Species	0.01	0.01	-	0.03	0.07	-
Total Live	30.04	15.18	-49.47	30.67	15.37	-49.89
Litter	67.91	83.56	+23.05	69.33	84.63	+22.07
Total Live & Dead	97.95	98.74	+0.81			
	Mean Similarity Index of Basal Cover					
Similarity Index	47.3%	(More dissimilar than similar)				

Table 40. Mean basal cover (%) and mean relative composition (%) for native grasses with short shoots and long shoots on the four reference areas in the Little Missouri River Badlands, 1936-2011.

	Mean Basal Cover			Mean Relative Composition		
Mean of Four Ecological Sites	% Grazed	% Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Short Shoots Basal Leaves	20.51	5.26	-74.35	71.69	37.79	-47.29
Long Shoots Stem Leaves	3.65	1.71	-53.15	12.76	12.28	-3.76
Domesticated Grasses	4.45	6.95	+56.18	15.55	49.93	+221.09
Total Grasses	28.61	13.92	-51.35	95.37	91.73	-3.82

Table 41. Mean forb density (#/0.10 m^2) and mean relative composition (%) for native rangeland on the four reference areas in the Little Missouri River Badlands, 1936-2011.

	Mean Density			Mean Relative Composition		
Site: Mean of Four	#/0.10 m^2 Grazed	#/0.10 m^2 Exclosure	% Difference	% Grazed	% Exclosure	% Difference
Late Succession Forbs	9.85	4.73	-51.98	75.65	60.41	-20.15
Mid Succession Forbs	1.92	2.61	+35.94	14.75	33.33	+125.97
Early Succession Forbs	1.23	0.49	-60.16	9.45	6.26	-33.76
Woody Species	0.02	0.00	-	0.15	0.00	-
Total Live	13.02	7.83	-39.86			

	Mean Similarity Index of Forb Density	
Similarity Index	27.3%	(More dissimilar than similar)

Table 42. Late succession forbs growing only on the grazed areas of the four reference areas on the Little Missouri River Badlands, 1936-2011.

		Ecological Sites			
		Sandy	Shallow	Silty	Overflow
Antennaria neglecta	Pussytoes	X	X	X	
Aster ericoides	White prairie aster	X		X	
Cerastium arvense	Prairie chickweed				X
Chrysopsis villosa	Hairy golden aster		X		
Erigeron strigosus	Daisy fleabane		X		X
Haplopappus spinulosus	Spiny ironweed		X		
Linum rigidum	Yellow flax		X		X
Lithospermum incisum	Narrow-leaved puccoon	X	X		
Lygodesmia juncea	Skeleton weed	X			
Oenothera serrulata	Tooth-leaved evening primrose				X
Penstemon albidus	White beardtongue	X			
Phlox hoodii	Hood's phlox	X			
Plantago patagonica	Wooly plantain		X		
Polygala alba	White milkwort				X
Potentilla pensylvanica	Cinquefoil			X	
Ratibida columnifera	Long-headed coneflower		X	X	X
Senecio plattensis	Prairie ragwort				X
Solidago rigida	Stiff goldenrod				X
Viola nuttallii	Nutall's violet		X		
Viola pedatifida	Prairie violet			X	

Table 43. Shrubs, cacti, and trees present on the four reference areas in the Little Missouri River Badlands, 1936-2011.

	Four Ecological Sites	
	Grazed	Exclosure
Artemisia cana	X	X
Juniperus communis		X
Juniperus horizontalis		X
Prunus virginiana		X
Rhus trilobata		X
Rosa arkansana	X	X
Shepherdia argentea		X
Symphoricarpos occidentalis	X	X
Yucca glauca		X
Escobaria vivipara	X	X
Opuntia polyacantha	X	X
Fraxinus pennsylvanica		X
Juniperus scopulorum		X
Populus deltoides		X
Mean Similarity Index of Shrubs Present		
Similarity Index	33.2% (More dissimilar than similar)	

Table 44. Acres and percentages of nonwoody and woody plant communities on the four exclosure areas in the Little Missouri River Badlands, 1936-2011.

Ecological Site	Exclosure Total Area Acres	Nonwoody Acres	Woody Acres	Nonwoody %	Woody %
Sandy	6.27	2.93	3.34	46.67	53.33
Shallow west	4.90	2.15	2.75	43.90	56.10
Silty	14.10	6.52	7.58	46.23	53.77
Mean of 3	8.42	3.87	4.55	45.60	54.40
Overflow	2.90	0.40	2.50	13.80	86.20

Table 45. Belowground plant root biomass (pounds per acre and kilograms per cubic meter) on the four reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	lbs/ac Grazed	kg/m^3 Grazed	lbs/ac Exclosure	kg/m^3 Exclosure	% Difference
Sandy	44,175.84	32.48	19,517.34	14.35	-55.82
Shallow	46,964.03	34.53	36,545.71	26.87	-22.18
Silty	33,757.52	24.82	22,754.37	16.73	-32.59
Overflow	19,517.34	14.35	15,124.24	11.12	-22.51
Mean of Four	36,103.68	26.54	23,485.42	17.27	-34.95

Table 46. Rhizosphere biomass (pounds per acre and kilograms per cubic meter) on the four reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	lbs/ac Grazed	kg/m^3 Grazed	lbs/ac Exclosure	kg/m^3 Exclosure	% Difference
Sandy	232,589.59	171.01	141,096.10	103.74	-39.34
Shallow	207,536.67	152.59	222,892.13	163.88	+7.40
Silty	188,549.76	138.63	179,641.15	132.08	-4.72
Overflow	212,922.64	156.55	148,535.81	109.21	-30.24
Mean of Four	210,399.67	154.69	173,041.30	127.23	-17.76

Table 47. Soil available mineral nitrogen, nitrate and ammonium, (lbs/ac and mg/kg) for native rangeland on the four reference areas in the Little Missouri River Badlands, 1936-2011.

