GRAZING PATTERNS, DIET QUALITY, AND PERFORMANCE OF COW- CALF PAIRS GRAZING SHORT GRASS PRAIRIE USING CONTINUOUS OR HIGH STOCKING DENSITY GRAZING STRATEGIES

By

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ABSTRACT

Two experiments were performed at the WTAMU Nance Ranch (Canyon, TX) to compare different grazing strategies. The first measured differences in intensity of defoliation among species when cattle were allotted the same mean daily herbage allowance but with different stocking densities and grazing period lengths on reclaimed farmland dominated by old world bluestem (*Bothriocloa ischaemum* L.). Eighty-seven cows were randomly assigned to four treatment herds from January 12 – February 13, 2018. Fifty-nine mature cows (567 kg ± 10.8 kg, std. dev.) were stocked to achieve a target mean daily herbage allowance of 68 kg standing biomass $\cdot$ hd^{-1} $\cdot$ day^{-1} for the grazing period allotted among four replicates of the continuous grazing treatment. Another 28 cows received the same daily herbage allowance, but moved daily in small paddocks among four replicates, consecutively. Paddock size was determined each day by standing biomass in the area to be used to achieve an herbage allowance of 68 kg standing biomass $\cdot$ hd^{-1} $\cdot$ day^{-1}. Botanical composition of standing herbage was measured before and after completion of the study in order to measure herbage disappearance by species. At the end of the grazing season, a nearest-plant step point transect was used to measure severity of defoliation by species between treatments. Total standing herbage at the beginning and end of the grazing season was not different ($p>0.05$) between treatments. Neither herbage removal nor proportional weight remaining were different ($p>0.05$) between treatments for any species measured. The before and after index (BAI)

was used to estimate the relative change in standing biomass (BAI_{weight}) or composition (BAI_{comp}) by weight for individual species in the plant community. Neither BAI_{weight} nor BAI_{comp} were different between treatments for any species measured. Proportional utilization index (PUI) was developed to evaluate differences in utilization among species comprising different proportions of the plant community among replicates. The only difference in PUI from the expected (even defoliation severity between species and treatment) was observed in minor species.

The objectives of the second study were to: 1) measure differences in diet quality using fecal near-infrared reflectance spectroscopy and performance of cow-calf pairs; and 2) quantify and compare vegetation defoliation and regrowth patterns on native rangeland in the Texas Panhandle when cattle were managed using continuous or rotational grazing employing weekly moves at the same stocking rate and intensity. Eighty lactating cow-calf pairs were weighed and assigned to two treatment groups among six native shortgrass-dominated rangeland pastures dominated by blue grama (*Chondrosum gracilis* Willd.), and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). Botanical composition was measured before the study began to measure standing biomass by species, and after completion of the study in order to measure biomass disappearance by species. Grazing distribution was measured using point transects out to 386 meters from the water tank. Fecal near-infrared reflectance spectroscopy (F.NIR) was used to compare differences in diet quality between HSD and CG treatments. Weights of cows and calves and average daily gain were recorded and compared between treatments. Cattle in the CG treatment maintained higher ($p<0.05$) mean dietary DOM and CP levels, but there were no significant differences in any measure of individual performance between treatments.

Major species (blue grama and gummy lovegrass) exhibited no significant differences in TDN and CP levels between treatments. Total defoliation intensity at the end of the grazing season was different ($p<0.05$) between treatments in periods 1, 5, 6, and 7. Standing biomass of gummy lovegrass was lower ($p<0.05$) at the end of the grazing season in HSD than CG. Standing biomass and composition of cool season annual grasses were lower ($p<0.05$) at the end of the grazing season in CG than HSD.

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CHAPTER I

REVIEW OF LITERATURE

Introduction

Ecological and economic constraints differ among operations in all resource management systems. This heterogeneity of constraints demands thoughtful interpretation of both experimental and empirical evidence (Briske et al. 2008; Provenza et al. 2013) to fully understand their implications and develop grazing management strategies that can successfully meet management lifestyle, livelihood and landscape goals.

Briske et al. (2008) described management as a "confounding variable" that is seldom explicitly recognized, and renders the value and efficacy of grazing management research difficult to interpret. In discontinuously stable environments (Ash and Stafford Smith, 1996) like semi-arid rangelands, the value of supplemental feeding, labor, or infrastructure may not be realized immediately (Danckwerts et al. 1993). However, as more information regarding the processes driving these ecosystems becomes available (Provenza et al. 2013) to rangeland managers, their decision making process may become more robust (Danckwerts et al. 1993), allowing them to optimize the costs associated with supplemental feeding, labor, infrastructure and depreciation (Briske et al. 2008).

While grazing studies emphasize ecological and biological parameters, managers analyze the value of grazing strategies through an "economic-ecological review process"

(Grissom, 2014). Producers “tinker” (Grissom, 2014) with processes on scales that suit their risk tolerance, ecological and economic goals. However, the results of private “tinkering” with only one observation is context specific, and limits the scientific inferences that can be drawn and their applicability in a broader context. Therefore, grazing studies should be designed to discover response mechanisms and the variables driving self-organizing systems (Provenza et al. 2013), which can then be applied to a manager’s unique goals, resources and constraints. For instance, a grazing manager producing yearlings on seasonally leased property should develop different management strategies than a cow/calf producer with a single contiguous land resource (Wilson, 1986).

One apparent tradeoff made with continuous grazing is allowing animals the full expression of selectivity over extended periods of time (Wilson, 1986) to the detriment of palatable plants (O’Connor, 1989). One goal in rangeland management is to maintain or improve the frequency and productivity of palatable plant species (Danckwerts et al. 1993). The challenge in doing so is that extreme weather events in event driven communities (Danckwerts et al. 1993) may slow or reverse successional changes toward species composition goals. However, as predicted by Watson et al (1996), more rapid and/or favorable responses after an extreme weather event have been observed (Earl and Jones, 1996; Pieper et al. 1991) when facilitated by a grazing strategy that allowed palatable plants to fully recover between defoliations.

Relative palatability among species changes seasonally (Bailey and Brown, 2011), and plants of different species have different periods during the growing season when they are most sensitive to defoliation events (Mullahey et al. 1990; Mullahey et al. 1991; Reece et al. 1996). The ability to regain plant vigor between defoliations is a function of plant physiology (Briske, 1991; Caldwell et al. 1981; Caldwell, 1984; Cruz, 1998) and timing of defoliation (Mullahey et al. 1990; Mullahey et al. 1991; Reece et al. 1996; Stephenson et al. 2015).

One concern to address with grazing management is the tendency of cattle to exhibit "central place foraging" (Stuth, 1991; Valentine, 1947) around preferred areas of the landscape. The preference for the area around water points increases the amount of severe defoliation around a water trough in continuous grazing strategies, resulting in chronic stress (Ash and Stafford Smith, 1996) on the plant community and the deterioration of palatable perennial species in waves around the tank (Wilson, 1986).

The National Research Council (2016) recommends further research be conducted to "improve production and nutritional value of grazed and harvested forage." If less selectivity among plant species is expressed while nutrient intake remains above the threshold nutrient requirements for lactation, maintenance and pregnancy of mature cows, more economic value can be derived from forages of poorer quality, and carrying capacity would increase. Additionally, if the competitive ability of high quality, preferred species is maintained by allowing adequate regrowth between defoliations, the production of quality feeds is increased, thereby improving average nutritional value of forages available and the choices of livestock classes and species that can profitably and sustainably use the landscape. Therefore, to formulate pertinent questions regarding how grazing management affects production and nutritional quality of forages, the effects of grazing at different temporal and spatial scales on plant productivity and competitive relationships among neighboring plants over the long-term should be evaluated. In addition, the ability of animals to select from among plants and plant parts of varying quality and consume enough dry matter daily while doing so must also be taken into account. These topics will be considered in the following sections.

Factors that affect forage quality and forage availability

The term forage quality refers to the digestibility of above ground plant parts (Rittenhouse and Roath, 1987). The plant metabolite pool (compounds that can be used by animals to sustain life) is a stock contained within the plant, with major inflows being soil nutrients, soil water, light and CO_2, and major outflows being plant respiration and development of indigestible structures (Lechtenberg et al. 1973). The cell contents are found in the intracellular space of a plant and contain the organelles of a plant cell (chloroplasts, mitochondria, cytoplasm and nucleus), while the intercellular space is composed of the cell wall (Briske, 1991).

The cell contents are broken down into sugars, starches, lipids, amino acids, nucleic acids, that are highly digestible by all classes of livestock via hydrolysis or enzymatic breakdown of the constituent parts in the abomasum or small intestine, as well as other non-protein nitrogen (NPN) (National Research Council, 2016). In ruminants the additional microbial degradation and conversion to volatile fatty acids (VFA), and microbial protein allows them to consume plants with a high proportion of starch or NPN and still meet their nutrient requirements (Rittenhouse and Roath, 1987; citing Van Soest, 1982), though higher proportions of cell wall constituents decrease digestibility rate of digestion.

