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Research Article

The decline of the white-tailed jackrabbit (*Lepus townsendii*): carbohydrate and soil texture analysis

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ABSTRACT

A decline of the white-tailed jackrabbit, (*Lepus townsendii*), has been occurring throughout the species natural range. This has provoked the need for research and a greater understanding of the reasons behind the decline. Literature suggests that the white-tailed jackrabbit forage quality may not be sufficient, which is important for pre-natal nutrition and further, that the metabolism of the jackrabbit is higher in the winter; however, the amount of carbohydrates available to jackrabbits has not been investigated. Prairie grasses and soils from white-tailed jackrabbit inhabited areas in central and western South Dakota, were sampled from three counties from the fall of 2013 until the spring of 2015. The results of this study suggest that the carbohydrate concentration (glucose and fructose) of grasses are low during the fall and winter when pre-natal nutrition for the first litter is important and the concentrations of glucose, fructose, and soil texture between all three counties were significant ($p<0.001$). Jackrabbits were also found in areas with a higher clay concentration for soils. Jackrabbit biochemical studies coupled with physiological research is needed to help portray a better understanding of white-tailed jackrabbit population health.

Keywords: White-tailed jackrabbit; *Lepus townsendii*; Glucose; Fructose; Soil texture; Vegetation.

1. INTRODUCTION

The white-tailed jackrabbit (*Lepus townsendii*) is an endemic species located in the north-central to north-western United States to as far south as northern New Mexico to upwards into Canada [1]. This species has diffused dispersal into eastern Iowa and Wisconsin; however, the range has retracted [2-4]. The white-tailed jackrabbit is listed as a species of “special concern” for several states including Iowa, Wisconsin, Nevada, Washington and Oregon. However, the jackrabbit is listed as a predator or varmint status in other states such as Wyoming and South Dakota. Also called the Prairie Hare, the white-tailed jackrabbit preferred habitat includes pasture, cropland [5], prairie [3], sagebrush steppe [6]. To date, it has been thought that jackrabbit declines are due to land use intensification [3] human intrusion, predators [7], while others have suggested fragmentation of habitat and monocultures of crop plants [4].

Past literature suggests that the jackrabbit distribution was associated with cultivation or settlement activities (e.g. [2, 8, 9]) and glaciated soils [5]. However, edaphic conditions and soil moisture can impinge on the fecundity of animals [10]. This underpins our assumptions that jack-rabbits could be associated with vegetation and soils that are most like fresh cleared land converted to cultivation (see [11] for discussion). In addition, [12] and [13] say that moisture, soil elements, and chemistry impinge on the distribution of fauna. The moisture levels, chemistry, and soil elements create different environments where various species of vegetation grows and further, the vegetation determines which fauna will be in the area. The different soils also play a factor in the distribution of the vegetation which then in turn, affects the fauna. However, soil texture has not been analyzed in areas where jackrabbits are located.

Studies have been put forth regarding black-tailed (*Lepus californicus*) and white-tailed jack-rabbit nutrition and preferred vegetation (e.g. [14-18]). The study completed by [18] identified white-tailed jackrabbits coming into Canadian city limits to forage on spike plants (*Cordyline australis*) during the winter. As [18] point out, eating the spike plant could also indicate a lack of sufficient supply of jackrabbit preferred vegetation, or perhaps lack of sufficient nutrition for the jackrabbit. Further, [17] indicated that late winter forage quality may impinge on prenatal mortality for the first litter of white-tailed jackrabbits.

Other studies have highlighted the body condition of the white-tailed jackrabbit. For example, [19] conducted South Dakota state-wide research on the white-tailed jackrabbit and indi-cated seasonal changes of kidney fat index (KFI) on the jackrabbits and [4] also found kidney disease in white-tailed jackrabbits in Iowa. One role of the kidneys is to regulate glucose homeo-stasis [20].

Given that the metabolic rate of white tailed jackrabbits is higher in the winter [21], it is impor-tant to investigate the amount of carbohydrates available to them, especially as the jackrabbits prepare for their first litter of leverets in the spring. To date, the edaphic and vegetation parameters have not been studied with the white-tailed jackrabbit, especially in South Dakota and this is what we report here. There are specific areas in South Dakota where jackrabbit populations are present and areas where they are not located at all, but could be present. We report the areas where jackrabbits are present.