	Nitrate-Ammonium (NO_3-NH_4)				
Ecological Reference Area	lbs/ac Grazed	mg/kg Grazed	lbs/ac Exclosure	mg/kg Exclosure	% Difference
Sandy	31.52	9.66	23.52	7.21	-25.38
Shallow	33.12	10.15	41.26	12.64	+24.58
Silty	46.62	14.29	42.02	12.88	-9.87
Overflow	58.23	17.84	51.03	15.64	-12.36
Mean of Four	42.37	12.98	39.46	12.09	-6.87

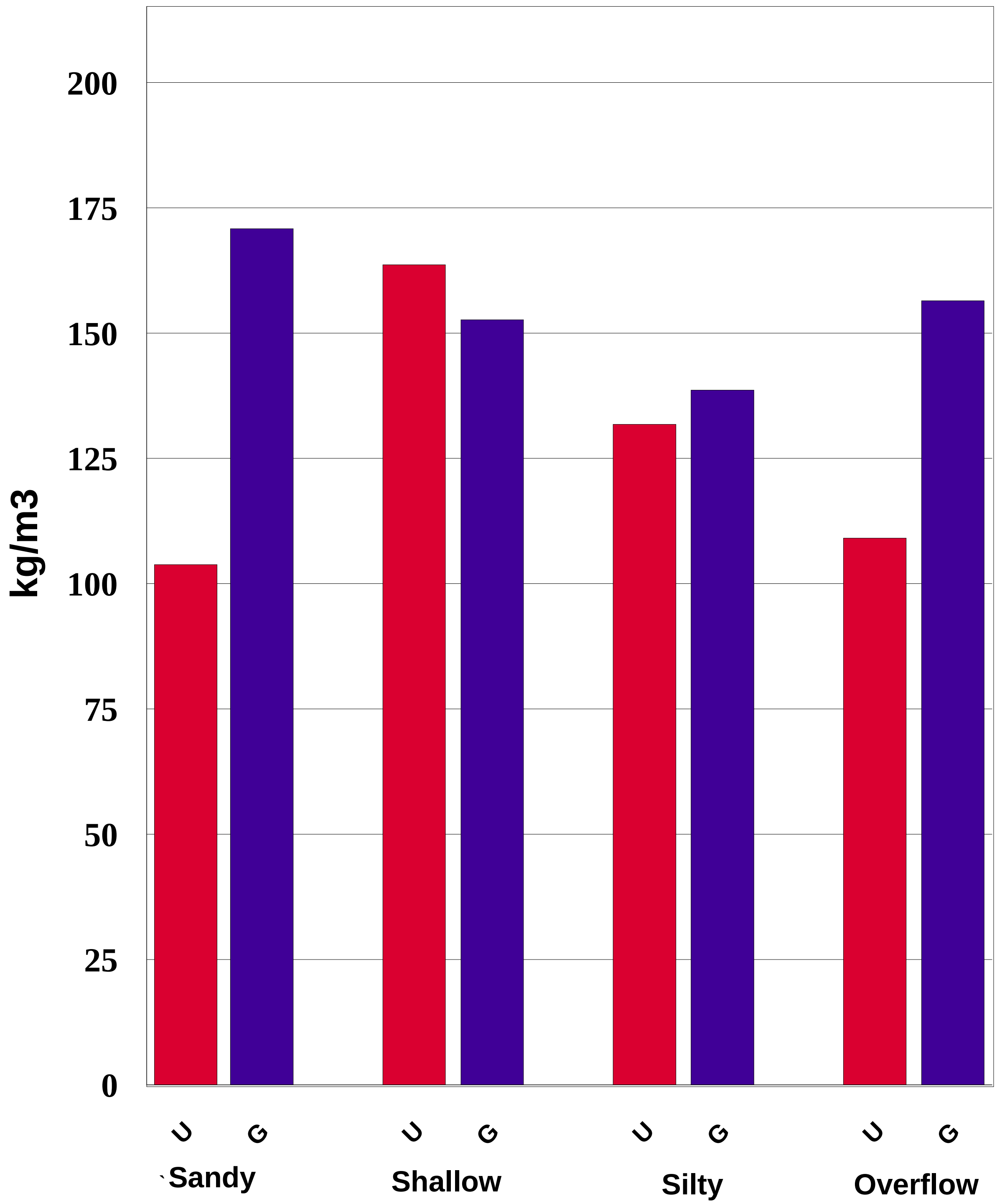

Figure 22. Rhizosphere weight (kg/m3) for the ungrazed exclosure (red) and grazed area (blue) on the ecological site reference areas in the Little Missouri River Badlands, 1936-2011.

Table 48. Percent difference in plant community characteristics on the ungrazed area of the four rangeland reference areas in the Little Missouri River Badlands, 1936-2011.

Plant Community Characteristics	Sandy Ecological Site	Shallow Ecological Site	Silty Ecological Site	Overflow Ecological Site	Mean of Four Ecological Sites
Herbage Biomass					
Native Grass	-69.3	-83.3	-74.9	-37.8	-62.9
Cool Season	-70.2	-96.1	-80.0	-31.9	-58.7
Warm Season	-78.2	-98.3	-99.7	-63.0	-86.5
Sedges	-59.8	-46.2	-23.9	-94.7	-55.6
Domesticated Grass	+100.0	+100.0	+106.1	+1647.2	+481.3
Forbs	+6.3	+72.4	+20.0	-58.2	+4.0
Total Live	-3.3	+41.5	+7.1	-30.1	-0.3
Total Dead	+123.1	+1273.9	+293.6	+200.2	+250.0
Basal Cover					
Native Grass	-62.5	-63.8	-90.2	-82.3	-77.2
Cool Season	-49.2	-88.7	-100.0	-78.5	-80.2
Warm Season	-84.6	-98.2	-100.0	-96.7	-92.7
Sedges	-39.2	+1.9	-79.8	-91.7	-33.5
Domesticated Grass	+3700.0	+100.0	-33.2	+2225.0	+56.2
Total Live	-43.8	-45.3	-49.4	-62.2	-49.5
Forb Density					
Late Succession	-75.8	-82.6	+145.3	-82.1	-52.0
Mid Succession	+980.0	+1533.3	-92.5	-44.9	+35.9
Early Succession	-88.9	-90.9	-100.0	+21.1	-60.2
Total Live	-40.4	-58.4	+22.1	-56.7	-39.8
Species Present	-53.9	-50.0	-56.3	-52.9	-53.1
Shrub Density					
Species Present	+166.7	+250.0	+500.0	+100.0	+180.0
% Woody Area	53.3	56.1	53.8	86.2	

Table 49. Similarity indices comparing plant communities the grazed areas and the ungrazed areas on the four reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	Similarity Index of Herbage Biomass %	Similarity Index of Basal Cover %	Similarity Index of Forb Density %	Similarity Index of Shrubs Present %
Sandy	18.9	49.0	42.8	37.5
Shallow	12.3	34.2	10.8	28.6
Silty	30.4	59.7	31.8	16.7
Overflow	42.8	46.2	23.8	50.0
Mean of Four	26.1	47.3	27.3	33.2

Table 50. Similarity index of range condition for the grazed areas and ungrazed areas on the four reference areas in the Little Missouri River Badlands, 1936-2011.

Ecological Reference Area	Similarity Index of Range Condition		
	Grazed Area	Ungrazed Area	% Difference
Sandy	59.8	36.8	-38.4
	Low Good	Low Fair	
Shallow	68.4	20.1	-70.6
	Good	Poor	
Silty	53.6	19.1	-64.4
	Low Good	Poor	
Overflow	52.7	36.1	-31.6
	Low Good	Low Fair	
Mean of Four	58.6	28.0	-51.3
	Low Good	Low Fair	

Discussion

Removal of cattle grazing does not promote development of stable climax plant communities and does not preserve prairie grasslands in perpetuity.