The composition of the intercellular space may also create major variations in forage quality, as some components are more susceptible to microbial breakdown and hydrolysis than others (Huston and Pinchak, 1991). For instance, cellulose and hemicellulose (major components of the primary cell wall) are apparently digestible to the same extent, whereas non-carbohydrate compounds found in the secondary cell wall, such as lignin and silicates, are indigestible and create negative interactions with forage quality (Rittenhouse and Roath, 1987). A secondary cell wall is common in warm season plant parts such as bundle sheaths, and lignification increases with maturity (Huston and Pinchak, 1991). Water stress (barring death) reduces the mobilization of N in plant tissue, as the rate of both N decline in growing plants and digestibility of consumed plants are decreased in water stressed leaves compared to well-watered leaves (Rittenhouse and Roath, 1987 citing Van Soest, 1982).

High temperatures (compared to the thermo-neutral range of a given species) have a strong detrimental effect on dry matter digestibility of plants, because cell solubles are reduced while intercellular constituents and lignification increase (Rittenhouse and Roath, 1987). Grazing can also affect forage quality, since defoliated plants send hormonal signals to continue aboveground vegetation growth, which is phenologically younger (i.e. a greater fraction of cell solubles when compared to cell wall) than undefoliated contemporary plants (Rittenhouse and Roath, 1987). The tradeoff between yield and quality is apparent in production of alfalfa (*Medicago sativa* L.), where alfalfa cut at full bloom was the highest yielding, but also the poorest quality, as measured by total digestible nutrients (Blank et al. 2001).

The term forage availability refers to the amount of palatable plant material present, but also to a herbivore's ability and desire to consume a plant at the location where that plant occurs. Forage availability is a function of individual preferences and preferences of the herd or social group (Bailey et al. 2015; Provenza et al. 2015). Hanley (1982) hypothesized that grazing herbivores have feedbacks that make selecting high quality forages rewarding, so that livestock are drawn into the area to defoliate the patches until grazing at that location is no longer metabolically efficient and exploration must be initiated again. Bailey et al. (2015) observed that animals used patches (plant communities on a landscape with relatively homogenous composition) of high quality food until a patch was depleted to the point that additional nutrient intake per unit weight was no longer optimized by the work required to harvest it (as measured by increased bite rates and smaller bite size).

Cattle on sites with more homogenous terrain and vegetation tend to alternate between different grazing patches more frequently than those in more heterogeneous terrain and vegetation (Bailey et al. 2015). The net effect of this behavior is that cattle that stay in one site for longer periods have a less diverse diet than those that change sites more rapidly (Provenza et al. 2015).

Provenza et al. (2015) observed and recorded the proclivity of herbivores to return to sites and feedstuffs that reward them with satiety. Briefly, herbivores eat a variety of foods to meet nutrient requirements to satiate and to avoid toxic consequences. Flavorspecific satiety and toxicity avoidance, where flavors are associated with a comforting or distressful digestive response, are controlled in a manner similar to operant conditioning, as pioneered by Thorndike (1898). Nutrient requirement feedback loops will be discussed in the section on diet selection and nutrient intake.

Toxins in plants create a negative physiological effect when consumption exceeds a threshold level that varies with the toxin concentration in the plant and the other nutrients and toxins consumed at the same time (Provenza et al. 2015), thereby reducing the probability that consumption of that toxic plant at levels that cause adverse effects will be repeated. Having forages available with high secondary compound diversity may reduce the negative associated effect of toxin consumption, and herbivores can learn to consume a variety of plants containing different toxins – e.g. consuming terpenoids with tannins, or consuming more fiber in response to subclinical acidosis (Provenza et al. 2015).

Fortunately, cattle do not have to go through the learning process as an individual if they are raised in a herd where they have the opportunity to observe the grazing behavior of their contemporaries and dams to formulate social preferences for foods (Provenza et al. 2015).

There is evidence that feed preferences are affected at a young age. Wiedmeier et al. (2012) observed that when dams consume high fiber diets early in pregnancy, physiological changes occur for calves in utero that allow them to digest fiber more completely and retain nitrogen from the feed more efficiently. The preference of herbivores as it relates to forage quantity is important to study, since severe defoliation events, senescence, and death reduce photosynthetic capacity of remaining tissue, and eventually the energy available to carry out respiration (Briske, 1991).

The physical characteristics of plants also affect the capability of the animal to ingest enough nutrients to meet its requirements. Hodgson (1981) observed that intake per bite is positively related to sward height. The bite rate (number of bites per unit time) was reduced as sward height increased (Hodgson, 1981). Bite rate has been used as a metric to predict cattle are more likely to move to a different patch – when bite rate increases in pastures with turfy sward structure, forage intake is becoming limited, and animals are more likely to move to a new patch (Bailey et al. 2015). The theory behind this principle is that the energy expended during nutrient acquisition from smaller bite size does not make up for the increased nutrient density in a patch, causing cattle to search for a new grazing patch to exploit.

Management effects on plant productivity, vigor and recruitment

Factors associated with plant productivity that are affected by the timing, frequency and severity that livestock use plants include regrowth of leaves after defoliation (Caldwell, 1984), tillering and shading (Deregibus et al. 1983), root growth (Crider, 1955), and competitive relationships with neighboring plants (Mueggler, 1971). Repeat, severe defoliation reduces plant biomass over time (Mullahey et al. 1990; Mullahey et al. 1991), and continuous grazing is more likely to result in multiple bites of the same plants in a grazing period than when shorter grazing periods are used at the same stocking rate (Derner et al. 1994). Crider (1955) observed reduction in root production (glass box method) in grasses that were severely defoliated. Additionally, root growth was stopped for 33 days in all plants when 90% of the leaf area was removed (Crider et al. 1955).

Competition also plays a significant role on the response of plants to defoliation. In Southwestern Montana (40 cm annual rainfall), Mueggler (1971) clipped bluebunch wheatgrass (*Pseudoroegnaria spicatum* [Pursh] Á. Löve) to remove 50% of herbage weight just before emergence of flower stalks with partial competition (clipping surrounding plants within 90 cm to ground level). Dry weight yield of the target plants was not different from unclipped plants under full competition (no clipping of surrounding plants). While the dry weight yield was greatest for unclipped plants with no competition (hoeing and weeding of plants within 90 cm to a depth of 5-8 cm), the extreme clipped plants (removal of 50% of herbage weight and a second clipping to 8-cm stubble height at dough stage) with no competition yielded the same herbage weight as the unclipped plants at full competition (Mueggler, 1971). So, both the intensity of defoliation on an individual plant, and the uniformity of defoliation among plants can profoundly affect total yield and composition of herbage over time.

Caldwell et al. (1981) observed similar photosynthetic rates between crested wheatgrass (*Agropyron cristatum* L.) and bluebunch wheatgrass that were well adapted to grazing and sensitive to grazing, respectively. However, crested wheatgrass grew more leaves after two severe defoliation events, which increased net photosynthetic capacity (Caldwell et al. 1981).

While cumulative aboveground biomass (standing herbage at the end of the study plus weight removed at each defoliation event) of crested wheatgrass was greater in a heavily defoliated treatment than in the control group, belowground root biomass was reduced in the heavily defoliated treatment (Caldwell et al. 1981). Bluebunch wheatgrass allocated fewer resources to aboveground production after a defoliation when compared to crested wheatgrass, which caused bluebunch wheatgrass root biomass to decline due to reduced photosynthetic capacity (Caldwell et al. 1981).

In Whitman, NE (annual precipitation 24.3-66.3 cm), Mullahey et al. (1990) observed no effect ($P>0.10$) of a single July 10th clipping to a height of 7cm on dry matter yield, number of tillers, tiller weight, or number of buds of little bluestem (*Schizachyrium scoparium* [Michx.] Nash), NE when compared to an ungrazed control after three years when the range in precipitation ranged from 24-66 cm. Dry matter yield was reduced ($P<0.10$) in multiple defoliation treatments when compared to single defoliation treatments after three years (Mullahey et al. 1990). In addition, August 10th defoliations reduced ($P<0.10$) dry matter yield, number of tillers, and number of buds in years 2 and 3 of the study when compared to the undefoliated control (Mullahey et al. 1990). However, these results must be interpreted carefully. While clipping studies allow precise control of what plants are defoliated, it does not account for herbivores' ability to select different parts of a plant, which may in turn affect a plant's ability to recover after a grazing bout.

In a study of different timing and length of grazing of cattle in the Nebraska Sandhills, Reece et al. (1996) observed the only grazing period that had no effect ($P>0.05$) on either prairie sandreed or Sand bluestem production was a single grazing period in October when compared to grazing periods in; June, July, August, June and July, June and August, or June, July, and August. The lowest sand bluestem production was observed in treatments that were either grazed in June and July, June and August or in the grazing period that lasted three months (June – August) (Reece et al. 1996). The same pattern was observed in prairie sandreed. Biomass was reduced ($P<0.05$), at the end of the 5 year study in every treatment where cattle were allowed to return within a grazing season when compared to the control (Reece et al. 1996).

