Buffalo for a Broken Agricultural System:

Land-Use Intensity of the Bison Meat Industry

from Montana to Indiana

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March 14th, 2012

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ABSTRACT

Many bison meat producers and trade associations claim that bison meat presents a more environmentally sustainable and healthier alternative to similar protein sources like beef or pork. Livestock, particularly ruminants like the American bison (*Bos bison*), present an alternative use for land that is too poor or erodible for cultivation in crop agriculture. However, in our study we find that there is significant variation in land use intensity, one descriptor of a ranch's sustainability, across a sample of bison ranches in the American West and Midwest. Using data from a survey of 54 ranchers in twelve Midwestern states, we calculated an intensity index from the amount of nitrogen fertilizer input, the percent of supplemental feed, and stocking rate. We tested three hypotheses on the effect of ranch size, annual dewormer applications and prior land use on the overall land use intensity of a ranch. Relationships between these independent variables, land use intensity, and indicators of intensity combined with the observed variability in intensity suggests that sustainability is not an inherent quality of bison meat production.

Acknowledgements

We would like to thank our advisor, Tsegaye Nega, Daniel Hernandez, and the Environmental Studies faculty for their guidance throughout the process, the National Bison Association for their survey support, Cherry Danielson, Dan and Jill O'Brien, the many bison ranchers that hosted us through the summer of 2011, and the students of the Environmental Studies Senior Seminar for their editing input. Thank you to the J. Oliver Lewis Memorial Fund for its generous funding.

I. Introduction

The American Food System

Over the course of the 20th century the American food system changed dramatically due to population growth, urbanization and technological advancements brought about by the Green Revolution. The mechanization of agricultural processes allowed for an increase in crop yield and simultaneously decreased the amount of human labor required to produce agricultural products. Furthermore, the physical inputs to agricultural systems shifted towards synthetic products, as exemplified by the development and rise of the Haber-Bosch process which fixes nitrogen for fertilizer, as well the development of synthetic pesticides and herbicides. This agricultural intensification successfully provided the growing American population with an abundant and stable food supply at relatively low cost. However, in recent decades these processes have also brought with them a number of unexpected environmental repercussions. Some of the consequences of industrialized agriculture include increased levels of air and water pollution as well as a loss of biodiversity (Burkholder et al, 2007; Campagnolo et. al, 2002; Fleischner, 1994; Mallin and Calhoon, 2003; Naeem et al., 1994). Regardless of one's views on the ethical obligations for environmental protection, human health and well-being are undeniably linked to ecosystem functioning (Millennium Ecosystem Assessment, 2005; Folet et al., 2006; Diaz et al., 2005). While increasing agricultural output may be necessary to feed a growing world population, maintenance of ecological integrity is also necessary to sustain the global population.

Critics of industrialized agriculture have been particularly forceful in their indictments of the prevailing system of meat production in the United States. These systems, known as

Confined (or Concentrated) Animal Feeding Operations (CAFOs), result in a highly concentrated output of manure, runoff from which can be harmful to both aquatic and terrestrial ecosystems (Burkholder et al., 2007; Mallin and Calhoon, 2003; Kumar et al., 2005). In addition to overloading the ecosystem with nutrients, this runoff often contains antibiotics, hormones, and pesticides, upon which CAFOs heavily rely. Hormone runoff is particularly concerning, as the chemicals involved can significantly alter biological functioning of organisms in the surrounding environment, even at low concentrations (Lee et al. 2007). Use of these chemicals in meat production can have a direct negative impact on human health. The threats associated with CAFO practices include the development of antimicrobial resistance (Silbergeld et al., 2008; Campagnolo et al., 2002), water contamination in nearby communities (Burkholder et al., 2007), and high levels of respiratory diseases in CAFO workers (Donham, 2000).

Although some critics argue that a “sustainable” agricultural system could more easily be attained by excluding meat, this perspective disregards the enormous degree to which meat production influences the overall food system. In 2010, the retail equivalent of the American beef and cattle industry alone was valued at $74 billion and in 2000, the USDA estimated that the average American consumed 195.2 pounds of meat annually (USDA, 2000). In a recent survey, the USDA Economic Research Service found that more than 25% of all land in the contiguous United States is grazed pastureland (Lubowski et al., 2006). Clearly meat production is a significant component of the American agricultural system and cannot easily be eliminated. Rather, a way must be found to reconcile the goals of sustainable agriculture with meat production.

A sustainable meat production system can play an important role in achieving broader environmental goals. Ranching is the predominant land use in the American West, particularly in the Northern Great Plains (Lubowski et al. 2002). While meat production systems can have severe and broadly distributed negative effects, these externalities are not inherent to meat production. Livestock, particularly ruminants, present an alternative use for land that is too poor or erodible for cultivation in crop agriculture (Oltjen and Beckett, 1996). Economically viable use for such land is restricted, often resulting in a choice between livestock grazing and inherently extractive land uses like mining and drilling. As such, meat production can present a more ecologically compatible alternative to development, particularly when managed responsibly (Oltjen and Beckett, 1996). Consumers, legislators, and conservationists alike are searching for an alternative meat production system that is compatible with their goals for environmental protection, human health, and animal welfare.

The myth of the sustainable bison

In the search for a "silver bullet" solution to environmental issues surrounding the American meat production system, a number of consumers have embraced the notion that bison present an inherently sustainable meat choice. As such, the bison industry has grown significantly in recent years. According to the National Bison Association, the number of bison slaughtered under federal and state inspection in 2011 more than doubled since 2002. This growth may be a result of the bison's resurgent historical and cultural significance (Isenberg, 2000).

Unlike cattle, wild herds of bison roamed the plains of North America until relatively recently (Isenberg, 2000). Although the wild bison is largely a thing of the past, many Americans have retained an image of the bison that connotes open-range, low-intensity grazing. A former chairman of the National Bison Association illustrated this perception in his claim that, "Bison are a romantic symbol of nature, of its power and its benevolence. Not only is helping to bring the Bison back fulfilling, but the symbol of the Bison might help our urban neighbors think about where their food comes from, might help them to accept the cycles of life, and might bring them a sense of peace and greater fulfillment in life" (Jonjak, 1999 as cited by Lulka, 2008).

Advocates of the bison industry often cite a study by Knapp et al. (1999) that claims that bison are a keystone species. Research has illustrated the positive effect that bison grazing behavior can have on plant species diversity and primary productivity (McMillan et al., 2011; Grubb 1977; Veen et al., 2008; Frank 2005; Knapp et al., 1999). However, these findings all assume that the herds in question engage in their natural behavior. This is an unrealistic assumption that requires verification. Ninety-seven percent of the existing North American bison population is privately owned (Gates and Aune, 2008) and have greater potential to be restricted, both physically and behaviorally, by man-made limitations. As a result, they are dependent on resource inputs to maintain high body weights under relatively confined conditions. The belief that low land use intensities are inherent to bison meat production ignores the diversity of potential inputs, and the wide array of possible bison meat production methods and management practices, from open-range, grass-feeding operations, to CAFOs

It is difficult to conceptualize the role that bison can play in a sustainable meat system without understanding the range of management practices producers employ. Environmental degradation is often considered a direct result of land use intensification (Stoate et al 2001), which is the process of increasing technological, material, or labor inputs to the system for the purpose of raising the yield of a given plot of land (Beaufoy et al. 1994). Within the bison industry, and the meat industry in general, there is potential for variation in land use intensity. A rancher can substantially reduce the negative environmental externalities associated with his ranch by employing an "ecologically minded" management system (Matson et al., 1997). A number of studies have suggested that land use intensity is the inverse of sustainability and can therefore be used to measure sustainability (Turner and Doolittle 1978; Shriar 2000; Herzog et al. 2006).

This paper seeks to apply this concept of land use intensity to the bison meat production in order to determine the practical implications of management variation within the bison industry. We calculate the land use intensity scores for a sample of bison production operations[*] in the Midwestern and Western United States and examine the management implications of variation within this sample. Using this information, we will provide a critical assessment of the assumption that bison meat production is inherently sustainable.