Mixed grass prairie communities deprived of large grazing animals decline steadily into unhealthy disfunctional ecosystems with severe reductions of native grasses, considerable decreases of desirable forbs, enormous increases of introduced domesticated grasses, remarkable increases of woody shrubs and trees, and excessive increases of standing dead and litter as a result of diminished grass plant defoliation resistance mechanisms, degraded ecosystem biogeochemical processes, and low grass plant resource uptake competitiveness. Activation of the defoliation resistance mechanisms, the ecosystem biogeochemical processes, and grass resource competitiveness requires partial defoliation by large grazing herbivores (graminivores). Grazing animals are essential annual growing season components of rangeland ecosystems.

Traditionally, rangeland ecosystems have been managed from the perspective of the "use" of the grassland. Livestock grazing along with watershed, wildlife, and recreation were considered to be the major uses. Management of rangelands from the perspective of a single use or for multiple uses narrowly considers only a few ecosystem components directly related with these primary uses or products removed. Management for a use does not consider rangelands as complex ecosystems and neglects to address the needs of all other ecosystem components. Management of rangelands for a use, no matter how noble, results in degradation of the ecosystems. The uses of rangeland resources should not be the objective of management. The management should be the means to accomplish the uses. Management strategies need to be designed to beneficially stimulate all ecosystem components to function at potential levels.

Rangelands are complex ecosystems consisting of numerous interactive biotic (living) and abiotic (nonliving) components. The biotic components are the plants, soil organisms, and large grazing graminivores that have biological and physiological requirements. The abiotic components include the essential major elements of carbon, hydrogen, and nitrogen in the presence of sunlight that have transformable characteristics through biogeochemical processes. Rangeland ecosystems are functioning units of coacting biotic organisms interacting with the abiotic components and the environment. The complex of mechanisms and processes connected with these extensive interactions have been identified as defoliation resistance mechanisms and biogeochemical processes. If any of the numerous processes are not functioning at potential level, the ecosystem does not function at potential level. Management of rangeland ecosystems needs to meet the biological and physiological requirements of the biotic components and stimulate the biogeochemical processes that cycle the abiotic components. Mixed grass prairie communities require biologically effective partial defoliation by annually managed grazing animals in order to persist as healthy and productive ecosystems. Thus, providing the means to accomplish the uses of watershed, wildlife habitat, recreation, and livestock forage at the same time on fully functional rangeland ecosystems.

Implementation of a biologically effective grazing management strategy that stimulates the defoliation resistance mechanisms will meet the biological and physiological requirements of the biotic components and will stimulate the biogeochemical processes that cycle the abiotic components (Manske 2011b). The three main defoliation resistance mechanisms are: compensatory internal physiological processes, internal vegetative reproduction of secondary tillers from axillary buds, and external symbiotic rhizosphere organism activity (McNaughton 1979, 1983; Coleman et al. 1983; Ingham et al. 1985; Mueller and Richards 1986; Richards et al. 1988; Briske 1991; Murphy and Briske 1992; Briske and Richards 1994, 1995; Manske 1999).

The defoliation resistance mechanisms developed early during the coevolution of grass plants and grazing graminivores (McNaughton 1979, 1983; Coleman et al. 1983; Briske 1991; Briske and Richards 1995; Manske 1999) and are a complex assemblage of biogeochemical and physiological processes that involve intricate interactions among rhizosphere microorganisms, grass plants, and large grazing graminivores. Activation of these mechanisms provides important biological and physiological processes permitting native grasses to produce greater herbage biomass and to increase basal cover; these mechanisms also enable grass plants to replace lost leaf material, to restore disrupted physiological processes, and to vegetatively reproduce secondary tillers from axillary buds after partial defoliation by grazing. The defoliation resistance mechanisms function at variable levels of activation depending on the quantity of available mineral nitrogen in grassland ecosystem soil. When mineral nitrogen is available at 100 lbs/ac or greater, the defoliation resistance mechanisms function at full activation. When mineral nitrogen is available at less than 100 lbs/ac, the defoliation resistance mechanisms function at levels less than full activation (Manske 2009). In addition, the water (precipitation) use efficiency processes decrease in grass plants growing in ecosystems with less than 100 lbs/ac available mineral nitrogen causing herbage biomass production to be reduced by 49.6% (Wight and Black 1972, 1979).

The quantity of available mineral nitrogen in grassland ecosystem soils is dependent on the rate of mineralization of soil organic nitrogen by rhizosphere organisms. The larger the rhizosphere volume and microorganism biomass, the greater the quantity of soil mineral nitrogen converted. Rhizosphere volume and microorganism biomass are limited by access to simple carbohydrates (Curl and Truelove 1986). Healthy grass plants capture and fix carbon during photosynthesis and produce carbohydrates in quantities greater than the amount needed for tiller growth and development (Coyne et al. 1995). Partial defoliation of grass tillers at vegetative phenological growth stages by large grazing graminivores causes greater quantities of exudates containing simple carbohydrates to be released from the grass tillers through the roots into the rhizosphere (Hamilton and Frank 2001). With the increase in availability of carbon compounds in the rhizosphere, the biomass and activity of the microorganisms increases (Anderson et al. 1981, Curl and Truelove 1986, Whipps 1990). The increase in rhizosphere organism biomass and activity results in greater rates of mineralization of soil organic nitrogen converting greater quantities of available mineral nitrogen (Coleman et al. 1983, Klein et al. 1988, Burrows and Pfleger 2002, Rillig et al. 2002, Bird et al. 2002, Driver et al. 2005). Mineral nitrogen available in quantities of 100 lbs/ac or greater allows defoliated grass tillers full activation of the defoliation resistance mechanisms (Manske 2009). Full activation of the compensatory internal physiological processes within grass plants accelerates growth rates of replacement leaves and shoots, increases photosynthetic capacity of remaining mature leaves, increases allocation of carbon and nitrogen, improves water (precipitation) use efficiency, and increases restoration of biological and physiological processes enabling rapid and complete recovery of partially defoliated grass tillers. Full activation of the asexual internal processes of vegetative reproduction increases secondary tiller development from axillary buds and increases initiated tiller density during the grazing season. Full activation of the external symbiotic rhizosphere organism activity increases mineralization of mineral nitrogen, increases ecosystem biogeochemical cycling of essential elements, and improves belowground resource uptake competitiveness (Wight and Black 1972, 1979; McNaughton 1979, 1983; Coleman et al. 1983; Ingham et al. 1985; Mueller and Richards 1986; Richards et al. 1988; Briske 1991; Murphy and Briske 1992; Briske and Richards 1994, 1995; Manske 1999, 2011b; Kochy and Wilson 2000).