Stephenson et al. (2015) also observed that timing of grazing in the eastern Nebraska Sandhills affected subsequent year standing biomass of both cool season and warm season grasses. For example, warm season standing biomass in the following year was reduced ($P<0.01$) when pastures were grazed in mid- to late summer (July 20-August 29). Additionally, cool season grass standing biomass was greater in years following grazing treatments from May 16-June 14 or June 13-July 20 than in pastures grazed late in the grazing season (August 27-October 7).

The results from these four studies corroborate the assertions of Briske (1991) that it is critical to reduce the intensity and frequency of defoliation during late stages of plant growth (boot and seed set) to promote recovery in later years. However, too much growth may be undesirable in wet climates as overgrown cell bundle sheaths contain a higher proportion of indigestible lignin and α-linked cellulose (Ash and McIvor, 1998). The defoliation of the same few plants leads to a dual positive feedback system that becomes a vicious cycle, wherein the plants that are not defoliated in a timely fashion begin to mature and forage quality declines, which in turn makes those undefoliated plants less desirable, while those previously defoliated are more likely to be defoliated again, thereby weakening them (Ash and McIvor, 1998; Rittenhouse and Roath, 1987).

When stocking rates were adjusted between years based on managers' recommendations, Pieper et al. (1991) observed that basal cover increased at a faster rate following a drought for a one herd, four pasture rotation scheme (15 month grazing cycle) with a stocking rate 125% that of the moderate treatment (stocking rates ranged from 14.97 ha · animal unit $(au)^{-1} \cdot yr^{-1}$ to 40.5 ha · $au^{-1} \cdot yr^{-1}$ in response to rainfall among years) in a semi-arid environment (381 mm annual rainfall). They observed that blue grama (*Chondrosum gracilis* Willd.) production was lower when continuously grazed compared to a four pasture one herd grazing system, at the same stocking rate (stocking rates ranged from 12.14 ha · $au^{-1} \cdot year^{-1}$ to 32.4 ha · $au^{-1} \cdot year^{-1}$ in response to rainfall among years). Total end of season (September) standing biomass of grass species was higher under the single rotational grazing treatment when compared to either continuous treatment. They concluded that heavy continuous grazing reduced perennial grass cover and production while increasing the production of unpalatable forbs. Additionally, two drought years led to removal of the cattle in the heavy continuous grazing treatment and supplemental feeding of the cattle in both the moderate continuous grazing treatment and the rotational grazing treatment.

In the Northern Tablelands of New South Wales (avg. rainfall 79.3 cm), Earl and Jones, (1996) studied grazing managers at three locations that adjusted "the length of the graze and recovery periods . . . according to the feed on offer and anticipated seasonal growth rates" to compare the results of their adaptive strategies to that of continuous grazing treatments at the same stocking rate. Plant basal cover was significantly higher in the adaptive grazing treatments than the continuous at all locations, at the end of two years, not only at locations stocked at the same rate, but also at Lana, which was stocked at twice the stocking rate (6.0 DSE · ha^{-1} · yr^{-1} vs. 3.1 DSE · ha^{-1} · yr^{-1}) in the adaptive cell grazing treatments compared to the continuous grazing treatments.

Basal diameter of desirable/palatable species also responded differently with adaptive grazing than under continuous grazing after two years of management (Earl and Jones, 1996). At Lana, the basal diameter of the highly palatable *Eragrostis leptostachya* (R.Br.) Steud. decreased at a reduced rate (7% over two years compared to 65%) under adaptive cell grazing vs continuously grazing at half the stocking rate. At Lana and Strathroy, the most significant changes in basal diameter of *E. leptostachya* between treatments were during a 12 month dry period when rainfall was 60% below average. The basal diameter of *E. leptostachya* at Strathroy increased by 20% under adaptive management but was reduced by 65% in the continuous grazing treatment. At Green hills, there was an increase in percent plant basal cover under cell grazing while the opposite occurred under continuous grazing.

However, the basal diameters of the most unpalatable plants at each location (*Aristida ramosa* [R.Br.] and *Poa sieberiana* [Spreng.]) were reduced at a faster rate in the adaptive grazing treatment than in the continuous treatment while frequencies of those plants were no different between years.

At Strathroy, Earl and Jones (1996) observed increased frequency of *E. leptostachya* in adaptive grazing treatments, while it was reduced under continuous grazing. However, the opposite happened with the unpalatable *A. ramosa* (Earl and Jones, 1996). At Strathroy *E. leptostachya* and *Sporobolus creber* (De Nardi) (a palatable species and moderately palatable species respectively) dominated the plant communities at the onset. However, over time *E. leptostachya* as a proportion of composition by weight increased in the adaptively grazed treatment while *A. ramosa* and *S. creber* increased in composition by weight in the continuous treatment. At Lana, changes in pasture composition were related more to season than grazing method.

Fair et al. (1999) observed that about 16 new individuals per 100 individuals sexually established annually, regardless of rainfall, though fewer than 50% of genets survived, on average, for two years (Fair et al. 1999) in this ungrazed site. Precipitation at the study site in Hays, KS was variable during the 38 year study (average annual precipitation = 55.8 cm, high = 110 cm, and low = 34 cm). A single severe defoliation event in Nunn, Colorado (25-28 cm annual precipitation) reduced herbage yield of blue grama even after 26 months of rest, when compared to an undefoliated contemporary group, except for those defoliations that occurred during quiescence (Trlica et al. 1977).

Therefore, timing, recovery, and severity of defoliation must be considered with any grazing strategy. Svejcar et al. (2014) hypothesized that either chronic stressors such as annual overgrazing with too little recovery or acute stressors such as drought can yield the same net effect of reduced production. Therefore, to maintain appropriate quantity and quality of forage on offer, it is imperative that adequate recovery is provided to palatable plants in order to curb extinction on a site (O’Connor, 1989; Svejcar et al. 2014).

Measurements of forage quality

TDN is an estimate of the energy density of a feedstuff. It is calculated as follows:

TDN = 102.33 - (1.1135 * ADF) (NRAES-63, 1995).

Where; ADF is Acid Detergent Fiber, the indigestible cellulose and lignin in the plant, expressed as a decimal (National Research Council, 2016).

Digestible organic matter (DOM) is made of polysaccharides, lipids, and protein that are digested by the animal (National Research Council, 2016).

Typically DOM is calculated as follows for metabolism studies;

DOM = (OMI – FOM) / DMI

Where; OMI is organic (mineral and water free) matter intake, FOM is fecal organic matter, DMI is dry matter (water free) intake (Huston and Pinchak, 1991).

Crude protein (CP) is calculated for a forage sample by first using the Kjeldahl method (Chromý et al. 2015) to find % nitrogen (N), then using the proximate analysis calculation:

CP = %N *6.25 (Huston and Pinchak, 1991)

The amino acids (AA) contained in most forage proteins are, on average, about 16% N (Lyons et al. 1995). However, the Kjeldahl method does not distinguish between non-protein nitrogen and true protein in the analysis, which could lead to overestimation of bioavailable protein in the diet (Galyean, 1996).

Cows are only 10-20% efficient at N conversion to body tissue. Differences in efficiency are due to the balance of rumen ungradable protein (RUP) and rumen degradable protein (RDP) in forages (Galyean, 1996; National Research Council, 2016). The advantage of using RDP as a CP source is that AA in the diet need not be as high quality (proper proportion of AA) as that found in monogastric diets, so long as the microbes in the gut have the constituent parts of the AA (National Research Council, 2016).

With limited CP in the diet, DOM utility is limited, because there may be energy available for anabolic function but inadequate AA to build tissues or mobilize plasma AA during an immune or stress response (National Research Council, 2016; Waggoner et al. 2009). However, cattle can recycle N by absorbing ammonia from fed non-protein nitrogen (NPN) as well as NPN from microbial degradation of protein in the rumen and small and large intestines. They then convert ammonia to urea in the liver, and transfer it in the blood across the epithelium of the rumen (National Research Council, 2016). Urea is then hydrolyzed in the rumen via microbial urease and can be used as a rumen degradable protein (RDP) supplement (National Research Council, 2016).

Beaty et al. (1994) observed that cattle in the third trimester of pregnancy who received a 31% CP supplement three times $\cdot$ week^{-1} did not differ in terms of pregnancy rate, calving interval, calf ADG or calf weaning weight, indicating that N recycling was adequate to meet their protein requirements during the recurring 72 hour supplement fast the cows experienced. While elevated plasma urea concentrations can be mobilized quickly when a high energy feedstuff is available, urea recycling is reduced when forage DOM is low

(Harmeyer and Martens, 1980). Urea recycling allows the rumen to manufacture AA while adapting to changing forage DOM or CP.

Animal selectivity and landscape use

Large herbivores are "central place foragers" (Stuth, 1991; Valentine, 1947) and choose to consume forage that is nearest preferred areas of the landscape until grazing nearby is energetically inefficient i.e. the reduced bite size and increased bite rate is more costly per kilogram consumed (Galyean and Gunter, 2016). For example, Irving et al. (1995) observed that cattle graze severely in waves that radiate out from a water tank, even under different stocking densities. Hart et al. (1993) found that "reducing pasture size from 207 to 24 ha usually produced marked improvements in cow and calf gains," probably because the maximum distance from the water tank in the 207 ha pasture of 5.0 km decreased the amount of the paddock that was actually utilized, and therefore, increased the effective stocking rate.