II. Theoretical framework

A number of different frameworks have been developed to evaluate the ecological sustainability of agricultural systems. One common approach is to conduct a "life cycle assessment" of a given product. In this methodology, the entire life cycle of the product is mapped, and all inputs and outputs to the system are inventoried and analyzed to determine their potential environmental impacts (Curran, 2006). Life cycle assessments presume that the researchers have uninhibited access to information about inputs and outputs of the system at each in the life cycle. Because we are not bison ranchers and have limited access to this information, such an analysis would be unrealistic given our time and resource constraints.

Other research has attempted to extrapolate a measure for the sustainability of an entire system, based on a series of indicator variables (Studer et al., 2009; Rigby et al., 2001). The

[*] *We acknowledge that not all bison producers are ranchers. However, for the sake of convenience and expediency, we will refer to all bison meat production operations as "ranches" and to their operators as "ranchers".*

Rigby et al. (2001) paper, for instance, developed a list of practices used in agriculture and assigned weights to each of them based on whether or not the practice improved or degraded a farm's sustainability, which includes economic, social and ecological viability. In order to complete this type of assessment on Midwestern bison ranches, we would have had to assign weights to each of their management practices. The authors admit that the legitimacy of assigning weights to management practices is questionable.

Alternatively, Smyth and Dumanski (1994) propose a system called the Framework for Evaluating Sustainable Land Management (FESLM). The FESLM approach models the suitability of the implemented land use in a given system, based on the sum of the perceived positive and negative effects of that use. The authors base their determinations of suitability on experience and "common sense" of the agricultural system in question. Such an approach is dependent on the perceived effects of practices on a farming system. It requires time to observe the full extent and magnitude of these effects, which are qualitative in nature. The FESLM approach is particularly subjective and determinations of suitability are often impressionistic, which would compromise the transparency of our study.

In situations where data is scarce, ecological sustainability can be measured as the inverse of agricultural intensity, defined and evaluated in terms of either agricultural output or input per unit of land. An output-based approach measures intensity in terms of crop yields, while an input-based approach measures intensity in terms of the amount of resources producers utilize to generate these yields. In most cases, the ultimate goal of agricultural intensification is to raise yields, and thus, output-based analysis is the more direct approach to measuring the success of intensification (Turner and Doolittle, 1978). Measuring land use intensity based on output makes no assumptions about the rate at which inputs will affect yield increases (Shriar, 2000).

However, it can be nearly impossible to compare output-based calculations of intensity between dissimilar agricultural systems because the universal unit with which to compare the output is monetary value. Temporal and geographical variation in product prices makes such comparisons unrealistic (Herzog et al., 2006).

Several studies have therefore implemented an alternative framework that measures land-use intensity by quantifying the agricultural inputs aimed at increasing productivity (Herzog et al., 2006; Shriar, 2005). Inputs are broadly defined to include both material inputs such as pesticides or fertilizers and management inputs such as plowing or irrigation use (Shriar, 2000). Because these inputs are intended to increase agricultural production, they can be used as proxies for assessing intensity. Additionally, unlike output-related variables, input indicators directly influence the unintended ecological externalities that, as discussed earlier, are frequently associated with intensive agricultural production. As a result, an input-based analysis of land-use intensity more accurately reflects a producer's environmental impact on a given system. Because our analysis is a comparative assessment of a bison producer's ecological impact, we will employ an input-based calculation of intensity.

In our analysis of bison meat production, we have chosen to replicate the methodological approach implemented by Herzog, et al. (2006) that defines an overall index for land use intensity based on three input indicator variables- nitrogen fertilizer application, livestock density, and pesticide application. Using a standardized questionnaire on management practices, Herzog et al. (2006) evaluated the intensity of agricultural production for a sample of farms in temperate Europe. They then used these results to test a number of hypotheses about the distribution and characteristics of intensively managed agricultural systems.

We calculate a land-use intensity index using three indicator variables applicable to a bison operation: the type and quantity of supplemental feed, stocking rate, and nitrogen fertilizer application. We chose these variables because they directly impact water quality, biodiversity, and soil quality and because data on these variables can be feasibly collected through a survey.

We define animal density as the animal units per acre of grazed land. The use of animal units accounts for the difference in size and consumption rate among the herd. A bull is counted as 1.5 animal units, a cow, either with or without calf, as 1, and a yearling as 0.5 (Arychuk, 2000). Animal density can have a number of effects on ecological functioning. Higher density can lead to increased soil compaction, which in turn reduces water infiltration rates and makes soil more susceptible to erosion (Daniel et al., 2002; Oldeman, 1994). In North America overgrazing has been identified as one of the major causative factors of soil degradation (Bridges and Oldeman, 1999). While some grazing can be beneficial in that it encourages a plant community with high root-to-shoot ratios, high-intensity grazing can destabilize plant communities, reducing both overall biomass and species richness (Fleischner, 1994).

Animal feed intensity was normalized for the percent of the herd diet comprised of hay, corn, and oats. While use of supplemental feed does not directly affect the land on which bison are being kept, additional land beyond the boundaries of the pasture are required to produce this feed. Whether grown on a portion of the rancher's property or off site, animal feed utilizes high rates of fertilizer and pesticide inputs. The manner in which corn and oats are typically grown exposes soil to high rates of erosion, increases run off of pesticides, and increases infiltration of ground water aquifers (Toy et al., 2002). Hay is often grown in low diversity plant assemblages, which have been shown to produce less biomass than those in high diversity plant assemblages (Tilman et al., 2001; Picasso et al., 2011). Proportion of supplemental feed is included in our land use intensity index to account for the adverse environmental impact of low diversity crop agricultural associated with bison production.

Using information on a rancher's fertilizer products and application rates, we calculated the average lbs acre^{-1} of nitrogen applied on each ranch. Nitrogen application can negatively impact ecosystem functioning through both nutrient runoff (Ommani et al., 2009) and soil organic matter reduction (McTiernan et al., 2001). Nutrient runoff is concerning because it can lead to the pollution of local waterways (Smith et al., 1999). Soil organic matter, particularly organic carbon, is often considered one of the most significant indicators of soil quality (Reeves, 1997). Low levels of organic matter can lead to decreased plant available water and increased rates of erosion (Bruce et al, 1995).

Using these three indicators of land use intensity we can test the hypothesis that a ranch's land use intensity is independent of the general characteristics (e.g., location, size) of that ranch. We identify two management decisions that a rancher makes—whether or not to employ rotational grazing and how frequently to apply dewormer—and two inherent ranch conditions—size and prior land use. If sustainability is an inherent quality of bison ranching, we would not expect to find a relationship between land use intensity and ranchers' management techniques. Such a relationship would imply that variation in land use intensity is not random, but rather contingent on the conditions of that land use. Differences in land use intensity depending on ranch size and prior land use would imply that under some conditions, variables beyond the ranchers' control significantly influences the suitability of bison ranching.

Following this framework, we will evaluate the land use intensity of bison ranches in order to test the following hypotheses:

1. High rates of dewormer use indicate a high intensity of management.
2. Use of rotational grazing indicates a high intensity of management.

3. Larger landholders manage the land less intensively.
4. Lands formerly used for livestock production are managed more intensively than those formerly in other land uses.

III. Materials and Methods

Survey

In order to gather data on the land use practices of bison ranchers, we distributed an electronic survey to approximately 450 ranchers in 12 Midwestern/Western states (Wyoming, Montana, Nebraska, South Dakota, North Dakota, Minnesota, Iowa, Wisconsin, Missouri, Kansas, Illinois, Indiana). We chose to limit our analysis to producers in these states in order to establish relatively common habitat and ecosystem characteristics (water, biodiversity, geological history, soil types, etc.) (Nelson et al, 2009; Rayburn and Major, 2008). Three hundred and seventy participants were contacted through the National Bison Association. Additionally, we sent the survey directly to 317 members of the state bison associations in these regions. As some memberships overlap and some contact information was out of date, we estimate that representatives of 450 different ranches received a notice asking them to participate.

The survey included questions about the ranch's general characteristics and management practices that the rancher implemented on his or her ranch (Appendix A). Questions on the survey ranged from closed questions about the composition of the herd's diet to open-ended questions about conservation practices that the operators may have implemented. When the survey closed, 117 people had answered at least one question and 53 had completed it in its entirety.