Biologically effective grazing management strategies have 4.5 month grazing seasons on native grasslands between early June and mid October with 2 grazing periods in each of the 3 to 6 pastures and the rotation dates coordinate partial defoliation by grazing with grass phenological growth stages. Removal of about 25% to 33% of the aboveground leaf material of grass lead tillers between the 3.5 new leaf stage and the flower stage increases the quantity of carbon exudates released through the roots into the rhizosphere, enlarges the rhizosphere volume to 227.06 ft^3/ac, increases rhizosphere biomass to 552.80 tons/ac, and raises rates of mineralization of soil organic nitrogen into mineral nitrogen to 177.84 lbs/ac (Manske 2009, 2011b). The partially defoliated grass tillers in grassland ecosystems with abundant quantities of available mineral nitrogen respond positively to grazing because the defoliation resistance mechanisms function at the high levels of full activation that results in complete recovery of defoliated tillers replacing leaf and stem material at greater quantities than that removed by grazing, increasing total tiller density and herbage production, and fully restoring, and then maintaining, the biogeochemical processes and the health of the grassland ecosystem (Manske 2009, 2010b, 2011a).

Traditional grazing management practices with 4.5 month grazing seasons on native grasslands between early June and mid October, but with no rotation dates or rotation dates that are not coodinated with grass phenological growth stages cause slow deterioration of the ecosystems. The antagonistic grazing defoliation results in decreases in the quantities of carbon exudates released through the roots into the rhizosphere, reducing the rhizosphere volume to 67.61 ft^3/ac, decreasing the organism biomass and activity, and reducing the rates of mineralization of soil organic nitrogen into mineral nitrogen to 76.70 lbs/ac. The grazed grass tillers in grassland ecosystems with deficient quantities of available mineral nitrogen respond negatively to grazing because the defoliation resistance mechanisms function at reduced levels of less than full activation that results in incomplete recovery of grazed tillers replacing less leaf and stem material than the quantity removed by grazing decreasing total tiller density and herbage production, and causing a slow steady decline in the biogeochemical processes and the grassland ecosystem health (Manske 2011a).

Traditional grazing management practices with 6.0 month grazing seasons on native grasslands starting before early June and continuing past mid October, and no rotation dates or rotation dates that are not coodinated with grass phenological growth stages are harmful to the perennial native grass plants, the rhizosphere organisms, and the ecosystem biogeochemical processes. This highly antagonistic defoliation by grazing causes reductions in the quantity of plant carbon exudation through the roots into the rhizosphere. The rhizosphere volume diminishes greatly to 49.75 ft^3/ac, reducing the organism biomass and activity, and decreasing the quantities of soil organic nitrogen converted into mineral nitrogen to 61.61 lbs/ac. The grazed grass tillers in grassland ecosystems with insufficient quantities of mineral nitrogen respond negatively to grazing because the defoliation resistance mechanisms and biogeochemical processes are activated at extremely low levels (Manske 2009, 2010a) and plant recovery from grazing is incomplete with limited amounts of leaf and stem material replaced, decreasing grass tiller density and herbage production greatly, and causing deterioration in the grassland ecosystem health (Manske 2011a).

Developed grazing management practices with 4.0 month grazing seasons on a deferred native grassland pasture between mid July and mid November that, by design, delays grazing until grass tillers are mature with most producing seeds. This extremely antagonistic grazing defoliation suppresses the amount of carbon exudates released through the roots into the rhizosphere, shrinking the rhizosphere volume and organism biomass, and reducing the rates of mineralization of soil organic nitrogen into mineral nitrogen to 31.20 lbs/ac. The grazed grass tillers in grassland ecosystems with inadequate quantities of mineral nitrogen respond negatively to grazing because the defoliation resistance mechanisms and biogeochemical processes barely function. Tiller development and herbage biomass production are extremely low. Numerous undesirable plants invade the native communities and the grassland ecosystem health degrades to low condition (Manske 2011a).

Nondefoliation management by complete rest of mixed grass prairie ecosystems is not a revitalizing inactivity. Removing graminivores from grassland ecosystems to provide rest from grazing is a devitalizing activity that results in decreased rhizosphere organism biomass causing deficiencies in mineral nitrogen and other essential elements, and that results in decreased sunlight intensity and soil water causing deficiencies in fixed carbon and vital organic compounds.

Seventy five years ago, the healthy native grass communities in the four reference area exclosures started to deteriorate as a result of withholding grazing by large graminivores. Soon after grazing graminivores had been removed from the grasslands, the native grass live root biomass decreased (Whitman 1974), standing dead leaves and litter accumulated (Brand and Goetz 1986), and ecosystem biogeochemical processes declined (Manske 2011b).

The reduction of live root surface area causes a decrease in active root length for interaction with symbiotic rhizosphere organisms and causes a decrease in absorption of water and nutrients from the soil. Reduction of active root biomass and diminishment of grass plant health vigor result in a loss of resource uptake efficiency and a suppression of the competitiveness of grass plants to take up mineral nitrogen, essential elements, and soil water (Kochy 1999, Kochy and Wilson 2000). The loss of active root length is a contributing factor in the reduction of rhizosphere biomass. The primary cause for the reduction in rhizosphere biomass is, however, the great reduction in the quantity of carbohydrates exuded from the grass roots into the rhizosphere zone. Without partial defoliation by grazing, only a small quantity of short carbon chain energy leaks from the grass roots into the rhizosphere; this low amount of simple carbon compounds is barely enough to sustain a small rhizosphere biomass. A small biomass of rhizosphere organisms mineralize small quantities of nitrogen and other essential elements (Coleman et al. 1983, Klein et al. 1988).

Rhizosphere organism biomass and activity are limited by access to simple carbon chain energy (Curl and Truelove 1986) because the microflora trophic levels lack chlorphyll and have low carbon (energy) content. Partial defoliation by large grazing graminivores of grass lead tillers at vegetative phenological growth stages is required to cause greater quantities of exudates containing simple carbon compounds to be released through the grass roots into the rhizosphere. Biomass and activity of the microorganisms increase with the increase in availability of energy from simple carbon compounds in the rhizozpshere. The increase in rhizosphere organism biomass and activity causes an increase in mineralization of nitrogen and other essential elements. Termination of annual partial defoliation by graminivores depletes these substantive processes resulting in deficiencies in mineral nitrogen and other essential elements.

An evolutionary survival mechanism of grass plants in response to partial defoliation and the loss of leaf area as forage to grazing graminivores is the production of double the quantity of leaf biomass than needed for normal plant growth and maintenance (Crider 1955, Coyne et al. 1995). This survival mechanism does not stop upon removal of grazing graminivores. Without grazing graminivores to remove half of the herbage production, the surplus leaf material accumulates rapidly and changes from an asset to a detriment. The accumulation of nondefoliated live and standing dead leaves of grasses reduce light penetration below native grass light saturation points (Peltzer and Kochy 2001). Native grasses have high light saturation points and require near full sunlight. Warm season grasses have higher light saturation points then cool season grasses (Kochy 1999, Kochy and Wilson 2000). Shading reduces native warm season grasses more than native cool season grasses. Introduced cool season domesticated grasses have lower light saturation points than native grasses, permitting domesticated grasses to live in low light conditions.