2. MATERIAL AND METHODS

Vegetation and soils were collected and analyzed from fall 2013 to the winter 2015 and then further analysis such as soil texture and carbohydrate content of vegetation collected were carried out. Collections were taken where jack-rabbits have eaten the plant or direct known presence (by observer or presence of fecal pellets). Soil depth collection was between 0-13 cm deep. Soil collec-tion was dependent upon the weather and how firm the ground was to collect the soil. GPS locations were taken with a Garmin Oregon 550. Additional tests on soil and vegetation were completed with a “Chemical Composition of soil kit” and A LaMotte® Plant Tissue Test kit was used to determine the presence or absence of nitrogen, phosphorus, and potassium in plant stems (see Appendix 1 for data). Single factor and two-way ANOVA in Excel was used for statistical analysis as there were more than two study areas and more than two means to compare. Two-way ANOVA was used to determine any significance between the three sites and four seasons. In addition, these areas were similar to each other in that they all had areas where jackrabbits were inhabited.

2.1. Soil parameters

Soil pH was measured with an Accumet Basic AB15. In addition, soil texture was analyzed by a LaMotte® soil texture unit. The procedures were followed with standard procedure.

2.2. Carbohydrate Assays

Vegetation stems and internodes were analyzed with Glucose and Fructose assay kits provided by Sigma Aldrich with a ThermoScientific Genesys 10S UV-VIS spectrophotometer. The procedures were followed according to the manual provided within the kits.

2.3. Study locations

Butte County, South Dakota: the soils there are Grummit clay (GrE), Manvel silty clay loam (McB), and Enning-Minnequa silty clay loams (PMd). This was a recreational area which contains species of wheatgrass (*Agropyron spp.*) clover (*Trifolium spp.*), sagebrush (*Artemisia spp.*), and smooth bromegrass (*Bromus spp.*). This is a grassland area with little shrubs and forbs.

Hughes County, South Dakota: the soil types are Highmore-Eakin silt loams and Onita silt loams. Some of the most predominant vegetation includes species of wheatgrass, ragweed (*Ambrosia spp.*), and alfalfa (*Medicago spp.*). This was an agricultural area.

Bennett County, South Dakota: the soil types are Keith-Rosebud silt loams and Oglala-Canyon loams. This was an agricultural area which contains species of wheatgrass and turf grasses.

3. RESULTS

3.1. Soil pH and Texture

Soil pH averaged to 7.36 between Butte, Hughes, and Bennett Counties. For sand content of soils ($\bar{X}$ = 37.4% SD=18.4) (Fig. 1), for silt, $\bar{X}$= 13.3% SD=11.4) (Fig. 2), and for clay soils, $\bar{X}$ = 48.5%, SD=26.6) (Fig. 3). Single factor ANOVA revealed no significant difference in soil texture between sites where jackrabbits inhabit (F=0.00015, p<0.001).

3.2. Glucose concentration

Single factor ANOVA revealed no significant difference in glucose concentrations between sites where jackrabbits inhabit (F=0.2817, p<0.001).Two way ANOVA also showed no significant difference in glucose concentrations between sites (F=0.2170, p<0.001) where jackrabbits are and season: fall, winter, spring, summer (F=0.3107, p<0.001) (Fig. 4). See Table 1 for data.

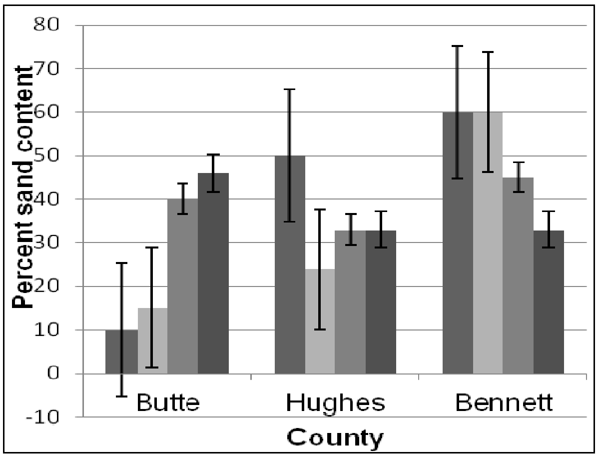

Figure 1. Percent sand content in Butte, Hughes, and Bennett Counties with standard error. For each county, there are four bars which represent winter, spring, summer, and fall left to right.