Intensity Assessment

Although our survey gathered data on a variety of aspects of bison meat production, the quantitative nature of our model restricted our indicator variables to those that generated responses on a continuous quantitative scale. From the pool of potential indicator variables we eliminated those that did not have significant variation in responses. Because our model does not include a mechanism for weighing the disparity between two indicators' level of influence, we only included those variables that could reasonably be considered highly significant, thus meriting equal consideration. For our purposes, land use intensity was calculated using three indicators: stocking rate, use of supplemental feed, and nitrogen input.

An overall intensity index for each respondent was calculated by averaging a normalized intensity index for each of the three indicators, with the following equation:

$$I = \frac{\sum_{i=1}^{n}(y_i - y_{\min})/(y_{\max} - y_{\min})}{n} \times 100$$

Where *I* is the overall land use intensity index, y_i is the observed value of the i^{th} variable, y_{min} and y_{max} are the minimum and maximum observed values, and n is the number of indicators (Legendre and Legendre, 1998). The creation of this index facilitates comparison of our results with those of different agricultural systems (e.g., cattle production, crop agriculture).

We used linear regression, t-tests and one-way ANOVAs to conduct hypothesis tests (Table 1). To test for the effects of ranch area, geographic location and dewormer application, we used linear regression to determine the relationship between the intensity index and the three indicator variables: stocking rate (AU $acre^{-1}$), use of supplemental feed (proportion of diet from corn, oats, and hay) and nitrogen input (lbs $acre^{-1}$). We completed a correlation analysis to determine whether or not the variables that comprise the land use intensity index are reasonably independent. We identified potential outliers in regression analyses using Cook's Distance formula, but there were no outliers with $d \geq 0.7$, so no points were eliminated from the regressions. To test for the effects of rotational grazing on intensity, we used t-tests to assess the effect of rotational grazing on intensity. To test for the effects of prior land use on intensity, we used a one-way ANOVA and Tukey's Honest Significant Difference post-hoc test to assess the differences in the mean values of the intensity index and other indicators for the prior use of the ranch land. Stocking rate and property size data were logarithmically transformed to correct for the right-skewed distribution of these variables in all relevant analyses. All tests of significance were conducted using a Bonferroni correction to counteract the problem of multiple comparisons. P-values are reported as is, but threshold p-values for rejection are lowered depending on the number of comparisons used.

Table 1. Hypotheses and types of analysis used to test each hypothesis.

Hypothesis	**Type of Analysis Used**
1: High rates of dewormer use indicate a high intensity of management.	Linear Regression
2: Use of rotational grazing indicates a high intensity of management.	Linear Regression
3: Larger landholders manage the land less intensively.	T-test
4: Lands formerly used for livestock production are managed more intensively as bison ranches.	One-Way ANOVA and Tukey's Honest Significant Difference Post-Hoc Test

We used net primary productivity (NPP) data from Imhoff et al. (2004) to determine whether variation in NPP across the study area would affect the outcome of our analyses with regards to intensity index and stocking rate. NPP values were normalized to a proportion of the highest measured NPP value for any of the ranches in the dataset. They were then included in the stocking rate calculation, replacing AU $acre^{-1}$ with (AU $acre^{-1}$) *NPP. All analyses involving the intensity index and stocking rate were subsequently repeated. The Imhoff et al. (2004) dataset measured NPP at a resolution of 0.25 degrees x 0.25 degrees using the Carnegie-Ames-Stanford Approach (CASA) Model, which is based primarily on precipitation, temperature, and solar irradiance data. The resolution is adequate for our purposes, as only four ranches (two pairs of two ranches), had NPP values from the same pixel.

During the course of our analysis we recognized the potentially significant effect of land prices on other variables used in our analysis. Using data from the USDA National Agricultural Statistics Service (NASS), we used linear regression analysis to determine whether there was a relationship between agricultural land prices and our indicator variables, as well as between agricultural land prices and ranch size. We used a one-way ANOVA and Tukey's Honest Significant Difference post-hoc tests to assess the difference in mean agricultural land prices between ranches where the prior land use was livestock production and those where the prior land use was crop agriculture.

All analyses were conducted using the freeware application R with 'MASS' package loaded. All charts were generated using Microsoft Excel.

IV. Results

A correlation analysis to determine whether sub-indicators were independent showed that only bison density and proportion of diet consisting of non-grazed hay were significantly correlated, though the correlation was not very strong (Table 2). The factor analysis showed that no sub-indicator was responsible for a disproportionate amount of variability in the intensity index and confirmed that intensity sub-indicators are reasonably independent (Table 3).

Table 2: Pearson correlation coefficients between intensity sub-indicators. "%Oat and Corn" and "%Hay" refer to the proportion of the animal's diet composed of each food. Significant values ($p \leq .05$) are in bold.

	Nitrogen/acre	Bison Density	%Oat and Corn	%Hay
Nitrogen/acre	1.00	-0.12	0.05	-0.05

Bison Density	1.00	0.17	**0.61**
% Oat and Corn		1.00	0.04
% Hay			1.00

Table 3: Eigenvalues of the intensity indicators, explained variance, and the proportion of total variance explained by each principal component.

Indicator	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
$N*acre^{-1}$	-0.1600	0.7101	-0.6802	-0.0865
Bison density	-0.6974	0.0148	-0.0577	-0.7142
% Oats and corn	-0.2005	0.7018	0.6655	0.1566
% Hay	-0.6692	-0.0559	-0.3018	0.6767
Explained variance	1.6628	1.0551	0.9132	0.3687
Proportion of total	0.4157	0.2638	0.2283	0.0922

Hypothesis 1: High rates of dewormer use indicate a high intensity of management

The use of dewormer was positively correlated with the overall intensity index, stocking rate, and use of supplemental feed ($p < 0.0125$; Appendix B: figures 1a, 1b, 1d). A positive trend (not significant) was found between fertilizer use and dewormer application. (Appendix B: figure 1c).

Hypothesis 2: Use of rotational grazing indicates a higher intensity of management

There was no relationship between use of rotational grazing and intensity index, stocking rate, nor use of supplemental feed (Appendix B: figures 2a, 2b, 2d). However, there was some evidence ($p < 0.025$) to suggest that fertilizer use is higher on ranches employing rotational grazing than ranches not employing rotational grazing (Appendix B: figure 2c).

Hypothesis 3: Larger landholders manage the land less intensively

There was a significant ($p < 0.0125$) negative correlation between property size and the overall intensity index, stocking rate, and the use of supplemental feed (Appendix B: figures 3a, 3b, 3d).

A negative trend (not significant) was found between fertilizer use and property size (Appendix B: figure 3c**).**

Hypothesis 4: Lands formerly used for livestock production are managed more intensively as bison ranches

The overall intensity index, stocking rate, and use of supplemental feed were significantly ($p < 0.0125$) lower for ranches formerly used for livestock production than for those formerly used for crop agriculture (Appendix B: figures 4a, 4b, 4d). There was no significant difference in fertilizer use between the two groups (Appendix B: figure 4c).

NPP adjustments

The inclusion of NPP as a potential moderating variable did not affect the results of any of the statistical analyses associated with the hypotheses. Stocking rates and NPP-adjusted stocking rates were highly correlated ($p < 0.025$) despite the fact that NPP was highly variable across the study area (Appendix B: figure 5b). NPP was significantly positively correlated with stocking rate, as well ($p < 0.025$; Appendix B: figure 5a).

Price of agricultural land

The average price of agricultural land (at the state-level) was significant negatively correlated ($p < 0.025$) with the total acreage of the ranch. (Appendix B: figure 6a). The mean price of agricultural land for ranches where the prior land use was crop agriculture was significantly higher ($p < 0.025$) than for ranches where the prior land use was raising livestock (Appendix B: figure 6b).

V. Discussion

Easily regulated management decisions

We found a significant relationship between dewormer application and the overall intensity index, stocking rate and use of supplemental feed. While this relationship between dewormer and stocking rate is expected because parasite transmittance increases in higher density herds (Lean et al., 2008), we were surprised to find a significant relationship between dewormer application rates and the use of supplemental feed. It is possible that the use of supplemental feed provides ranchers with an opportunity to apply dewormer. As most (51.22%) ranchers administer dewormer in an ingested form, supplemental feed provides a way of administering the medication to the bison. With supplemental feed there are also more opportunities to administer injected deworming medication, because the rancher has more contact with the animals. Since supplemental feed provides a means for ranchers to administer additional dewormer easily, ranchers can increase stocking rates while maintaining herd health. In this way, dewormer use facilitates more intensive land management.