In Stillwater, OK (annual precipitation, 831 mm annually), Derner et al. (1994) observed "little effect" on grazing height in relation to stocking rate in rotationally grazed pastures. However, the 8 rotational grazing paddocks were 1.2 ha each. If cattle are "central place foragers" (Stuth, 1991), there may not have been enough linear distance from the water for cattle to express differences in foraging behavior resulting from both vertical and horizontal distance from water (Roath and Krueger, 1982). However, mean grazed heights increased (17cm at 1.5AUM $\cdot$ ha^{-1} and 1cm at 2.5AUM $\cdot$ ha^{-1}) throughout the grazing period in all continuously grazed pastures (Derner et al. 1994).

In a meta-analysis, Smart et al. (2010) found that across grazing experiments, as herbage allowance increased, the proportion of total herbage disappearance resulting from livestock consumption decreased, indicating that high herbage allowances reduce the grazing efficiency of cattle, that is, the proportion of herbage disappearance actually consumed by the species of interest. However, theoretical herbage allowance for an entire pasture may be different than effective herbage allowance – i.e. effective herbage allowance is affected by the distribution of the animal on the landscape temporally and spatially (Hart, 1993; Irving et al. 1995), and uneven distribution of use on a landscape may make the area actually grazed much smaller than the potential area grazed (Senft et al. 1985). Additionally, poisonous and unpalatable plants on a landscape also reduce the effective forage allowance (Villalba and Provenza, 2009).

While the mechanism examined above sheds light on how cattle interpret information on small spatial and temporal scales, the application to larger spatial and temporal scales is limited by livestock behavior and changes that occur within the particular context of the systems as implemented (Galyean and Gunter, 2016). Linear distance to water, area allowance, animal distribution, and topographic limitations are not captured by either stocking rate or stocking intensity. Therefore, when transitioning from one grazing strategy to another, managers must be aware of how the new strategy affects each of these metrics. Managers can then use evidence based decision making processes to eliminate options that set them up for failure (Grissom, 2014).

Diet selection and nutrient intake

Cattle actively select for preferred plants on a landscape (Stuth, 1991; Villalba and Provenza, 2009). Selectivity changes in time and space, because of plant phenological changes or differences in the species composition of the plant community (Bailey and Brown, 2011). Volesky et al. (2007) observed that cattle in the Nebraska sand hills exhibited greater preference for needle and thread (*Hesperostipa comate* [Trin. & Rupr.] Barkworth) in early April when compared to both May 1 and 22. Proportional availability of needle and thread was higher in May, while the proportion of needle and thread found in the fistulates remained unchanged.

Dietary species composition that deviates from standing herbage composition can be attributed to forage quality and different anti-quality compounds or structures of the plants, which cause cattle to avoid/seek certain plants, stated simply as “taking the best and leaving the rest” (Villalba and Provenza, 2009). The caveats to species selectivity are; there needs to be a wide array of forages on offer (Villalba and Provenza, 2009) and trying new foods should be comforting or rewarding (Thorndike, 1898).

East of Bulawayo, Zimbabwe with a mean annual rainfall of 60 cm, Barnes and Denny (1991) measured average gains on Africander-type yearling steers grazing 8 paddocks with 5 day grazing periods, 4 paddocks with 10 day grazing periods, and continuous grazing (three paddock two herd with each paddock grazed for two consecutive years and rested a third) over the course of a six year study. Two different stocking rates were used in each grazing strategy (0.94 au $\cdot$ ha^{-1} $\cdot$ yr^{-1} and 0.65 au $\cdot$ ha^{-1} $\cdot$ yr^{-1}), and supplemental cottonseed meal was provided at the same rate between treatments to maintain weight through the dormant season. Live mass gains per steer were greater ($p<0.05$) for the continuous grazing group at low ($0.65 \text{ au} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) stocking rates while there were no significant differences among all other treatments. During the dormant season, live mass loss was reduced ($p<0.05$) for steers in the 8 paddock 5 day grazing period treatment at low stocking ($0.65 \text{ au} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). However, live mass gains per ha were greater ($p<0.05$) in all treatments at higher stocking rates than at low stocking rates. Species composition was also compared among treatments. No important species composition changes occurred, except in the case of the 4-paddock, 10 day grazing treatment at low stocking rate, where the composition of *Loudetia simplex* (Nees) C.E.Hubb. (an undesirable grass) increased at a slower rate when compared to all other treatments. The observation concerning species composition changes indicates producers have more flexibility in managing undesirable species before they become a problem in rotational grazing systems.

Taylor et al. (1980) observed that cattle in a high intensity low frequency grazing system (7 pasture, one herd, moved every 3 weeks with a grazing cycle of 147 days, stocking rate = $4.8 \text{ ha} \cdot \text{au}^{-1} \cdot \text{yr}^{-1}$, Stocking intensity = 30.6 animal unit-days (aud) $\cdot \text{ha}^{-1}$) had a diet that varied from the beginning to the end of the grazing period, consuming fewer palatable plants and more unpalatable plants, including prickly pear (*Opuntia macrorhiza* Engelm.) at the end of the grazing period than at the beginning(20.2% prickly pear, on average in the early part of the grazing period vs 32.23% on average, late in the grazing period).

Even when seasonal variations in plant quality exist (McCollum et al. 1994), cattle can consume a diet more likely to meet their requirements without supplementation if they are allowed to express adequate selectivity (McCollum et al. 1994, Revell, 2014).

Lignification and structural carbohydrate formation is accelerated at elevated temperatures, while cell solubles are reduced, and high temperatures combined with severe water stress have the capacity to induce senescence during a drought (Huston and Pinchak, 1991). McCollum et al. (1994) observed a decay curve for CP $g \cdot kg^{-1}$ OM in esophageal masticates of cattle grazing tallgrass prairie in Stillwater, OK (average rainfall 831 mm), over the course of the grazing season (152 days initiated either April 15 or May 1, two different years), indicating a reduction in the proportion of CP to OM as the grazing season progressed within a paddock or that they were progressively exhausting the higher quality components of the sward as the season progressed.

From the preceding examples, it is apparent that grazing strategies can be implemented to overcome, to some degree, expression of preference for high quality plants and avoidance of low quality plants. However, the interaction of livestock production and landscape management must then be managed by developing reasonable expectations based on what is possible within abiotic and biotic constraints of the plants and animals, and then adaptively manage forage demand, spatially and temporally, in response to cues from both plants and animals to reliably meet those expectations.

Productivity on an individual animal basis as it relates to stocking rate

Ash and Stafford Smith (1996) observed that higher levels of herbage utilization of a grazed pasture decreased individual animal performance. They postulated that discontinuously stable environments, such as heterogeneous rangelands, were more likely to experience a delayed response to overgrazing, causing forage resources to degrade exponentially rather than linearly, compared to continuously stable environments like tame pastures employing cultural practices. Reductions in plant vigor, heterogeneity, functional redundancy and production asynchrony lead to a decrease in the forage quantity and quality and make a site susceptible to precipitous transitions to alternate, less productive stable states if natural ranges of variability for disturbances like grazing, drought, wildfire, flash flood, extreme wind/temperatures are exceeded (Ash and Stafford Smith, 1996). Livestock with lower physiological responses to nutrient limitation, like breeding cows or sheep and angora goats raised strictly for fiber, provide less urgent cues that grazing pressure may be excessive, and therefore, create a greater likelihood of sudden precipitous transitions.

Norton (1998) proposed a ‘family’ of production curves that illustrate the livestock production per area as stocking rate increases when the efficiency of forage utilization changes because of changes in animal spatial distribution. These curves illustrate how livestock production of a landscape subject to inequitable distribution is reduced compared to a landscape where forage demand more closely resembles the sustainable forage supply on all parts of the landscape. Continuing degradation of the forage resource, however, leads to continued reduction in production potential per unit area (Norton, 1996).

In a semi-arid steppe in northeastern Colorado (annual rainfall 31 cm), Senft et al. (1985) found that regression equations including standing N of preferred species ($r^2 = 0.745$), biomass of preferred species ($r^2 = 0.712$), and standing N of live plants ($r^2 = 0.707$) were positively related to community preferences. Their results indicate that cattle select for plant communities higher in CP (Senft et al. 1985), which will, in theory, improve livestock performance.

In Cheyenne, WY (average annual precipitation 33.8 cm), Hart et al. (1988) observed no difference in average daily gain between yearling steers grazing in season-long (continuously grazed from June to early October), rotationally deferred (4 pasture, 3 herd from June to September 1, with cattle sorted to a four pasture four herd system on September 1), or short duration (8 pastures, 1 herd with a 56 day grazing cycle) grazing programs. Stocking rate was 11.9 to 47.2 AUD $\cdot$ ha^{-1} among years, and treatments were set at the same stocking rate among treatments within a year. Stocking intensities in each paddock were not reported. However, stocking intensity would have been lower in the rotationally deferred grazing treatments, and higher in short duration grazing treatments, as a result of management. In the first two years of the study, ADG was lower in the short duration grazing treatment (Hart et al. 1988). The protocol for setting stocking intensity in each paddock in the short duration treatment was then adjusted to reflect the standing herbage in that paddock. After the adjustment, there was no significant difference in livestock production among grazing strategies with the same stocking rate (Hart et al.