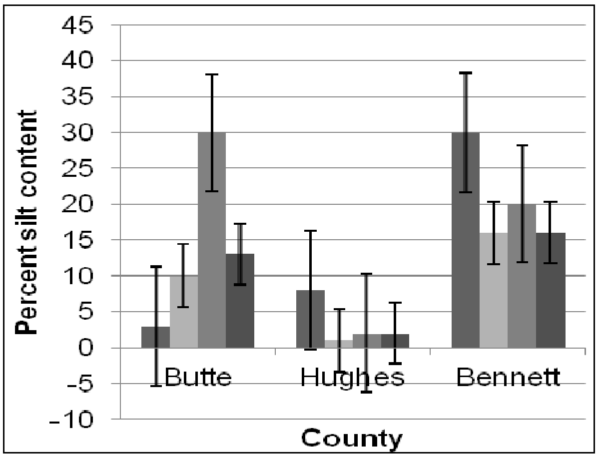

Figure 2. Percent silt content in Butte, Hughes, and Bennett Counties with standard error. For each county, there are four bars which represent winter, spring, summer, and fall left to right.

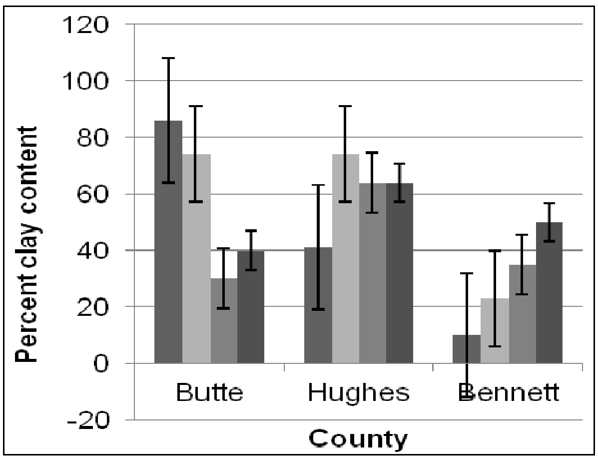

Figure 3. Percent clay content in Butte, Hughes, and Bennett Counties with standard error. For each county, there are four bars which represent winter, spring, summer, and fall left to right.

Table 1. Glucose concentrations between Butte, Hughes, and Bennett Counties.

Glucose						
Butte (mg)					**Hughes (mg)**	**Bennett (mg)**
	GrE	McB	PMd	PMd*		
Winter	0.0533	0.0489	0.6702	NA	0.8510	NA
Spring	0.3874	0.4149	0.3010	NA	0.0806	0.0170
Summer	0.7125	0.3982	0.1803	0.5661	0.0535	0.5431
Fall	0.4022	0.4174	0.3119	0.1304	NA	0.3923

*denotes second sample at PMd.

Table 2. Fructose concentrations between Butte, Hughes, and Bennett Counties.

Fructose						
Butte (mg)					**Hughes (mg)**	**Bennett (mg)**
	GrE	McB	PMd	PMd*		
Winter	1.378	0.4083	0.6908	NA	0.1719	NA
Spring	0.9578	0.8535	0.4851	NA	0.6631	0.4359
Summer	1.903	0.4236	0.3622	0.2885	0.4476	0.7846
Fall	0.2517	0.1720	0.1720	0.2517	NA	0.2271

*denotes second sample at PMd.

3.3. Fructose concentration

Single factor ANOVA revealed no significant difference in fructose concentrations between sites where jackrabbits inhabit (F=0.4047, p<0.001). Two way ANOVA also showed no significant difference in fructose concentrations between sites (F=0.5517, p<0.001) where jackrabbits are and season: fall, winter, spring, summer (F=2.089, p<0.001) (Fig. 4). See Table 2 for data.