Alternatively, a review by Lean et al. (2008) suggests that this relationship may exist because high stocking rates both necessitate the use of supplemental feed and lead to more frequent animal contact, causing higher rates of parasite transmittance. Their review suggests that higher stocking rates increase the rate of nematode parasite transmission. In either case, high stocking rates result in greater land use intensity. Similar studies on grassland ecosystems have demonstrated that, above a certain density threshold, increases in stocking rates have a negative impact on bird (MacMahon et al., 2012) and arthropod (Plantureaux et al., 2005) diversity.

Our findings indicate that there was no difference in land use intensity or any of the land use intensity indicators on ranches that did and did not rotate their herds. This is not surprising in light of the findings by Briske et al. (2008) that the use of rotational grazing has no effect on the capacity of the land to support higher stocking rates. However, given the popular perception that rotation mitigates the ecological threats of overgrazing, we would have expected that stocking rates would be higher under rotational grazing than under continuous grazing.

Rotational grazing is employed to reduce the impact of grazing on plant communities by allowing pastures to rest and re-grow between grazing events (Teague and Dowhower, 2003). However, it has been found repeatedly that the use of rotational grazing as opposed to continuous grazing actually has no impact on plant productivity or animal weight (Briske et al., 2008; Heady, 1961). Despite this, rotational grazing continues to be employed in many livestock industries in the belief that stocking rates can be increased under rotational grazing because grazing pressure is applied to the land for less time (see Booysen, 1975).

The application rate of nitrogen fertilizer was the only indicator that differed somewhat between ranches practicing rotation and those not practicing rotation and was significantly related to rotation before the Bonferroni correction. Bison ranchers who rotate their herds were found to apply, on average, thirteen more pounds of nitrogen per acre than those who do not ($p=0.0249$). One possible explanation for this relationship is that lower levels of fertilization on continuously grazed pastures may simply be a factor of accessibility. If the herd is kept on one pasture, particularly if that pasture is small, it is more difficult for a rancher to apply fertilizer using conventional equipment. Ultimately, because rotation does not demonstrate a significant relationship with land use intensity or any of the land use intensity indicators, we cannot extrapolate any influence rotation may have on variation in land use intensity. The fact that we found no relationship between rotational grazing and intensity is verified by other studies of the effect of rotational grazing on pastureland. These studies find that rotational grazing does not affect the forage quality of pastures (Denny and Barnes, 1977; Walker et al., 1989; Holechek et al. 2000) and does not maintain plant productivity more effectively than continuously grazed systems (Parsons et al., 1983; Briske and Heitschmidt, 1991).

The relationships that we found suggest that a rancher's feeding decisions are influenced by factors beyond ecological sustainability to include logistical considerations. We would have expected more significant relationships between management practices and land use intensity given the numerous studies linking the management practices of commercial livestock ranching with negative impacts on plant species composition, production and diversity (Burkholder et al., 2007; Campagnolo et al., 2002; Fleischner, 1994; Mallin and Calhoon, 2003). However, the significant relationships we did find are sufficient to conclude that variation in the distribution of land use intensity among the bison ranches in our sample is not random. However, we only tested three intensity indicators and two independent management practices. There are many other variables that could serve as indicators of land use intensity and the relationship with indicators of intensity could have been tested with more management practices. A comprehensive examination of these individual relationships is necessary to more fully understand the complexity of the overall relationship management style and sustainability.

Management decisions outside the rancher's control

Some aspects of land use intensity like ranch size and prior land use are determined by factors outside of a rancher's control. This suggests that any attempts to measure ranch sustainability should be sensitive to the predetermined challenges that a rancher may face, particularly the availability of land and how easily it can be converted to bison ranching. However, ranchers should also be aware of these limitations when making management decisions.

Our results indicate that larger ranches are managed less intensively, utilizing lower stocking rates, and less supplemental feed. Having more space allows large landholders to decrease stocking rates, preventing overgrazing of pastures. Low stocking rates negate the need for supplemental feed in the form of hay or cereals because bison gain sufficient nutrition through pasture grazing. Larger ranches can sustain the same number of animals as a densely stocked small ranch while maintaining the quality of the land's natural resources. Ranchers with smaller land holdings compensate for high stocking rates by supplementing feed with hay, oats, or corn to prevent overgrazing. The size of the ranch is not entirely outside of a rancher's control, but high land prices often limit the number of acres a rancher can afford to purchase and maintain.

We demonstrate a significant correlation between cost of land and the size of the ranch. In areas where land is inexpensive and readily available, ranchers can maintain their herds at much lower stocking rates than would be economically viable when land is a limiting factor. For example, agricultural land in Indiana is, on average, $3180 more expensive per acre than agricultural land in South Dakota (NASS, 2011). Intensity indicators like high stocking rates and supplemental feed can be a consequence of insufficient capital to acquire more land. Capital and labor inputs are difficult to sacrifice in a business with small profit margins in the most lucrative years.

Intensity scores, stocking rate and supplemental feed for land formerly in crop agriculture were significantly higher than those of land formerly in livestock production. We predicted the opposite. In most cases, it requires a high level of management intensity to maintain the quality of the meat produced from domestic livestock, a finding supported by a study by Keane and Allen (1998). In this study, researchers compared the taste of beef cattle across three levels of management intensity and two different slaughter weights and determined that the most intensive management system and highest slaughter weight produced that juiciest and most tender meat (Keane and Allen, 1998). Although beef cattle and bison are different animals and therefore respond distinctly to variations in management, rancher assumptions about which practices positively impact the product's taste may be applicable. As such, we imagined that if ranchers had switched from cattle to bison, they would have maintained similar management practices. However, this assumes that the individual currently managing the ranch was also responsible for the land's prior use, which is not a reasonable assumption to make. Agricultural land regularly passes to a new owner, who may or may not have experience in either livestock or crop agriculture. While this is an interesting theory, and would suggest that experience in general livestock translates well to bison management, research focused directly on the agricultural experience of the rancher is necessary to determine the credibility of such a hypothesis.

As with ranch size, we propose that the statistically significant difference in intensity indices is a product of the geographic distributions of livestock and crop agriculture land uses, which are mediated by agricultural land values (Appendix C: Figure 7). The land prices for ranches converted from crop agriculture are significantly higher than those converted from livestock production (NASS, 2011). Land prices tended to be higher in the eastern states of our sample, where ranches are predominantly converted from crop agriculture. This suggests that the location of a ranch and alternative land uses in the region influence the stocking rates and use of supplemental feed by ranchers. Higher land use intensities result when ranchers need to offset the cost of using land for bison ranching by increasing output per unit of land.

Ranchers choose to implement high stocking rates and use supplemental feed on more expensive lands in order to offset the cost of the lands. However, ranchers still have a choice to decrease the land use intensity of their ranches. The most expensive land tends to have been converted to bison ranching from crop agriculture. Our results indicate that ranchers could reduce land use intensity of bison ranches in these areas by decreasing stocking rates and thus the amount of feed they supplement from outside sources.

VI. Sources of Error

Survey

There are a number of factors that may have interfered with our survey results. First, we surveyed ranchers via the Internet. Only ranchers with somewhat regular email and Internet access and the know-how to answer online could complete the survey. Had we attempted to mail the survey, we may have received a wider breadth of responses. Secondly, we asked for ranchers to voluntarily take the survey, which lends itself to response bias. We suspect that ranchers of high intensity ranches may have a tendency to be less forthcoming about the intricacies of ranch management, particularly because the survey contained questions about sustainability.

As we began to receive responses to the survey, we realized that a number of our questions were flawed. This was particularly problematic for our question of fertilizer application. Although our question asked about fertilizer type and application rate, the response format was open answer, and a number of ranchers did not provide this information. While we attempted to follow up on this question at a later point, a number of the original subjects did not respond to the second round of questions, and we were forced to estimate some of the nitrogen application rates using a weighted average. This is undeniably a less accurate way of predicting nitrogen type and application rate for ranchers who did not complete their answers.