Low amounts of sunlight reaching native grass leaves decrease the rate of photosynthesis, which reduces the quantity of atmospheric carbon dioxide fixed, reducing the quantity of simple carbohydrates produced (Coyne et al. 1995). Low quantities of carbohydrates cause decreases in growth of roots, leaves, and stems, and development of secondary tillers. Low quantities of carbohydrates also cause increases in the rates of leaf senescence and increases in tiller mortality that results in reductions of grass plant density (basal cover) and reductions of herbage biomass production (Langer 1972, Grant et al. 1983, Briske and Richards 1995).

The rapidly accumulating quantities of standing dead biomass cannot make contact with the soil surface and decompose quickly through microbial activity. The standing dead biomass decreases slowly by leaching and weathering and builds up into a thick mulch layer. Thick mulch effectively blocks sunlight from reaching understory young grass leaves. Thick mulch insulates the soil from warm spring air temperatures preventing heating of cold soil that causes delays in plant and soil organism activity. Thick mulch ties up and holds organic nutrients above the soil surface preventing accession to the soil organic matter which limits nutrient cycling through biogeochemical processes increasing the deficiencies of essential elements. Thick mulch absorbs and holds precipitation for later evaporation preventing the water from infiltrating into the soil diminishing soil water to deficiency quantities (Wright and Bailey 1982, Manske 2000, 2011a). These undesirable modifications to the ecosystem cause decreases in soil microorganism biomass and activity resulting in further reductions in the rates of organic material decomposition (Anderson et al. 1981, Curl and Truelove 1986, Whipp 1990).

Grass plants developed several physiological, biological, and biogeochemical processes early during coevolution with graminivores in response to partial defoliation and the removal of leaf area (McNaughton 1979, 1983; Coleman et al. 1983; Briske 1991; Briske and Richards 1995; Manske 1999). This set of processes are collectively recognized as defoliation resistance mechanisms (Briske 1991, Briske and Richards 1995). Annual partial defoliation by grazing graminivores of grass lead tillers at growth stages between the 3.5 new leaf stage and the flower stage is required to activate the defoliation resistance mechanisms.

Native grass plants need the essential major elements of carbon, hydrogen, and nitrogen in the presence of sunlight for physiological growth processes to produce leaves, stems, roots, and secondary tillers (Manske 2011b). Removal of grazing graminivores from grasslands and the failure to activate the defoliation resistance mechanisms restricts grass plants use of important mechanisms and processes necessary for normal grass growth and development.

The carbon allocated for grass growth does not come from stored material in the roots but is carbon recently fixed (Richards and Caldwell 1985, Coyne et al. 1995, Briske and Richards 1995). The carbon comes from atmospheric carbon dioxide which composes about 0.03% of the gasses in the atmosphere and exists at concentrations of around 370 to 385 mg/kg. Atmospheric carbon dioxide is not limiting on rangelands. The carbon dioxide is fixed with hydrogen from soil water during the process of photosynthesis which converts energy from sunlight into chemical energy and assimilates simple carbohydrates. However, when nondefoliated live and standing dead leaves of grasses reduce sunlight reaching understory grass leaves, photosynthetic rates are greatly reduced and available fixed carbon becomes deficient.

The hydrogen allocated for grass growth comes from soil water absorbed through the roots. Soil water is infiltrated precipitation. In western North Dakota, the perennial plant growing season months have a long-term periodicity rate of water deficiency conditions at 32.7%, for a mean of 2.0 months with water deficiency per growing season (Manske et al. 2010). The thick mulch that builds up on nondefoliation managed grasslands causes additional soil water problems. Thick mulch intercepts a portion of the precipitation inhibiting infiltration. The thicker the mulch, the greater the quantity of the precipitation absorbed. Absorption of the precipitation by the mulch causes a deficiency in soil water further inhibiting carbon assimilation.

The nitrogen allocated for grass growth can be mobilized from shoot and root tissue (Briske and Richards 1995) when the preferential source of mineral nitrogen recently converted from soil organic nitrogen by active rhizosphere organisms is low. Low quantities of available soil mineral nitrogen below 100 lbs/ac is the major limiting factor of herbage growth on rangelands (Wight and Black 1979). However, mixed grass prairie soils are not deficient of nitrogen. Most of the nitrogen is immobilized in the soil as organic nitrogen. Untilled grassland soils contain about 3 to 8 tons of organic nitrogen per acre. Soil organic nitrogen must be mineralized by rhizosphere organisms to become plant usable mineral nitrogen. The quantity of rhizosphere organisms is the limiting factor in grassland ecosystems low in mineral nitrogen. Biomass and activity of organisms in the rhizosphere are limited by access to energy from simple carbohydrates which can be exudated from grass lead tillers with partial defoliation by grazing graminivores when grass tillers are at vegetative growth stages. Available mineral nitrogen becomes extremely deficient when grazing graminivores are removed from a grassland.

Light is radiant energy from the sun and is necessary for photosynthesis. Intensity of sunlight can be greatly reduced by shading from other plants. Nondefoliated live and standing dead leaves of grasses reduce light penetration to a similar degree as shrubs, even though shrub leaves are flat and wide and grass leaves are erect and linear (Kochy 1999). The light levels penetrating the leaf canopy can be about 20% of the light levels above the canopy (Peltzer and Kochy 2001).

Nondefoliation of native grass plants reduces exudation of short carbon chain energy to slow leakage into the rhizosphere, reducing biomass and activity of soil organisms, decreasing mineralization processes that cause deficiencies in mineral nitrogen and other essential elements. Failure to remove the double produced leaf biomass annually causes shading that greatly reduces the sunlight intensity reaching native grass leaves, reducing photosynthetic rates that cause deficiencies in available fixed carbon. Accumulation of undecomposed grass leaf material modifies soil temperatures, causes deficiencies in soil water, and causes additional deficiencies in essential elements. The deficiencies of indispensable component resources of carbon, hydrogen, nitrogen, and other essential elements prevent grass plants from synthesizing sufficient quantities of vital carbohydrates, proteins, and nucleic acids. Without sufficient quantities of vital organic compounds native grass plants cannot maintain production of herbage biomass and tiller numbers (Langer 1972, Briske and Richards 1995).