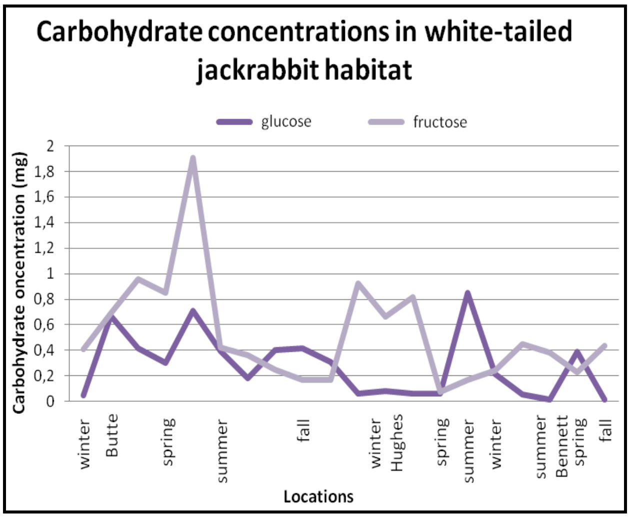

Figure 4. Glucose and fructose concentrations in white-tailed jackrabbit habitat.

4. DISCUSSION

One study had assembled a list of seasonal preferred foods for the white tailed jackrabbit [15]; however, the carbohydrate content of various forbs, grasses, and shrubs that the white-tailed jackrabbits eat at various seasons had not been attempted until this study. Our vegetation species identified where jackrabbits forage and inhabit were similar to the findings of [15]. These include a mixture of exotic and native grasses and shrubs (e.g. smooth brome, wheatgrass species, and sagebrush).

The results of this study also demonstrate the similarity of soil texture and glucose and fructose concentrations on the three white-tailed jackrabbit habitat sites in western South Dakota; however, for the majority of our plant species (except fall thickspike wheatgrass and winter ragweed), fructose was usually higher than glucose concentrations. This was also a similar result to [22] with higher fructose concentrations in vegetation species such as smooth brome grass. Since [8] describes the white-tailed jackrabbit in sagebrush habitat (also higher in fructose concentrations), could imply that jackrabbits in these study areas prefer higher fructose concentrations. Literature suggests that too much fructose may induce fatty liver and kidney disease [23]. Further, [24] discussed the relationship between higher fructose diets and kidney fat accumulation in rats. However, this study was for rats and the dietary fructose concentration within jackrabbits vs. kidney fat has not yet been determined.

When it comes to peaks of carbohydrate concentrations, our results were comparable to [25], who found that carbohydrate concentrations peaked in the summer for brome grass. Further, [26] found that brome grass had a commendable metabolizable energy value. If brome grass had a metabolizable energy value and if the metabolic rate of white tailed jackrabbits is higher at lower temperatures in the winter [21], this could indicate a preferable dietary choice for the jackrabbit. Unfortunately, there is no data on the white-tailed jackrabbit that specifies a healthy carbohydrate load for seasons.

Between Butte, Hughes, and Bennett Counties, the white-tailed jackrabbits seemed to prefer clay soils. It is unknown as to why the jackrabbits would have preference with clay soils and lower silt concentrations. Clay soils are one of the most chemically active [27]. One possible explanation with clay soil association could be the nutrient availability as described by [28].

One study demonstrated that the amount of carbohydrates vary in rye grasses during different times of the day with fructose being at the highest concentration at noon [29], while [22] pointed out that the carbohydrates vary at different parts of the grasses and at different maturity stages. While our study analyzed the carbohydrate concentration during various seasons, future studies could focus on analyzing the carbohydrate concentrations of the grasses during various parts of the day with a focus of plant maturity. If one were to determine the time of day and season that jackrabbits foraged more heavily on that vegetation, one could determine if jackrabbits were optimizing their carbohydrate concentrations from the grasses.

Other studies have analyzed the relationship between organismal physiology and dietary preference. For example, [15] showed seasonal changes with uterine width and size of ovaries [15]. Further, that study showed that jackrabbits chose which vegetation they eat by season (e.g. the preference of shrubs such as Parry's rabbitbrush during the winter [15]). Further studies examining the relationships between physiology and biochemistry and diet are needed to help portray a better understanding of white-tailed jackrabbit population health.