1988). However, individual animal ADG was negatively related ($r^2 = 0.66$) to stocking rate across all treatments.

At the same site, (Cheyenne, WY), using the same grazing strategies outlined by Hart et al. (1988), Manley et al. (1997) observed the same trends, namely that higher stocking rates decrease individual animal ADG. The lower ADG observed in short duration grazing treatments when compared to the rotationally deferred treatments and continuously grazed treatments (Manley et al. 1997) indicates that the opportunity to increase production simply by changing the grazing strategy is not immediately beneficial. However, no replication of moderate or light stocking rates at either the rotationally deferred treatment or the short duration treatment is unfortunate, since the vegetation responses of treatments managed with periodic grazing deferment may have increased herbage production (Manley et al. 1997).

These studies (Hart et al. 1988; Manley et al. 1997) seem to demonstrate that as stocking rate increases, individual animal production decreases. Derner et al. (1994) and Senft et al. (1985) give some mechanistic explanation for why that may happen. However, there is evidence that reduced individual animal performance may be a product of differences in effective forage allowance due to inequitable livestock distribution, rather than stocking rate *per se* (Hart et al. 1988; Norton et al. 1996). Additionally, Hart et al. (1988) illustrate the need for a grazing manager trained in the art of range management, as protocols for setting stocking intensity affected livestock performance in the rotationally deferred treatment.

Physical constraints on nutrient intake

Cattle are classified as roughage eaters (Hofmann, 1989; National Research Council, 2016), meaning they are capable of consuming and efficiently digesting plant material containing high proportions of cellulose. When grazing, roughage eaters gather forage rapidly by biting a plant, and with a quick jerk of the head, clipping it off to swallow it with little further mastication, so that as much can be consumed and placed into the reticulorumen as possible in a given time period. Then, in the reticulorumen, contractions of both the rumen and the reticulum mix fresh digesta with rumen contents so that microbial breakdown can begin (National Research Council, 2016).

After mixing, the digesta is regurgitated into the mouth one bolus at a time, remasticated (ruminated) and swallowed again (National Research Council, 2016). When cattle ruminate, they mechanically break through the cell wall, releasing cell solubles, (soluble starches, sugars, lipids and proteins) into the digestive tract (National Research Council, 2016). Rumination also creates more surface area for the cellulolytic bacteria to begin breaking down plant cell walls in the rumen. Cattle can ruminate 20 to 40 $g \cdot d^{-1} \cdot kg^{-1}$ of metabolic weight daily, depending on the proportion and lignification of plant cell wall constituents (McAllister et al. 1994; National Research Council, 2016; Welch, 1982).

The rumen in a mature cow can hold nearly 60L, comprising nearly 70% of the digestive tract volume, and harbors cellulolytic bacteria that produce enzymes that break ß1-4 linkages found in cellulose and hemicellulose (National Research Council, 2016). The ability to break these chemical linkages in cellulose allows more energy to be digested by roughage eaters than monogastrics, browsers or intermediate feeders when they consume forages with low concentrations of soluble carbohydrates and proteins and high proportions of structural carbohydrates (Hofmann, 1989). However, cell solubles can be digested 3 to 10 times faster than rate of passage (National Research Council, 2016), while cell wall digestion is more dependent on “plant species and physiological stage of maturity of the forage.” (Mertens, 1993; National Research Council, 2016). So, if the rate of digestion and resulting rate of disappearance from the rumen is too slow, they will have diminished energy absorption compared to these other classes of herbivores who digest cellulose less efficiently but have higher rates of passage (Hofman, 1989; McNaughton, 1985).

“The end products of ruminal fermentation are volatile fatty acids (VFA), methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), and microbial cells” (National Research Council, 2016). VFA provide energy, while CH_4 and CO_2 are waste gases released during eructation, and NH_3 in the presence of a hexose (six carbon sugar) can be used by rumen microbes to reproduce and release AA in the rumen (National Research Council, 2016). About 60 to 75% of digestible energy comes from rumen fermentation (National Research Council, 2016; Sutton, 1979).

In addition to releasing VFA, microbes that enter the hindgut are a protein source for the ruminant, and reduced CP in the diet may additionally reduce intake because microbial synthesis of VFA and rate of disappearance from the rumen are reduced (Galyean and

Tedeshci, 2014; National Research Council, 2016). The tendency of cattle to patch graze may be partly caused by this process i.e. higher rates of passage and digestibility of high quality forages have higher rates of disappearance, which triggers an appetite response (Provenza et al. 2013). In the case of low quality forages the reduced rates of passage discourage eating at the same feeding station because an appetite response is not triggered as quickly following consumption of low quality forages, and a satiety response occurs over a long time period with too much delay to link the experience of consuming low quality forages with the experience of satiety (Provenza et al. 2013).

Measuring/estimating nutrient intake

Prior to the widespread use of the esophageal fistula in ruminants, the only way to test diet quality was through indirect methods such as hand clipping (Guthrie et al. 1967). However, Guthrie observed hand clipping at random locations within a field prior to grazing yielded lower CP and ash while yielding higher ADF and lignin than samples collected from fistulates. Even in a Bermuda grass monoculture (Guthrie et al. 1967) mown to a 10 or 20 cm stubble height, cows were selective enough to maintain improved forage quality (CP and TDN) compared to the hand clipped treatments.

The use of an esophageal fistula is valuable because the sample is selected by a grazing cow (Van Dyne and Torell, 1964) exhibiting natural foraging selectivity. The use of *in vitro* digestibility on the sample provides one accurate means of determining the digestibility of the diet consumed from a landscape (Galyean and Gunter, 2016; Lyons and Stuth, 1992). However, fistulating the animal requires irreversible surgery, and the only samples collected are from cattle with a fistula (Van Dyne and Torell, 1964).

The microhistological technique (Deardon et al. 1975) has been used to measure composition of intake by grazing animals. Briefly, microhistological analysis of feces is identification of plant parts in the feces by measuring the frequency of microscopically sorted plant parts from the feces or rumen contents to estimate the proportion of those species in the diet (Deardon et al. 1975). The microhistological technique is non-invasive and can be performed on any number of cattle in a grazing study. While microhistological analysis is useful to evaluate indigestible dietary species composition, other methods must be combined (hand plucking with *in vitro* digestibility analysis on diets formulated from the hand plucked samples based on the microhistological analysis) to be well suited to evaluate quality of the species and different plant parts in the diet (Deardon et al. 1975; Stuth, 1991).

Indigestible markers such as chromic oxide can be used to measure feed passage rate, but have limited utility if feed total fecal output is not measured, due to lack of repeatability of intake estimates (Carruthers and Bryant, 1983). Total fecal collection is the standard of estimating DMI for grazing animals with indigestible markers (Cordova et al. 1978). However, total fecal collection is time consuming, and differences between animals introduce bias in studies that use one animal per treatment as an experimental unit (Cordova et al. 1978).

The use of internal markers (such as lignin or fecal nitrogen) is non-invasive, easy to sample, and does not require daily dosing of an external marker. The drawback is that the error when using internal markers (CV = 9-13%, Cordova et al. 1978), is typically high enough that it renders the estimation of feed intake useless.

Fecal near-infrared reflectance spectroscopy (F.NIRS) to estimate diet quality

Near-Infrared Reflectance Spectroscopy (NIRS) analysis relies on the absorptive properties of material for different wavelengths of near-infrared light (Walker, 2010). NIRS technology has been used to assess the nutritive properties of feedstuffs. Fecal material can be analyzed to determine DOM and CP (Coleman, 2010; Lyons, 2010), which is advantageous in a rangeland setting, where capturing an animal may be impractical because of behavior change associated with stress of capture, or time restrictions. Additionally, the ability to measure DOM and CP composition from fecal samples accounts for the selectivity that cattle express in rangelands (Coleman, 2010). Lyons et al. (1995) found that 72 hours after entering a little dominated pasture to graze, the F.NIR results for DOM and CP matched (r^2=0.87 and r^2=0.98, respectively) those of the esophageal extrusa. Lyons and Stuth (1992) observed an r^2 of 0.93 and 0.71 for DOM and CP between F.NIR analysis and *in vitro* fermentation.