Finally, we experienced significant problems with our survey program, which unexpectedly froze on a number of our respondents. We have no way of knowing whether this occurred randomly, but even if it did, it limited the number of responses.

Analysis

For our analysis, we had to assume that the practices that each rancher implements are geographically and temporally uniform across the ranch, despite the fact that this is not the case for all ranchers. For instance, some ranchers' fertilizer application varies between fields, and frequently differs throughout the year. As a result, the figures that we used to analyze fertilizer application are, at best, an average of a rancher's practices.

In our calculations, intensity is a function of nitrogen application rate, feed inputs, and stocking rate. Because high stocking rates often lead to greater feed inputs, it may appear that the calculations punish ranchers twice for the same problem. However, these two rancher choices can be made independently. For instance, a rancher could choose to decrease the stocking rate of his herds while maintaining his same feeding practices. Alternatively, he could choose to increase stocking rate without supplementing additional feed, which would lead to increased grazing intensity. For this reason, we include both feed type and density in the intensity index calculations.

There are also a number of variables that could have been included in our analysis of land use intensity. However, in many cases, the responses we received regarding these variables were not in a form that we can include in our analysis. These variables, such as water source, were categorical rather than quantitative. We also chose not to include variables with little variation across respondents, such as pesticide application (very few ranchers consistently apply pesticides). The few who do apply pesticides inevitably have higher land use intensity.

It is also unlikely that all of the indicators of land use intensity that we did consider have an equivalent impact on the land. We are unaware of which indicators have a greater impact on land use intensity and the degree to which they impact more significantly. This is an area that future studies of this variety could attempt to evaluate.

Methodological Approach

After attempting to replicate the methodology employed by Herzog et al. (2006), we must question the viability of using this approach to examine ecological sustainability. This methodology is reliant on the assumption that intensity is the direct inverse of sustainability. It assumes that concentrated input levels inevitably lead to ecological degradation. While we have shown that the indicator variables that we included can be ecologically harmful, we do not attempt to measure the extent of their actual impact. There are a number of factors that can mitigate the effects of these inputs, including management techniques that the rancher can employ. For example, in our survey we asked ranchers to describe any actions they took to prevent erosion, fertilizer, or pesticide runoff from the land. While some ranchers simply cited the need to keep grazing levels low, others told us that they use riparian barriers, terraces, or hay bales to stop erosion. Some also told us that their land was relatively flat, and therefore at a lower risk of erosion. Our model was not able to account for any differences in either the physical landscape or the mitigation techniques used.

This methodology has the benefit of requiring relatively low access to data, however it comes at the cost of significantly limiting our scope of analysis. Although we generate an overall intensity index this value is based on an arbitrary weighting of a small sample of the variables that actually influence intensity. As a result, the overall index itself is nothing more than our best measurement of a ranch's actual land use intensity. Because our analysis is dependent on determining trends and variation in these values, the lack of precision is a serious hindrance.

Conclusions

The assumption that all bison meat is sustainably produced does not hold up to critical examination. Consumers and trade associations alike believe that by supporting the production of bison meat they aid in the improvement of environmental and human health. However, we cannot ultimately conclude that all bison ranches are sustainable. If this were the case we would expect land use intensity to vary randomly across the Midwestern region examined. Instead, two of the three indicators of land use intensity that we examined are correlated with variables representing characteristics of the ranch or management decisions made by the rancher. These relationships suggest that a ranch's ecological impact cannot be isolated from other characteristics.

The findings of our study also have important implications for the health of grassland ecosystems. One of the greatest benefits of bison ranching is that bison grazing and wallowing increase the productivity, diversity, and function of grassland ecosystems in North America (Knapp et al., 1999; Collins et al., 1998). The National Bison Association touts these external benefits of bison ranching, along with the fact that bison require few inputs to thrive in North American grasslands. Despite this, our research shows that many bison ranchers still use substantial inputs, the most notable of which is the use of hay and cereals as supplemental feed. For the benefits of bison grazing and wallowing to be realized, bison must consume primarily native grasses in non-hayed form. It would be further beneficial if bison freely select grazing patches across the landscape and engage in natural behaviors year-round (Fuhlendorf et al., 2009).

All of the ranchers that completed our survey indicated that they believe that they manage their land and herd in an environmentally sustainable manner. If bison ranchers, across the entire spectrum of bison ranching, value the ecological benefits of bison grazing, there are clear paths for improvement. Reducing use of supplemental feed and increasing grazing of native grasses is one course of action that would enhance the ecological benefits of bison ranching.

One way to decrease variation in land use intensity across bison ranches and to maintain the name of sustainability for the product would be to standardize bison meat production practices. Like USDA 'Certified Organic' standards, for instance, the National Bison association could impose universal standards on their members. These standards would minimize land use intensity and maximize ecological benefits of bison grazing on participating ranches. Bison ranchers would inevitably remain varied in their levels of land use intensity, but the National Bison Association's claims that bison meat is environmentally friendly would be better supported.

By viewing bison ranching as a homogenous industry, one ignores variation in management practices. This attitude disregards the potential for improvement within the industry. Regardless of how bison compare to other livestock, the wide variation in ranching practices suggest that ranchers have the capacity to adopt practices that decrease their negative impact on the surrounding environment.

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Appendix A: Survey to Bison Ranchers
* - denotes required question

*1. Check here if you agree to the terms outlined above
I agree

2. Are you a member of the National Bison Association?
Yes
No

*3. In what zip code is your ranch/farm located?
ZIP:

*4. What is the total acreage of your ranch/farm (owned and leased)?
Acres

*5. How many acres are used to raise your bison?
Number of acres:

*6. How many acres are available to bison during the following seasons?
Acres in spring:
Acres in summer:
Acres in fall:
Acres in winter:

*7. For how many years has your land been used to raise bison?
Number of years

*8. What was the primary use of this land before it was used to raise bison?
Crop agriculture
Never cultivated or grazed (i.e. native prairie)
Development
Unknown
Other
Other livestock (please specify)

*9. During 2011, when your herd was at its largest, how many of each of the following did you have?
Cows
Bulls
Yearlings
Calves

*10. How many bison have you purchased in the last 12 months?
Cows
Bulls
Yearlings
Calves

*11. How many animals purchased in the last 12 months did you keep as breeding stock?
Bulls/bull calves
Cows/heifers

*12. Do all of the bison in your herd have the same diet?
Yes
No

*13. Describe your bison herd's diet. What do they eat and what proportion of the herd eats each type of food?

*14. What are the major food sources for your bison (indicate the percent of each food type your bison consume for the entire herd)? This question applies to all bison you own. If you have multiple herds please estimate an average.
Native grass (e.g., big and little bluestem, 'indian' grass, western wheat grass) - grazed
Native grass - hayed
Non-native grass (e.g, reed canarygrass, smooth brome, Kentucky bluegrass) - grazed
Non-native grass - hayed
Hay from off-farm
Corn
Corn Silage
Oats
Mineral Supplement
Other

*15. Do you rotate your bison to different pastures on your land?
No
Yes

*16. How many pastures do you have in your rotation?
Number of pastures:

*17. Approximately how many acres are your largest and smallest grazing pastures?
Largest pasture (acres):
Smallest pasture (acres):

*18. On average, how often do you rotate the herd to a new pasture (that is, how long does the herd stay on each pasture)?
Number of weeks:

*19. On average, how many weeks pass between periods of grazing on each pasture?
Number of weeks:

*20. What is the primary source of water for your bison? (choose one)
On-site well
On-site lake or pond (natural or constructed)
On-site river or stream (natural or constructed)
Off-site source
Other (please specify)

*21. Do you treat your herd with dewormer or antibiotics?
Yes
No

Q22
*22. How many times in the past 24 months did you administer the following products to your herd (please include only products that were administered to more than 25% of the herd)?
Dewormer applications
Antibiotics applications

*23. How many bison did your herd lose to disease, predation, or handling accidents during the last 24 months?
Number of bison lost:

*24. How many bison did you harvest in the last 24 months?
Number of bison:

*25. Are your animals slaughtered on your ranch/farm?
Yes
No

*26. How many miles do the bison travel from the pasture to the slaughtering facility?
Number of miles traveled:

*27. What do you do to control prairie dogs, gophers, or other burrowing mammals?
Not applicable (I don't have any prairie dogs, gophers, or other burrowing mammals)
Nothing (I have prairie dogs, gophers, or other burrowing mammals, but I do not do anything to control them)
Guns (I shoot prairie dogs, gophers, or other burrowing mammals for sport or to control their populations)
Poison
Explosives or flammable gas
Other (please specify)

*28. What do you do to control noxious weeds (e.g. Canada or Musk Thistle, Leafy Spurge, Spotted or Russian Knapweed, Johnsongrass, etc.) on your land? Choose all that apply:
Herbicide: broadcast application (from tractor, aircraft, center pivot irrigator, etc.)
Herbicide: spot-spray
Hand pulling
Mowing
Intense grazing of affected areas
Nothing
Other (please specify)

29. If you have land enrolled in the Conservation Reserve Program (CRP), how many acres of your land are currently enrolled?
Acres:

30. If you hunt on your land or allow others to hunt on your land, what game species occur on your land (e.g., sharp-tailed grouse, pheasant, deer)?