5. CONCLUSION

This study quantitatively analyzed the amount of carbohydrates in grasses and soil texture in white-tailed jackrabbit habitats in central and western South Dakota. The results of this study suggest that the carbohydrate concentration (glucose and fructose) of grasses are low during the fall and winter when pre-natal nutrition for the first jackrabbit litter is important. The results of this study also showed the concentrations of glucose, fructose, and soil texture between all three counties were statistically significant ($p<0.001$). Jackrabbits were also found in areas with a higher clay concentration for soils. It would be beneficial to compare carbohydrate concentrations and soil texture analyses to other states that contain white-tailed jackrabbits and where they are not located to see if they are statistically significant. Further jackrabbit biochemical studies coupled with physiological research is needed to help portray a better understanding of white-tailed jackrabbit population health and population declines from the species.

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AUTHORS' CONTRIBUTION

KG: was the P.I. of the project, secured a grant, had the idea to test carbohydrate amounts in vegetation and test soil properties, developed the methodology.
KG, KI, AP, GB: obtained the data, tested the data, made analyses and wrote up. The final manuscript has been read and approved by all authors.

TRANSPARENCY DECLARATION

The authors declare no conflicts of interest.

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APPENDIX 1. Macronutrients from Butte, Hughes, and Martin Counties.

Butte													
	Macronutrient	**Winter**			**Spring**			**Summer**			**Fall**		
		GrE	**McB**	**PMd**	**GrE**	**McB**	**PMd**	**GrE**	**McB**	**PMd**	**GrE**	**McB**	**PMd**
Vegetation	Phosphorus	NA	NA	1	NA	1	1	1	1	1	1	1	1
	Nitrates	NA	NA	1	NA	1	1	0	0	1	0	0	1
	Potassium	NA	NA	1	NA	1	1	1	0	1	1	0	1
Soil	Carbonates	1	0	NA	NA	NA	1	0	1	1	0	1	1
	Nitrates	0	0	NA	NA	NA	0	0	0	0	0	0	0
	Sulfates	1	1	NA	NA	NA	1	0	0	1	0	0	0
	Ammonium	0	0	NA	NA	NA	0	0	0	0	0	0	0
	Phosphates	0	NA	NA	NA	NA	1	0	0	1	0	0	0
	Magnesium	1	NA	NA	NA	NA	0	0	0	0	0	0	0
	Calcium	1	1	NA	NA	NA	1	1	1	1	1	1	1
	Potassium	0	0	NA	NA	NA	0	1	0	0	1	0	0
	Iron	0	0	NA	NA	NA	0	1	0	0	1	0	0

Note: 0 denotes the lack of the nutrient and 1 denotes presence of the nutrient. "NA" denotes that these values were not examined.

Hughes					
	Macronutrient	**Winter**	**Spring**	**Summer**	**Fall**
Vegetation	Phosphorous	1	1	NA	1
	Nitrates	1	1	0	1
	Potassium	1	0	NA	0
Soil	Carbonates	0	NA	1	1
	Sulfates	0	NA	0	0
	Ammonium	0	NA	0	0
	Phosphates	1	NA	1	0
	Magnesium	1	NA	1	1
	Calcium	1	NA	1	1
	Potassium	1	NA	0	1
	Iron	1	NA	0	0

Note: 0 denotes the lack of the nutrient and 1 denotes presence of the nutrient. "NA" denotes that these values were not examined.

Martin					
	Macronutrient	**Winter**	**Spring**	**Summer**	**Fall**
Vegetation	Phosphorous	NA	NA	1	1
	Nitrates	NA	NA	1	1
	Potassium	NA	NA	0	0
Soil	Carbonates	NA	0	0	0
	Sulfates	NA	0	1	0
	Ammonium	NA	0	1	0
	Phosphates	NA	0	1	0
	Magnesium	NA	0	0	0
	Calcium	NA	1	1	1
	Potassium	NA	0	1	0
	Iron	NA	0	0	0

Note: 0 denotes the lack of the nutrient and 1 denotes presence of the nutrient. “NA” denotes that these values were not examined.