Objectives for this study

The objective of the first study was to measure differences in intensity of defoliation among species when cattle were allotted the same average daily forage allowance, but with differences in the stocking density and length of grazing period. The objectives of the second study were to: 1) measure differences in diet quality using fecal near-infrared reflectance spectroscopy and performance of cow-calf pairs grazing native rangeland in the Texas Panhandle, and 2) quantify and compare vegetation defoliation patterns for cattle managed with the same stocking rate and stocking intensity using continuous grazing or rotational grazing that employed weekly moves without reintroduction to a paddock

CHAPTER II

DEFOLIATION PATTERNS OF DRY COWS GRAZING DORMANT OLD WORLD BLUESTEM DOMINATED PASTURES IN THE TEXAS PANHANDLE USING TWO GRAZING STRATEGIES

ABSTRACT

This study developed and tested a method to measure differences in defoliation intensity among species when cattle were allotted the same mean daily herbage allowance, but with different stocking densities and grazing period lengths on old world bluestem (*Bothriocloa ishaemum* L.) dominated reclaimed farmland. Eighty-seven cows were randomly assigned to five treatment herds from January 12 – February 13, 2018. Fifty-nine mature cows (567 kg ± 10.8 kg, std. dev.) were stocked to achieve a target mean daily herbage allowance of 68 kg standing herbage $\cdot$ hd^{-1} $\cdot$ day^{-1} for the grazing period, allotted among four replicates of the continuous grazing treatment (CG). Another 28 cows received the same daily herbage allowance, but were moved daily in small paddocks among four replicates, consecutively (HSD). In HSD, paddock size was determined each day based on standing biomass in the area to be used. At the end of the grazing season, a nearest-plant step point transect was used to measure severity of defoliation by species between treatments. Total standing biomass at the beginning and end of the grazing season was not different ($p>0.05$) between treatments. Neither biomass removal nor proportional weight remaining were different ($p>0.05$) between treatments for any species measured. The before and after index (BAI) was used to estimate the relative change in standing biomass (BAI_{weight}) or composition (BAI_{comp}) by weight for

individual species in the plant community. Neither BAI_{weight} nor BAI_{comp} were different between treatments for any species measured. Proportional utilization index (PUI) was developed to evaluate differences in utilization among species comprising different proportions of the plant community among replicates. The only difference in PUI from the expected (even defoliation severity between species and treatment) was observed in non-dominant species. Grazing strategy did not significantly affect herbage utilization or species selectivity of cattle grazing dormant season forages when herbage allowance remained constant among treatments.

INTRODUCTION

One apparent problem associated with continuous grazing is selective defoliation over extended periods of time (Wilson, 1986) that can detrimentally affect palatable plants (O'Connor, 1989) in preferred areas of the landscape (Senft et al. 1985), leading to many attempts to control animal distribution to mitigate these problems through periods of rotational grazing and deferment. Yet Briske et al. (2008), in a review of the scientific literature from around the world found no consistent benefits of rotational compared to continuous grazing for plant productivity or animal performance. They described management as a "confounding variable" that is seldom explicitly recognized, and renders the value and efficacy of grazing management research difficult to interpret.

The challenge for maintaining or improving the frequency and productivity of palatable plant species is that extreme weather events may slow or reverse successional changes toward species composition goals in event driven, discontinuously stable environments (Ash and Stafford Smith, 1996; Danckwerts et al. 1993), rendering the returns on required labor, or infrastructure questionable (Danckwerts et al. 1993). However, preparing a site to recover more rapidly after or to respond favorably to an extreme weather event (Watson et al. 1996) has been observed when facilitated by a grazing strategy that allows palatable plants to fully recover between defoliations (Earl and Jones, 1996; Jacobo et al. 2006; Pieper et al. 1991; Taylor et al. 1993). As more information regarding the processes driving these ecosystems becomes available (Provenza et al. 2013) to rangeland managers, their decision making process may become more robust (Danckwerts et al. 1993), allowing them to better optimize the costs associated with grazing management that would facilitate desirable changes in the vegetation, increase system economic and ecological resiliency (Briske et al. 2008).

Derner et al. (1994) observed fewer undefoliated little bluestem (*Schizachrium scoparium* Michx.) tillers and fewer tillers receiving multiple defoliations at the same stocking rates (1.5AUM $\cdot$ ha^{-1}, 2.0 AUM $\cdot$ ha^{-1}, and 2.5AUM $\cdot$ ha^{-1}) in rotational grazing treatments than in the continuously grazed treatments. Cattle in the rotational treatments only regrazed 10% of tillers during a grazing cycle, even at the highest stocking rate. However, regardless of grazing strategy, the number of defoliation events imposed on an individual plant increased as stocking rate increased (Derner et al. 1994). However, this study only examined defoliation of individual tillers of one species on very small paddocks.

Cattle tend to graze around a focal point (Bailey and Provenza, 2008). Two livestock distribution studies have measured spatial and temporal distribution of livestock on diverse plant communities. Irving et al. (1995) observed visually that within a grazing period, utilization of available herbage radiates out from a water tank. In a semi-arid steppe (annual precipitation 31 cm), Senft et al. (1985) found that regression equations including standing N of preferred species ($r^2 = 0.745$), biomass of preferred species ($r^2 = 0.712$), and standing N of live plants ($r^2 = 0.707$) were positively related to community preferences. Their results indicate that plant communities higher in CP may be a grazing focal point as well (Senft et al. 1985).

However, the literature is lacking regarding temporal and spatial patterns of grazing severity resulting from the expression of animal selectivity in a diverse plant community. Measurements that provide indicators of selectivity and grazing severity would be beneficial to the study of grazing management to improve forage resources. Therefore, the objective of this study was to develop and test a method to measure differences in intensity of defoliation among species when cattle were allotted the same average daily herbage allowance, but with differences in the stocking density and length of grazing period.

MATERIALS AND METHODS

Study Site

The study was conducted on the West Texas A&M University Nance Ranch, located 11 km east of Canyon in Randall County, TX from January 12 – February 13, 2018.

The site has a semi-arid climate, with an average annual precipitation of 49 cm, an average annual high temperature of 21˚ C, and an average low temperature of 6.5˚ C. The site experiences an average frost-free period of 186 days. First frost (< 0˚ C) occurs earlier than October 4th, one year in ten and earlier than October 21, five years in ten (USDA-NRCS, 2020a).). Interannual average daily high is 12.8˚ C interannual daily low is -3.4˚ C for the months of January-February and average cumulative precipitation for the months of January-February is 1.25 cm. (USDA-NRCS, 2020a). Actual precipitation during the trial was 0 cm, and the average daily high and low temperatures were 13˚ C ± 0.8˚ C and -6˚ C ± 0.78˚ C, respectively (NOAA, 2020 Table 2.1). Actual precipitation for 2018 was 58.2 cm (NOAA, 2020).

The study site was a Deep Hardland ecological site with 0-1% slopes (USDA-NRCS, 2020b), composed of the Pullman, Olton, and Acuff series (fine, loamy or mixed superactive thermic Aridic or Torrertic Paleustolls). West Old World Bluestem (OWB) and East OWB pastures (Fig. 2.1) were a former cropland field of about 19.82 ha that was seeded to old world bluestem (*Bothriocloa ischaemum* L.) in 2010. North "Racetrack" (RT), East RT, South RT, West RT, East Infield, and West Infield pastures (Fig. 1) were originally one 40.46 ha cropland field seeded to the same mixture of grasses as the East and west OWB pastures in 2011, but due to several years of drought did not result in a full stand before initiation of the study (Fig. 2.1). All treatment areas were dominated by Old World Bluestem (*Bothriocloa ishaemum* L.) with subdominants of sideoats grama (*Bouteloua curtipendula* Michx.), blue grama (*Chondrosum gracilis* Willd.), sand dropseed (*Sporobolus cryptandrus* Hitchc.), and tumble windmill grass (C*hloris verticillata* L.). A complete list of species encountered by functional group at this site are provided on Table 2.2.

<u>Infrastructure Development</u>

In the context of this study, the word pasture refers to the area in each treatment that the cattle used for the length of the study, while a paddock is a subdivision within a high stocking density (HSD) pasture used for a grazing period. The East OWB and West

OWB were developed using a single strand of high tensile wire to create two 9.91 ha pastures (Fig. 2.1) from the previous 19.82 ha permanent pasture. Existing water troughs on each end were used to supply water to cattle in these pastures for the duration of the experiment.

The remaining pastures originally comprised one 40.46 ha pasture. The East Infield and west Infield pastures were created by fencing off a 20.23 ha square equidistant from the original perimeter fences with 3 strands of galvanized high tensile wire (Fig. 2.1). The East Infield and West Infield were then separated by a single strand of high tensile electric wire to create two 10.12 ha paddocks.

A water line constructed of 3.175cm PVC pipe was buried just outside the permanent fence surrounding the East and West Infield pastures (Fig. 2.1). A Plasson ® Quick Coupler Valve was placed at 22.5 m intervals with a plastic cover around it so that water was readily available around the perimeter for either the 'Racetrack' or 'Infield' pastures.

The remaining area surrounding the 'Infield' pastures was designated as 'The Racetrack' (i.e. North RT, South RT, East RT, And West RT) pastures, each was rotationally grazed by further subdivision using braided polypropylene twine with 12 small-gauge stainless steel wires interwoven to carry electrical current (polywire), on 7.62 cm wide x 45.7 cm spools. The stockman would make several wraps of the polywire around the existing perimeter fence of the 'Infield', then tie a slip knot to secure and electrify polywire, unreel the electrified polywire to the opposite fence (outside perimeter of RT) and tie the spool 0.75 m from the ground to existing perimeter fence, ensuring that the poly wire did not sag all the way to the ground (Fig. 2.1).