*31. On average, what is the percent vegetation cover in one square meter of your pasture?

0-10%
11-25%
26-50%
51-75%
76-94%
95-100%

32. Please describe any actions you take to prevent erosion, fertilizer, or pesticide runoff from your land (e.g., riparian barriers around streams and rivers, placing bails of hay as fencing, planting vegetation on slopes):

*33. Have you ever planted seed in your pasture (either by direct seeding, a broadcast spreader, or by hand)?
Yes
No

*34. Approximately how many different species did you plant?
Number of species planted:

*35. Do you conduct controlled burns on your land?
No
Yes

*36. How often do you conduct burns on your land (this is a free-response question; both words and numbers can be used)?

*37. Have you applied fertilizer to your land in the past 24 months?
Yes
No

*38. In an average year, what type of fertilizer(s) do you use and how much do you apply per acre?

*39. Have you applied any pesticides (including insecticides, fungicides, and herbicides) to your land in the past 24 months?
Yes
No

*40. In an average year, what type of pesticide(s) do you use and how much do you apply per acre?

*41. Estimate the number of miles you drove this year in each of the following vehicles for bison-related business:
Number of miles in a Pickup Truck or Van:
Number of miles in a Large Truck:
Number of miles in a Tractor:
Number of miles in a Car:
Number of miles in 'Gator' or All-Terrain Vehicle (ATV):

*42. On your most recent bill, how much did you pay for electricity and gas toward your bison operation?
Electricity ($)
Natural Gas ($)

*43. Do you believe that you manage your land and your herd in an environmentally sustainable manner?

Yes
No

44. If you would like to receive a copy of our final report by email, please provide us with your address:
Email Address:

Appendix B: Results Figures

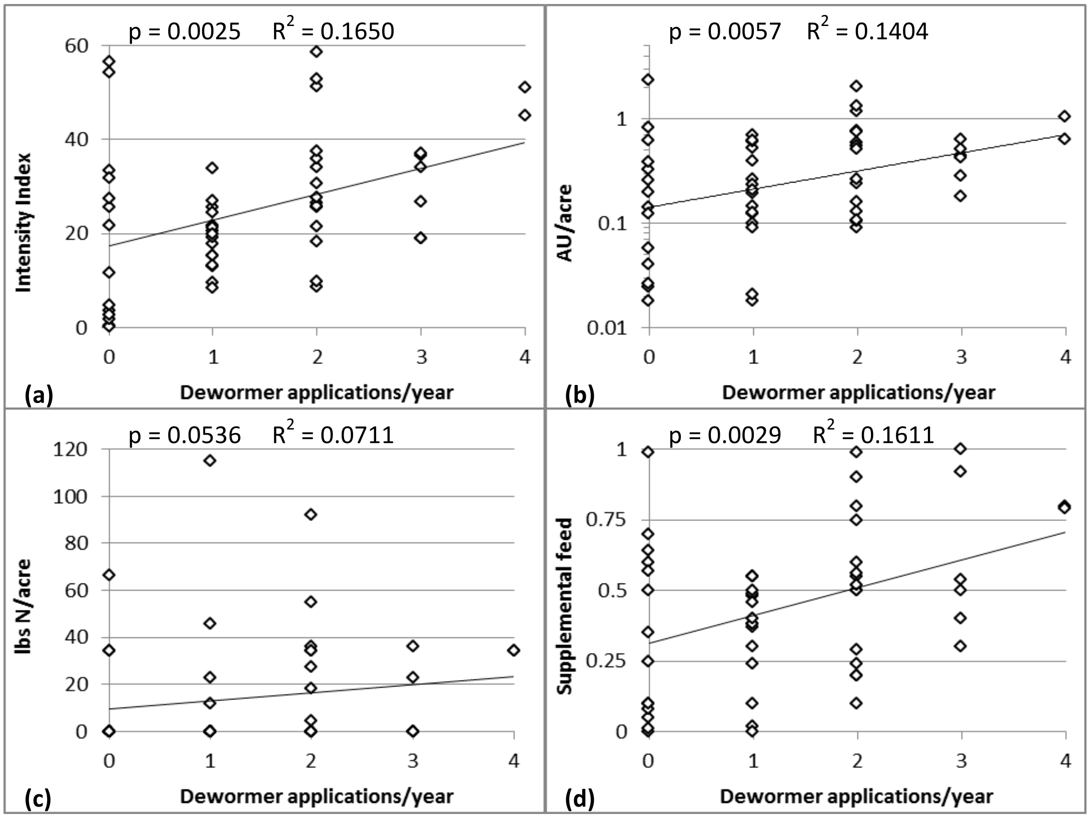

Figure 1: Correlations between de-wormer application and a) overall intensity index, b) bison density, c) nitrogen input, and d) proportion of diet composed of hay and corn.

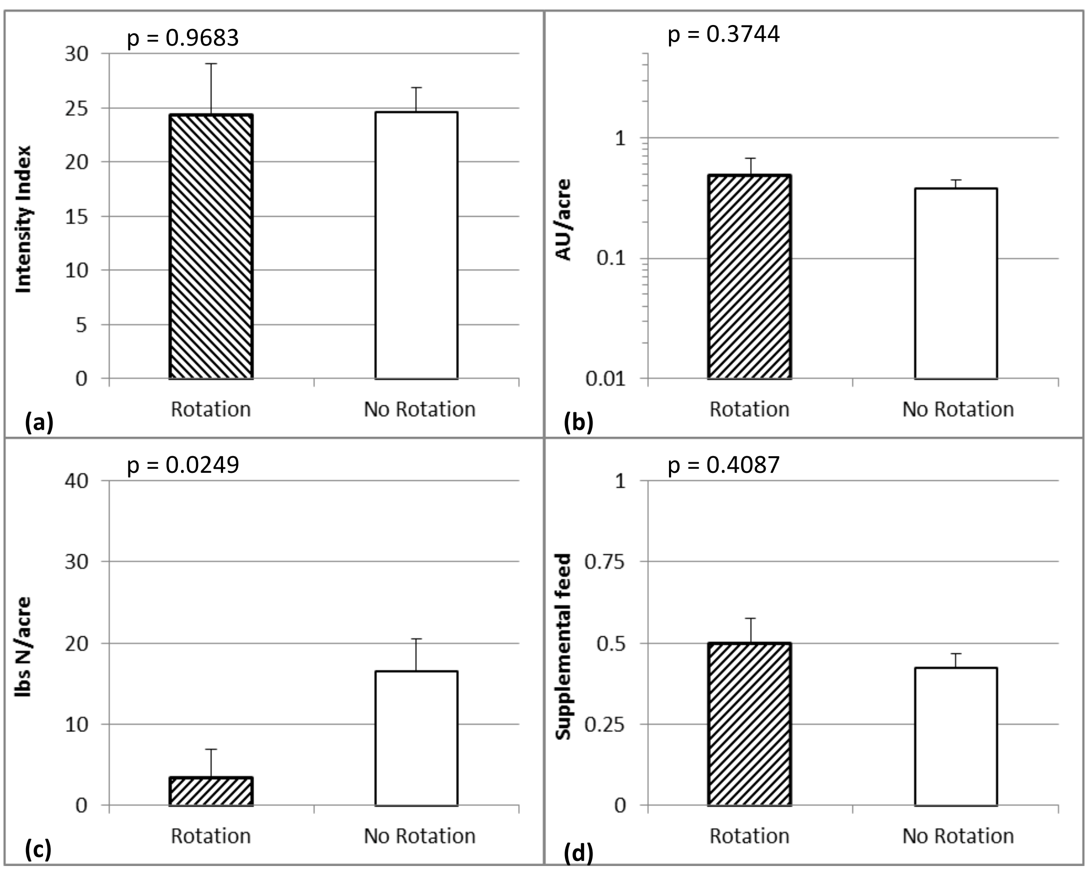

Figure 2: Difference in mean a) overall intensity index, b) bison density, c) nitrogen input, and d) proportion of diet composed of hay and corn for ranches practicing pasture rotation and ranches not practicing pasture rotation.