Advanced degradation by antagonistic nondefoliation management of mixed grass prairie communities results in creation of numerous large bare spaces between native grass plants in the plant community. These open spaces, that lack competition from native grasses, are ideal habitat for growth of introduced cool season domesticated grasses like Kentucky bluegrass, and smooth bromegrass, and for growth of other opportunistic “weedy” plant species. These introduced plants have labile roots that break down easily making the nutrients contained in dead roots readily available to support continued growth and expansion of these nonnative plants without assistance from symbiotic rhizosphere organisms. The composition of plant species changes with decreases in the desirable species and increases in less desirable species, and later with increases in undesirable species. The change in plant composition from desirable to undesirable species is actually the symptom of ecosystem degradation; the fundamental degradation is the diminishment of defoliation resistance mechanisms within grass plants, decrease of ecosystem biogeochemical processes, and the reduction of available mineral nitrogen below 100 lbs/ac. The degree of plant species change lags behind the degree of ecosystem biogeochemical degradation.

Nondefoliation management can degrade mixed grass prairie more drastically than poor grazing management. Removal of cattle grazing from mixed grass prairie plant communities causes discontinuation of defoliation resistance mechanisms, degeneration of ecosystem biogeochemical processes, depletion of plant species composition with severe reductions of native grasses, excessive increases of standing dead and litter, extreme increases of introduced domesticated grasses, remarkable increases of woody shrub and tree species, and degradation of range condition to very low percentages of potential climax vegetation after 75 years.

A remarkably high quantity of woody shrub and tree species and an exceptionally great number of individual woody plants were able to develop on the four reference area ungrazed exclosures because the competitive advantage of grasses for belowground resources was diminished in conjunction with the degradation of the native grass plant communities that resulted from removal of grazing defoliation by large graminivores. The existence of a shrub component in a grassland plant community is not an ecological beneficial relationship. Shrubs and grasses are adversarial inhibitive competitors. Grasses and shrubs compete for sunlight, mineral nitrogen, and soil water.

The degree of difference in competitive abilities between prairie grasses and shrubs on the mixed grass prairie was investigated during 1994 to 1998 at the University of Regina, Saskatchewan, with direction from Dr. S.D. Wilson. The grass growth form has competitive advantages over the shrub growth form. The per gram of biomass effects on resource use efficiency are smaller for shrub growth forms than for grass growth forms (Kochy and Wilson 2000). Shrubs must use a portion of the photosynthates produced in the leaves to build and maintain their unproductive woody stems; the result is a great reduction in resource uptake efficiency. Shrubs require 6 times greater aboveground biomass than the grasses before grass production is decreased as a result of competition from the shrubs (Kochy 1999). Grass aboveground biomass is primarily productive photosynthetic leaves; the result is a high resource uptake efficiency. Grasses have a 1.4 times greater per gram of biomass resource efficiency effect than shrubs (Kochy 1999). Grasses on prairie habitat attenuated more light, took up more mineral nitrogen, and took up more soil water per gram of biomass than did shrubs on brush habitat (Kochy 1999, Kochy and Wilson 2000). Because grasses have high root : shoot ratios and no woody stems to maintain; grasses are good competitors for belowground resources and superior competitors for mineral nitrogen. Shrub's taller growth form makes the plants superior competitors for aboveground resources (Kochy and Wilson 2000).

Competition between shrubs and grasses during early stages of shrub expansion into prairie habitat of healthy grasses is primarily for belowground resources of nutrients and soil water; under these initial conditions, grasses have the advantage and the shrubs are suppressed (Kochy and Wilson 2000, Peltzer and Kochy 2001). Competition from healthy grasses also reduces the growth rates of shrub rhizomes and causes high mortality rates of young suckers, preventing expansion into healthy grass communities (Li and Wilson 1998). Seedlings of grasses and shrubs are also unable to compete effectively for resources in healthy established grass plant communities and are suppressed (Peltzer and Kochy 2001). Successful competition of grasses for belowground resources prevents shrubs from becoming established in healthy grass communities. Shrubs can compete for some of the belowground resources only after the grass plants have been degraded by antagonistic management practices.

Following the reduction in grass plant resource competitiveness, establishment of shrubs can occur in degraded grasslands, which frequently starts as clumps (Li and Wilson 1998). The belowground resources previously used by the healthy robust grasses, but no longer consumed by the smaller, less vigorous degraded grasses, are taken up by the shrub plants resulting in proportional increases of biomass production (Kochy and Wilson 2000). After grass competition for belowground resources is reduced, shrub rhizome suckers can regain the faster growth rates and higher survival rates (Li and Wilson 1998) resulting in greater shrub stem densities. As shrub stem density increases, the competition shifts to primarily the aboveground resources of light; under these different degraded conditions, shrubs have the advantage and the grasses are strongly suppressed (Kochy and Wilson 2000).

The reduction of the competitiveness of the grasses for belowground resources of mineral nitrogen and soil water in conjunction with diminution of the defoliation resistance mechanisms and degradation of the biogeochemical processes in the grass plant communities that resulted from the antagonistic nondefoliation management practices fully explains the extraordinary increase of woody shrubs and trees growing in the four ungrazed exclosures.

The increase of woody shrubs and trees in grass communities would have traditionally been explained as a result of fire suppression (Humphrey 1962, Stoddart, Smith, and Box 1975, Wright and Bailey 1982). The grazed areas and the ungrazed exclosures of the four reference areas have all had at least 75 years without fire defoliation. However, if fire suppression had caused the increase of shrubs and trees, the quantity of woody plants would have been nearly similar on the ungrazed and grazed areas. The ungrazed exclosures have had a far greater intrusion of woody plants than the grazed areas. The grazed grasses have maintained a greater degree of competitiveness than the ungrazed grasses. The greater increase of woody plants into the grass communities of the ungrazed exclosures has not been the result of fire suppression. The increased woody plant infestation of the exclosures has been caused by the greatly reduced competitiveness of the ungrazed grasses and the degradation of the biogeochemical processes in the grass plant communities that resulted from the removal of partial defoliation by large grazing graminivores.

Many ecologists have observed that the repeated occurrence of fire was the force that prevented intrusion of shrubs and trees into grasslands (Weaver 1954, Humphrey 1962, Daubenmire 1974, Stoddart, Smith, and Box 1975, Wright and Bailey 1982), and, the obvious corollary, that suppression of fire has facilitated the invasion of shrubs and trees into grasslands (Humphrey 1962, Stoddart, Smith, and Box 1975, Wright and Bailey 1982, Manske et al. 2006a). However, the presence of fire does not prove that grasslands need or are caused by fire (Heady 1975). In the northern mixed grass prairie, fire cannot prevent the invasion of or cause the removal of shrubs and trees that reproduce by vegetative secondary suckers growing from crown (stem base) or rhizome buds (Wright and Bailey 1982, Manske et al. 2006a, Manske 2006b). Almost all deciduous woody plants growing in the Northern Plains grassland reproduce vegetatively.