After the poly wire was up, the stockman drove 10mm fiberglass posts at every point in the fence where the polywire hung <0.3 m from the ground, and inserted the polywire into insulators attached to the posts approximately 0.75 m above ground level. Three polywire partition fences were used – one on either side of the cattle and another delineating the boundary of the next paddock. In this way, cattle could be easily moved to the next paddock and the back fence taken up and moved to be the new front fence for the next paddock.

Treatments and Management

Standing biomass by species was determined for each pasture prior to implementation of the study to accurately allot cattle to each replicate pasture so that mean daily herbage allowance (HA) would be similar among treatment replicates. Following procedures approved by the West Texas A&M University Institutional Animal Care and Use Committee (Proposal #030218), 87 mature (non-primiparous), pregnant, Angus x Hereford cows with an average weight of 567 kg ± 10.8 kg (std. dev.) were randomly assigned to five treatment herds. Fifty-nine head were allotted to the continuous grazing (CG) treatment among four replicates based on HA.

Where;

HA = (kg standing herbage* ha in the pasture or paddock) ÷ (no of animal units* grazing period).

Therefore;

no of animal units in a given pasture = (kg standing herbage $\cdot$ ha^{-1} * ha in the pasture or paddock) / length of grazing period.

Stocking densities among continuous replicates were 0.91 hd · ha^{-1}, 1.19 hd · ha^{-1} 1.48 hd · ha^{-1} and 2.32 hd · ha^{-1} to achieve a target mean daily HA of 68 kg standing herbage · hd^{-1} · day^{-1} for the 33 day grazing period (January 12 – February 13, 2018).

Another 28 cows (HSD) were managed as a single herd (HSD) and received the same HA. Animals in the HSD treatment were managed using daily moves with a mean stocking density of 45.67 hd·ha^{-1} and moved daily among four replicates (North, South, East, West RT), consecutively (Fig. 2.1).

Paddock size for a day was determined based on the desired HA and the productivity of the plant community in the area to be used. Each paddock was 0.4 to 0.8 ha in size to adjust for variations in plant productivity among the temporary paddocks to provide the same HA among rotational treatment paddocks and continuous treatment paddocks. The section on biomass and composition measurements provides more detail on how the size of paddocks was determined. Cattle in the HSD treatment were moved at 1430 daily by releasing the poly wire slipknot, allowing the cattle to walk to the other side and retying the knot. Then, the back fence from the previous paddock was released in the same way, reeled up, posts were pulled, and the fence reconstructed at the appropriate distance in front of the cattle for the next day's paddock as previously detailed in the section on infrastructure development.

Cattle in the HSD treatment were supplied *ad libitum* water with a portable water tank no farther than 2 m from the perimeter fence separating the 'Infield' from the 'Racetrack' (Fig. 2.1). The trough was moved immediately after HSD cattle were moved into a new paddock. The HSD water tank was a simple sled made from 7.5 cm well stem designed to carry a 2.4 m diameter galvanized tank. The float was hung on the wall of the trough and attached to a 19mm hose connected to the Plasson ® Quick Coupler valve with a quick connect fitting. Cattle in the continuous treatments had *ad libitum* access to fresh water from either a permanent or temporary tank located in one corner (10-20 m from corner post) of each continuously grazed paddock (Fig. 2.1).

Cows were supplemented daily with 0.95 kg of 33% protein range cubes between 0800 and 0815. The cattle in the continuous pastures were fed along the short fence opposite the water tanks (Fig. 2.1). The cattle in the rotational paddocks were supplemented along the permanent fence opposite the water tank (Fig. 2.1).

Measurements

Standing biomass and species composition by weight

Standing biomass and species composition by weight were estimated using the Dry Weight ranked method (DWR) (Mannetje and Haydock, 1963 as revised by Dowhower et al. 2001) before the study to measure standing biomass, and after completion of the study in order to measure biomass disappearance by species. Briefly, when performing the DWR procedure, a quadrat frame of sufficient size to have no more than 3 species in the majority of frames is used. In this study, .25 m^2 quadrat frame was appropriate. The quadrat frame is placed randomly, and the observer then determines the three species in the quadrat with the greatest standing biomass by weight. These species are given rankings of 1, 2, or 3, with 1 being the most biomass and 3 being the lowest.

A rank of 1 corresponds to 70% composition by weight, rank 2 is 20%, while rank 3 is 10%. If > 3 species are found, all other species in the quadrat frame are ignored. If only two species are present in a quadrat, one species is given multiple ranks i.e. 1 and 2, 2 and 3, or 3 and 1 to make the percent composition of that species most closely approximate its estimated actual percentage in the quadrat frame. If only one species is present in a quadrat, all three rankings are assigned to that species, and the composition of that plant is estimated as 100% composition.

For each CG replicate, 20 0.25 m^2 quadrat frames were randomly placed on the north half of a pasture and 20 0.25 m^2 quadrat frames were randomly placed on the southern half of a pasture, three days before grazing. The mean of these observations was used to calculate standing biomass, and species composition by weight, in order to set stocking rate based on HA. After ranking, all standing biomass inside the quadrat frame was clipped to ground level, and placed into a bag. The air-dry herbage was then weighed. The mean standing biomass of each species was then calculated by multiplying the mean standing biomass by the mean percentage that each species represented, and the total standing biomass was compared between treatments.

In two cases in the CG treatment (sideoats grama, tumble windmill grass) and one case in the HSD treatment (old world bluestem), standing biomass estimates at the end of the study were higher by ≤ 15 $kg \cdot ha^{-1}$. Since the study was in the dormant season, making growth during the study unlikely, and since the differences were well within the standard error, the actual estimate of standing biomass are reported as estimated, and readers should be cognizant of this apparent discrepancy.

The DWR method (but with 40- 0.25 m^2 quadrat frames, 10 in each of the North, South, East, and West RT) was used to calculate standing biomass and set stocking rate for the HSD treatment. The smaller area of HSD pastures increased the sampling intensity of the HSD replicates.

In order to calculate the area needed to provide an adequate daily HA for each paddock in the HSD pasture, 5-.25m^2 quadrat frames were randomly placed and clipped within 40 m of the actively grazed HSD grazing paddock in the ungrazed area in front of the paddock. The formula: standing crop on the area immediately in front of the paddock being used ($kg \cdot ha^{-1}$)÷ (28 cows* 68 kg $HA \cdot d^{-1}$) was then used to determine how far the front fence should be placed from the existing fence to have the correct area allotted for the following day.

The before and after index (BAI) was used to estimate the relative change in standing biomass or composition by weight for individual species in the plant community. The formula for the BAI_{comp} is:

$BAI_{comp}=A_{comp}/R_{comp}$

Where: A_{comp}= Percent of the species composition by weight after the grazing period and R_{comp}= percent of the species composition by weight before the grazing period. BAI_{comp} values < 1 indicates a reduction in the composition of the standing biomass of that species in the plant community over the course of the grazing period relative to other species while BAI_{comp} values > 1 indicates that the composition of the standing biomass of that species in the plant community was higher compared to other species after the grazing period.

The formula for BAI_{weight} is:

$BAI_{weight}=A_{weight}/R_{weight}$

Where: A_{weight}= weights of a given species after the grazing period and R_{weight}= weight of a given species before the grazing period. Higher BAI_{weight} values indicate that lighter utilization, while lower BAI_{weight} values indicate heavier utilization.

Severity of defoliation

At the end of the grazing season a nearest-plant step point transect was used to measure and compare the pattern and severity of defoliation on individual plants of different species between treatments. Plants were examined along a series of transects (4000 plants · $treatment^{-1}$, $1000^{*}replicate^{-1}$) oriented roughly parallel to each other. The observer placed a piece of electric tape on the toe of each of their shoes to orient the plant to be identified and evaluated. The first transect began at a point ≈3m from a randomly selected corner and proceeded east or west until ≈ 5m from the fence perpendicular to the transect. At that point the observer turned 90˚ toward the area not yet sampled and began the next transect two paces away until 500 points were evaluated. The second 500 points were observed in a similar fashion starting from a non-adjacent corner in a pasture. Every three paces along the transect, the observer identified the plant species closest to the mark on his shoe and classified it as severely, moderately, lightly grazed or ungrazed according to the following classification system:

- Severe (>50% of leaves bitten *and* >50% tillers removed)
- Moderate (30-50% of leaves *or* tillers removed)
- Light (<30% of leaves or tillers removed)

- Ungrazed (No evidence of defoliation)

Proportional utilization index (PUI) was developed in order to accommodate differences in species composition among replicates to provide some gauge of relative preferences and the likelihood of severe defoliation among plants of different species in a diverse community with different proportions of plants among areas.

PUI was calculated as follows:

$PUI_{sd}=P_{sd}/P_d$

Where;

P_{sd} = (count within a defoliation category for a species/count of that species) ·100

P_d = (count of all plants in a defoliation category/total plants observed) ·100

Where; s=species and d=severity of defoliation category.

A PUI > 1 indicates a greater proportion of plants of that species was observed at a given defoliation level than the mean proportion of all plants defoliated at that level. A PUI < 1 indicates a lower proportion of plants of that species was observed at a given defoliation level than the mean proportion of all plants defoliated at that level, and indicates selection against that species, while a PUI > 1 indicates the opposite.