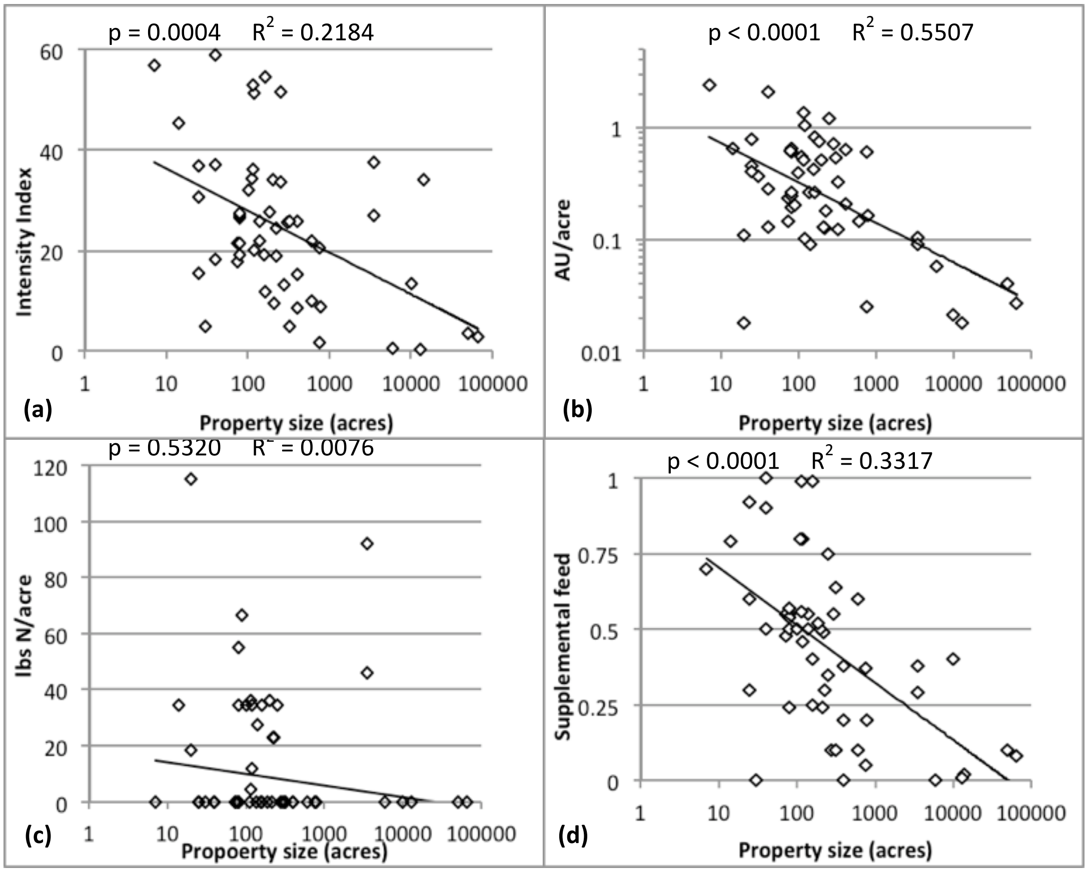

Figure 3: Correlations between property size and a) overall intensity index, b) bison density, c) nitrogen input, and d) proportion of diet composed of hay and corn.

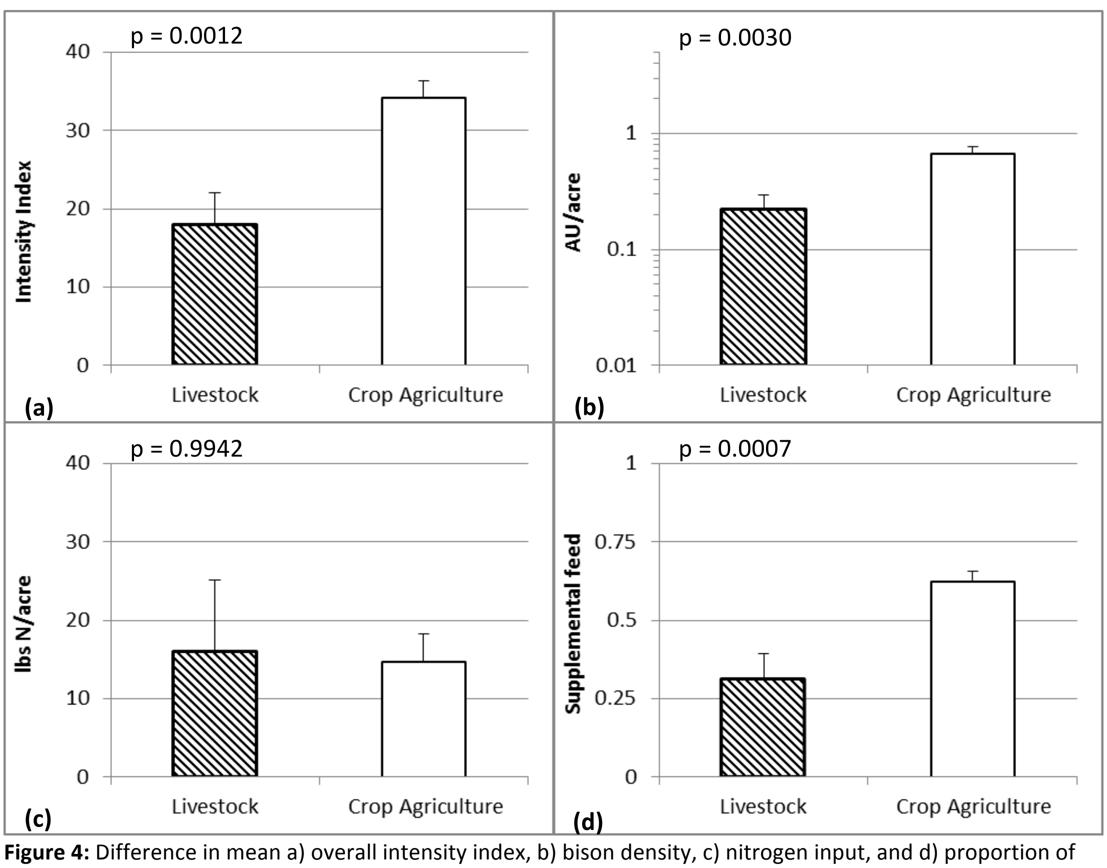

Figure 4: Difference in mean a) overall intensity index, b) bison density, c) nitrogen input, and d) proportion of diet composed of hay and corn for ranches in which the prior land use was livestock raising and crop agriculture. Other prior land use groups ('Other,' 'Never grazed or cultivated,' and 'Unknown; '9 observations total), are