The increase of undesirable introduced herbaceous grasses and forbs in grass communities has also often times been explained as a result of fire suppression (Wright and Bailey 1982). Kirsch and Kruse (1972) concluded that the cool season exotic grasses, Kentucky bluegrass and smooth bromegrass, have invaded much of the northern mixed grass prairie in the absence of fire. Seedlings of trees, shrubs, weedy forbs, and introduced grasses cannot become established in healthy functioning grassland ecosystems with grasses that have retained full resource uptake competitiveness (Peltzer and Kochy 2001). Establishment of intrusive seedlings can occur only after the grass communities have been degraded by antagonistic management practices. Furthermore, fire cannot prevent establishment and expansion of undesirable seedlings into degraded grass communities unless the fire frequency suppresses seed production of all invasive species in a region.

Repeated prescibed fire can change the percent composition of the aboveground vegetation biomass in degraded mixed grass prairie invaded by shrubs. The composition of introduced cool season grasses, early succession and weedy forbs, and shrub aerial stems decrease temporarily from four repeated every-other-year prescribed fires (Manske 2007a, 2011a). However, the fundamental problems of low native grass competitiveness, diminished defoliation resistance mechanisms, and degraded biogeochemical processes remain in the grassland ecosystems following repeated fire events.

None of the physiological and asexual processes of the defoliation resistance mechanisms within grass plants and none of the biogeochemical processes performed by symbiotic rhizosphere organisms within grassland ecosystems are activated by fire. Fire does not stimulate vegetative reproduction by tillering. Fire does not stimulate endomycorrhizal fungal colonization of perennial grass roots. Fire does not stimulate rhizosphere organism biomass and activity. Fire does not stimulate mineralization of soil organic nitrogen into mineral nitrogen (Manske 2007a, 2011a). Fire does not replace partial defoliation by grazing for management of healthy and productive rangeland ecosystems.

Had the early grassland ecologists known about the conclusions from the grass-shrub competition research conducted at the University of Regina and understood the defoliation resistance mechanisms and the biogeochemical processes, it would appear extremely plausible that the conjectural observations of increasing shrubs and trees and undesirable forbs and grasses in grassland communities that were explained as results of fire suppression, would have been scientifically explained as shrubs and trees and introduced forbs and grasses effectively competing for a portion of the belowground resources of nutrients and soil water after the competitiveness of the grasses had been reduced as a result of degradation of the grass community caused by antagonistic management practices. The key to woody shrub and tree and herbaceous plant control in grass communities is to regain the competitive advantage of the grasses by restoration of the mechanisms and processes in the mixed grass prairie ecosystem that results from biologically effective partial defoliation by large grazing graminivores.

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Literature Cited

Anderson, R.V., D.C. Coleman, C.V. Cole, and E.T. Elliott. 1981. Effect of nematodes Acrobeloides sp. and Mesodiplogaster lheritieri on substrate utilization and nitrogen and phosphorus mineralization. Ecology 62:549-555

Bird, S.B., J.E. Herrick, M.M. Wander, and S.F. Wright. 2002. Spatial heterogeneity of aggregate stability and soil carbon in semi-arid rangeland. Environmental Pollution 116:445-455.

Brand, M.D., and H. Goetz. 1986. Vegetation of exclosures in southwestern North Dakota. Journal of Range Management 39:434-437.

Briske, D.D. 1991. Developmental morphology and physiology of grasses. p. 85-108. in R.K. Heitschmidt and J.W. Stuth (eds.). Grazing management: an ecological perspective. Timber Press, Portland, OR.

Briske, D.D., and J.H. Richards. 1994. Physiological responses of individual plants to grazing: current status and ecological significance. p. 147-176. in M. Vavra, W.A. Laycock, and R.D. Pieper (eds.). Ecological implications of livestock herbivory in the west. Society for Range Management, Denver, CO.

Briske, D.D., and J.H. Richards. 1995. Plant response to defoliation: a physiological, morphological, and demographic evaluation. p. 635-710. in D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Burrows, R.L., and F.L. Pfleger. 2002. Arbuscular mycorrhizal fungi respond to increasing plant diversity. Canadian Journal of Botany 80:120-130.

Carstensen, V. (ed). 1968. The public lands, studies in the history of the public domain. The University of Wisconsin Press. Madison, WI. 522p.

Coleman, D.C., C.P.P. Reid, and C.V. Cole. 1983. Biological strategies of nutrient cycling in soil ecosystems. Advances in Ecological Research 13:1-55.

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317p.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. in D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Crider, F.J. 1955. Root-growth stoppage resulting from defoliation of grass. USDA Technical Bulletin 1102.

Curl, E.A., and B. Truelove. 1986. The rhizosphere. Springer-Verlag, New York, NY.

Daubenmire, R.F. 1974. Plants and Environment: A textbook of plant autecology. 3rd ed. John Wiley & Sons. New York, NY.

Driver, J.D., W.E. Holben, and M.C. Rillig. 2005. Characterization of glomalin as a hyphal wall component of arbuscular mycorrhizal fungi. Soil Biology and Biochemistry 37:101-106.

Emberger, C., H. Gaussen, M. Kassas, and A. dePhilippis. 1963. Bioclimatic map of the Mediterranean Zone, explanatory notes. UNESCO-FAO. Paris. 58p.

Grant, S.A., G.T. Barthram, L. Torvell, J. King, and H.K. Smith. 1983. Sward management, lamina turnover and tiller population density in continuously stocked *Lolium perenne*-dominated swards. Grass and Forage Science 38:333-344.

Great Plains Flora Association. 1986. Flora of the Great Plains. University of Kansas, Lawrence, KS.

Hamilton, III, E.W., and D.A. Frank. 2001. Can plants stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. Ecology 82:2397-2402.

Hanson, H.C., and W. Whitman. 1938. Characteristics of major grassland types in western North Dakota. Ecological Monographs 8:57-114.

Heady, H.F. 1975. Rangeland Management. McGraw-Hill Book Co. New York, NY.

Hibbard, B.H. 1965. A history of the public land policies. The University of Wisconsin Press. Madison, WI. 579p.

Humphrey, R.R. 1962. Range Ecology. The Ronald Press Co. New York, NY.

Ingham, R.E., J.A. Trofymow, E.R. Ingham, and D.C. Coleman. 1985. Interactions of bacteria, fungi, and the nemotode grazers: effects of nutrient cycling and plant growth. Ecological Monographs 55:119-140.

Kirsch, L.M., and A.D. Kruse. 1972. Prairie fires and wildlife. Proceedings of Tall Timbers Fire Ecology Conference. 12:289-303.

Klein, D.A., B.A. Frederick, M. Biondini, and M.J. Trlica. 1988. Rhizosphere microorganism effects on soluble amino acids, sugars, and organic acids in the root zone of Agropyron cristatum, A. smithii, and Bouteloua gracilis. Plant and Soil 110:19-25.

Kochy, M., and S.D. Wilson. 2000. Competitive effects of shrubs and grasses in prairie. Oikos 91:385-395.

Kochy, M. 1999. Grass-tree interactions in western Canada. Ph.D. Dissertation. University of Regina. Regina, Saskatchewan, Canada.

Langer, R.H.M. 1972. How grasses grow. Edward Arnold, London, Great Britain.

Li, X., and S.D. Wilson. 1998. Facilitation among woody plants establishing in an old field. Ecology 79:2694-2705.

Manske, L.L. 1994. History and land use practices in the Little Missouri Badlands and western North Dakota. Proceedings - Leafy Spurge Strategic Planning Workshop. USDI National Park Service, Dickinson, North Dakota. p. 3-16.

Manske, L.L. 1999. Can native prairie be sustained under livestock grazing? p. 99-108. in J. Thorpe, T.A. Steeves, and M. Gollop (eds.). Proceedings of the Fifth Prairie Conservation and Endangered Species Conference. Provincial Museum of Alberta. Natural History Occasional Paper No. 24. Edmonton, Alberta, Canada.

Manske, L.L. 2000. Management of Northern Great Plains prairie based on biological requirements of the plants. NDSU Dickinson Research Extension Center. Range Science Report DREC 00-1028. Dickinson, ND. 12p.

Manske, L.L., S.A., Schneider, and A.M. Kraus. 2006a. Management of western snowberry aka wolfberry and buckbrush. NDSU Dickinson Research Extension Center. Rangeland Research Extension Program 4009. Dickinson, ND. 107p.

Manske, L.L. 2006b. Chemical management of silver sagebrush. NDSU Dickinson Research Extension Center. Range Research Report DREC 06-1065. Dickinson, ND. 38 p.

Manske, L.L. 2007a. Effects on vegetation, endomycorrhizal fungi, and soil mineral nitrogen from prescribed burning treatments repeated every-other-year in mixed grass prairie invaded by western snowberry. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 07-3044. Dickinson, ND. 19p.

Manske, L.L. 2007b. Restoration of degraded prairie ecosystems. NDSU Dickinson Research Extension Center. Summary Range Management Report DREC 07-3045. Dickinson, ND. 6p.

Manske, L.L. 2008. Circumstances that impelled fertilization treatments research on native rangeland. NDSU Dickinson Research Extension Center. Range Management Report DREC 08-1073. Dickinson, ND. 4p.

Manske, L.L. 2009. Grass plant responses to defoliation. NDSU Dickinson Research Extension Center. Range Research Report DREC 09-1074. Dickinson, ND. 47p.

Manske, L.L. 2010a. Leaf stage development of western wheatgrass tillers. NDSU Dickinson Research Extension Center. Range Research Report DREC 10-1075. Dickinson, ND. 48p.

Manske, L.L. 2010b. Evaluation of the defoliation resistance mechanisms influence on vegetative tiller initiation and tiller density. NDSU Dickinson Research Extension Center. Range Research Report DREC 10-1076. Dickinson, ND. 13p.

Manske, L.L., S. Schneider, J.A. Urban, and J.J. Kubik. 2010. Plant water stress frequency and periodicity in western North Dakota. NDSU Dickinson Research Extension Center. Range Research Report DREC 10-1077. Dickinson, ND. 11p.

Manske, L.L. 2011a. Grazing and burning treatment effects on soil mineral nitrogen and rhizosphere volume. NDSU Dickinson Research Extension Center. Range Research Report DREC 11-1066c. Dickinson, ND. 15p.

Manske, L.L. 2011b. Biology of defoliation by grazing. NDSU Dickinson Research Extension Center. Range Management Report DREC 11-1067b. Dickinson, ND. 25p.

Manske, L.L. 2011c. Environmental factors to consider during planning of management for range plants in the Dickinson, North Dakota, region, 1892-2010. NDSU Dickinson Research Extension Center. Range Research Report DREC 11-1018n. Dickinson, ND. 40p.

Manske, L.L., and J.A. Urban. 2012. Humane soil beastie catcher: Its fabrication and use. NDSU Dickinson Research Extension Center. Range Research Report DREC 12-1079. Dickinson, ND. 9p.

McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. American Naturalist 113:691-703.

McNaughton, S.J. 1983. Compensatory plant growth as a response to herbivory. Oikos 40:329-336.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York, NY. 547p.

Mueller, R.J., and J.H. Richards. 1986. Morphological analysis of tillering in Agropyron spicatum and Agropyron desertorum. Annuals of Botany 58:911-921.

Murphy, J.S., and D.D. Briske. 1992. Regulation of tillering by apical dominance: chronology, interpretive value, and current perspectives. Journal of Range Management 45:419-429.

Peltzer, D.A., and M. Kochy. 2001. Competitive effects of grasses and woody plants in mixed grass prairie. Journal of Ecology 89:519-527.

Richards, J.H., and M.M. Caldwell. 1985. Soluble carbohydrates, concurrent photosynthesis, and efficiency in regrowth following defoliation: a field study with *Agropyron* species. Journal of Applied Ecology 22:907-920.

Richards, J.H., R.J. Mueller, and J.J. Mott. 1988. Tillering in tussock grasses in relation to defoliation and apical bud removal. Annals of Botany 62:173-179.

Rillig, M.C., S.F. Wright, and V.T. Eviner. 2002. The role of arbuscular mycorrhizal fungi and glomalin in soil aggregation: comparing effects of five plant species. Plant and Soil 238:325-333.

Smith, K.A. 1988. Lostwood National Wildlife Refuge station plan. US Fish and Wildlife Service.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. 3rd ed.. McGraw-Hill Book Co. New York, NY.

Weaver, J.E. 1954. North American Prairie. Johnsen Publishing Co. Lincoln, NE.

Whipps, J.M. 1990. Carbon economy. p. 59-97. in J.M. Lynch (ed.). The rhizosphere. John Wiley and Sons, New York, NY.

Whitman, W.C. 1953. Pyramid Park experimental area laboratory for rangeland research. North Dakota Agricultural Experiment Station Bimonthly Bulletin 16:63-66.

Whitman, W.C. 1974. Influence of grazing on the microclimate of mixed grass prairie. p. 207-218. *in* Plant Morphogenesis as the basis for scientific management of range resources. USDA Miscellaneous Publication 1271.

Wight, J.R., and A.L. Black. 1972. Energy fixation and precipitation use efficiency in a fertilized rangeland ecosystem of the Northern Great Plains. Journal of Range Management 25:376-380.

Wight, J.R., and A.L. Black. 1979. Range fertilization: plant response and water use. Journal of Range Management 32:345-349.

Wright, H.A., and A.W. Bailey. 1982. Fire Ecology: United States and southern Canada. John Wiley & Sons. New York, NY.