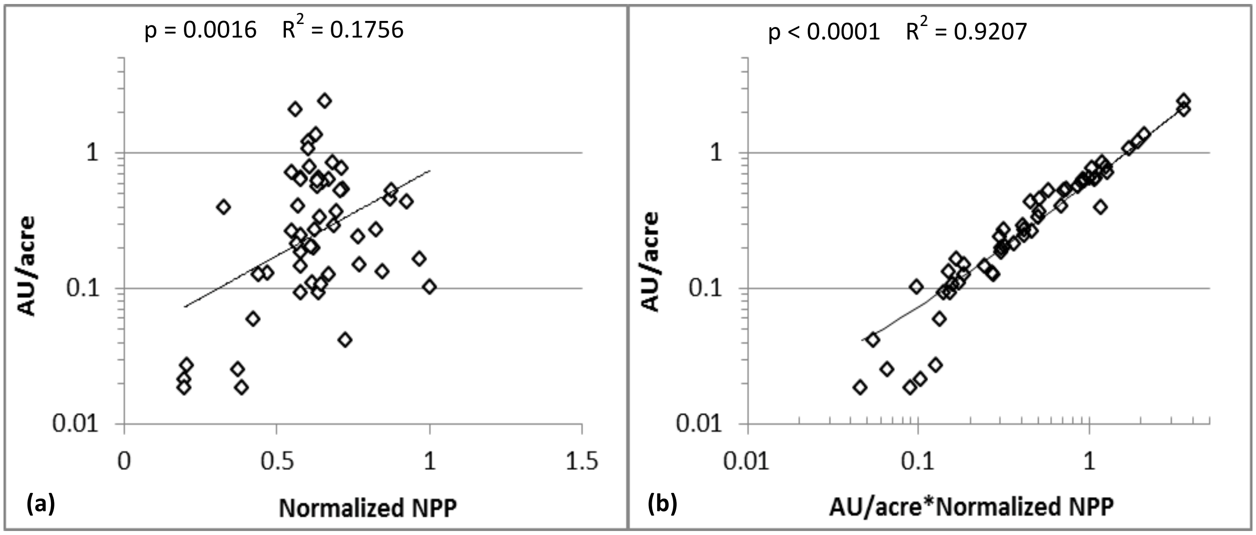

Figure 5: Correlation between a) bison density and normalized NPP and b) Density and NPP adjusted animal density.

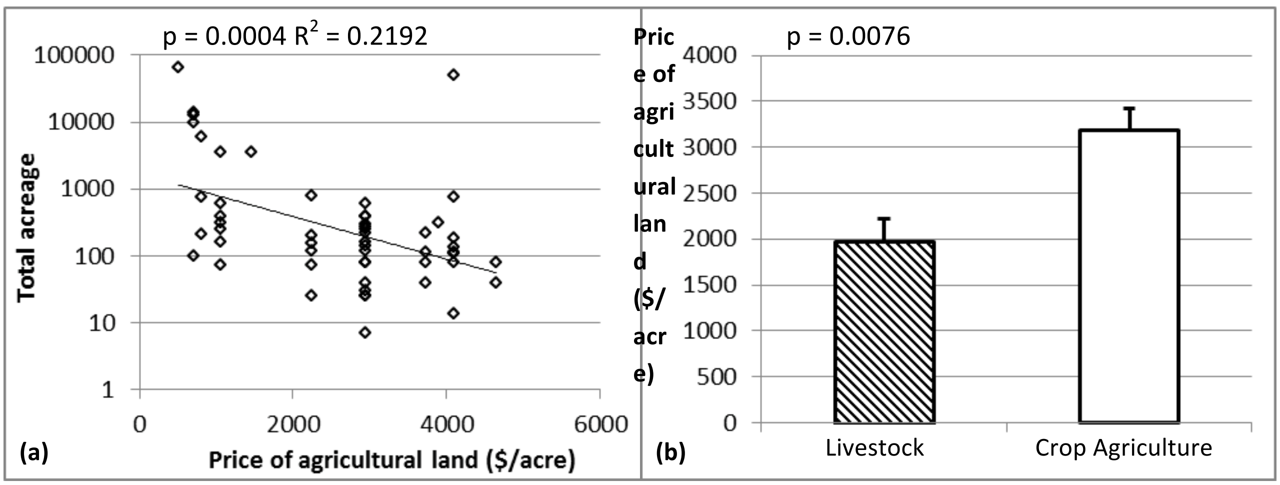

Figure 6: a) Correlation between ranch size and cost of agricultural land per acre; b) Difference in mean cost of agricultural land per acre for ranches where prior land use was identified as crop agriculture or livestock

Appendix C: Maps

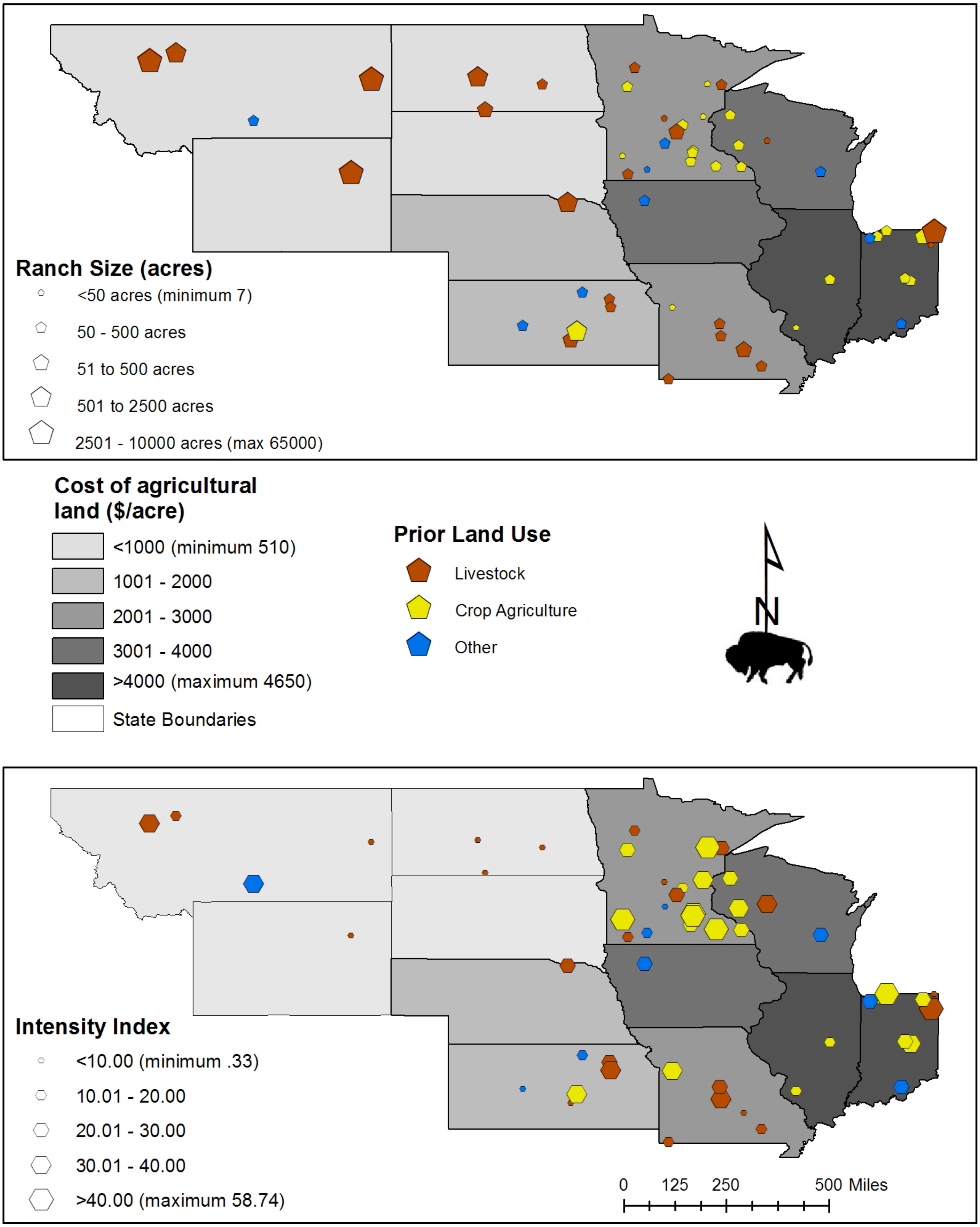

Figure 7: (Top) Map showing cost of agricultural land per acre (state shading), prior land use (marker color), and ranch size (marker size). (Bottom) Map showing cost of agricultural land per acre (state shading), prior land use (marker color), and intensity index (marker size).