Analysis

All data was analyzed using SAS 9.4 (SAS Institute, 2019).

Standing biomass and species composition by weight

Student t-tests were used to compare productivity and plant composition by weight before grazing and after grazing between treatments, BAI_{weight} by species between treatments,

BAI_{comp} by species between treatments, and composition change over the course of the grazing season between treatments.

Severity of defoliation

Chi-square goodness of fit analysis was used to determine differences from expected defoliation patterns (PUI) among species between treatments (CG vs HSD).

RESULTS

There were no significant differences in total herbaceous standing crop or standing crop of any of the common species between the CG or HSD grazing treatment sites at the beginning of the study (Table 2.3). However, percent composition by weight of tumble windmill grass, a minor species, was greater in HSD than CG (Table 2.4) at the beginning of the grazing season, with no significant differences in composition or standing crop among the other species at the end of the study.

Neither biomass removal ($kg \cdot ha^{-1}$) nor BAI_{weight} were different ($p<0.05$) between treatments for any species measured. Total biomass removal was not different ($p<0.05$) between treatments (Table 2.5).

Composition change was greater ($p<0.05$) for CG compared to HSD for tumble grass (Table 2.6). BAI_{comp} was not different ($p>0.05$) between CG and HSD for any measured species (Table 2.6). BAI was not calculated for Other due to a composition of zero at majority of observations in either treatment.

Chi-squared goodness of fit indicated that for all listed species, PUI was not significantly different ($p>0.05$) from 1. At least one observation in Other was different from 1 ($p<0.05$) (Table 2.7)

DISCUSSION

The results of step point frequency data indicate that management strategy (daily moves or continuous grazing) was not related to a significant difference in defoliation intensity or biomass removal on dormant warm season perennials when stocking intensity was the same for each strategy. Derner et al. (1994) observed fewer undefoliated little bluestem tillers and fewer tillers receiving multiple defoliations at the same stocking rates (1.5AUM $\cdot$ ha^{-1}, 2.0 AUM $\cdot$ ha^{-1}, and 2.5AUM $\cdot$ ha^{-1}) in rotational grazing treatments than in the continuously grazed treatments during the growing season, but rotational grazing treatments had lighter stocking intensities for each grazing period.

The higher probability of Other species to remain undefoliated is likely due to the abundance of perennial threeawn within that category. This is a reasonable response to grazing treatments as perennial threeawn is known to be unpalatable to cattle. Beyond that observation, the study was unable to reliably test a method (PUI) to measure differences in intensity of defoliation for diverse species between treatments that varied in grazing management, forage productivity, and species composition. Productivity and species composition were confounded by wide differences in species composition and production in two of the CG replicates compared to the other replicates. The high standard errors associated with the weights and compositions of the CG treatment are a product of the East and West OWB pastures that were managed differently prior to the initiation of the study. As a result, one end of each pasture had higher plant density and productivity with much higher proportions of Old World bluestem than the other treatment areas. It was believed that by allotting animals to treatments based on HA, these differences would be ameliorated. Further, since part of the objective was to test measurement methods to determine differences in intensity of defoliation among species in diverse environments and under different grazing regimens, the experiment was conducted incorporating these differences. After reviewing the data analysis, it is evident that a higher sampling intensity would be necessary under these conditions to be able to possibly detect differences in use if they exist.

CONCLUSION AND IMPLICATIONS

Further research at this scale, exploring defoliation patterns at different stocking intensities and herbage allowances may be needed without the need for grazing strategy comparisons. However, more care must be taken in experimental design. Treatments should be assigned with standing herbage accounted for by more than herbage allowance of the animals. If standing crop and species composition is not comparable at the beginning of the grazing period, sampling should be stratified based on the initial standing crop productivity and species composition, and more intense sampling should be performed on a site with this degree of diversity.

The indices, BAI_{comp} and BAI_{weight}, may have uses not explored in this research, and the ease that they can be calculated may be a valuable management tool in extensive, heterogeneous rangelands. Normalized ordinal measurements of defoliation were required within the context of this study, and have the potential for further use in grazing management research.

Additionally, using PUI as a tool to normalize the observed step point data served two purposes. PUI allowed for simplified interpretation of raw numbers, and indicated relative resistance to and likelihood of different defoliation severities among different species. The greatest utility of this study is derived from the development of PUI that can be used to directly measure defoliation severity by species as a result of livestock selectivity in diverse plant communities. The benefits of PUI as a tool for rangeland managers, consultants and academics are; the relative ease of data collection, the non-destructive sampling technique, and further testing of applications of PUI are merited to determine where it may be used appropriately.

Table 2.1 High and low temperatures, and precipitation, by month, for the study period.

Month	Average max (°C)	Average min (°C)	Actual precipitation (cm)
January 2018	12	-9	0
February 2018	15	-4	0
Period	13	-6	0

Table 2.2 Species found on the study site sorted by functional group in order of greatest production to least within a functional group.

	Warm season perennial	Warm season annual
Forbs	Silverleaf nightshade *Solanum elaeagnifolium* Cav. Yellowspine thistle *Cirsium ochrocentrum* Gray	Russian thistle *Salsola iberica* Sennen & Pau.
Grasses	Old World Bluestem *Bothriocloa ischaemum* L. Sideoats grama *Bouteloua curtipendula* Michx. Blue grama *Chondrosum gracilis* Willd. Sand dropseed *Sporobolus cryptandrus* Hitchc. Tumble windmill grass *Chloris verticillata* Nutt. Perennial threeawn *Aristida purpurea* Nutt. Tumblegrass *Scheldonnardus paniculatus* Nutt.	
	Cool season perennial	**Cool season annual**
Grasses		Little barley *Critesian pusillum* [Nutt.] Á. Löve Cheatgrass *Anisantha tectorum* L.

Table 2.3 Differences in standing biomass ($kg \cdot ha^{-1}$) before and after grazing season between continuously grazed (CG) and high stocking density (HSD) treatment groups when grazed during the dormant season from January 12-Feb 13. HSD animals were moved daily with the same mean daily herbage allowance but with mean stocking densities that were ~33x that of the continuously grazed treatment.

	trt	n	mean	SEM	p		trt	n	mean	SEM	p
Total						Sand dropseed					
Before	HSD	4	3809.3	377.4	0.32	Before	HSD	4	726	91.6	0.11
Before	CG	4	4767.1	794.5		Before	CG	4	388	158.3	
After	HSD	4	2934.3	343.1	0.20	After	HSD	4	508	66.8	0.18
After	CG	4	3672.6	376.9		After	CG	4	301	122.6	
Blue grama						Side oats grama					
Before	HSD	4	719.9	276.2	0.40	Before	HSD	4	698	113.9	0.29
Before	CG	4	429.8	159.7		Before	CG	4	427	206.1	
After	HSD	4	388.2	62.65	0.37	After	HSD	4	692	156.1	0.37
After	CG	4	279.8	93.32		After	CG	4	442	203.9	
Old world bluestem						Tumble windmill grass					
Before	HSD	4	498	121.9	0.11	Before	HSD	4	746	131.6	0.15
Before	CG	4	2655.1	954.4		Before	CG	4	399	161.3	
After	HSD	4	500.3	249.8	0.12	After	HSD	4	662	86.6	0.18
After	CG	4	2179	879.1		After	CG	4	405	146.3	
Perennial threeawn						Tumblegrass					
Before	HSD	4	256.1	83.5	0.58	Before	HSD	4	85	24.8	0.19
Before	CG	4	187.3	82.6		Before	CG	4	231	85.6	
After	HSD	4	143	72.5	0.25	After	HSD	4	36	18.2	0.48
After	CG	4	46.598	22.7		After	CG	4	18	15.8	
Other											
Before	HSD		72	66.0	0.74						
Before	CG	4	47.968	26.7							
After	HSD	4	3.3375	3.3	0.36						
After	CG	4	0	0							

Table 2.4 Differences in composition of standing biomass before and after grazing between continuously grazed (CG) and high stocking density (HSD) treatment groups when grazed during the dormant season from January 12-Feb 13. HSD animals were moved daily with the same mean daily herbage allowance but with mean stocking densities that were ~33x that of the continuously grazed treatment.

	trt	n	mean	SEM	p		trt	n	mean	SEM	p
Blue grama						Side oats grama					
Before	HSD	4	0.18	0.05	0.52	Before	HSD	4	0.19	0.03	0.18
Before	CG	4	0.12	0.06		Before	CG	4	0.10	0.05	
After	HSD	4	0.14	0.02	0.23	After	HSD	4	0.23	0.05	0.38
After	CG	4	0.09	0.03		After	CG	4	0.16	0.06	
Old world bluestem						Tumble windmill grass					
Before	HSD	4	0.13	0.04	0.12	Before	HSD	4	0.19	0.02	0.03
Before	CG	4	0.50	0.17		Before	CG	4	0.10	0.03	
After	HSD	4	0.14	0.05	0.08	After	HSD	4	0.24	0.03	0.08
After	CG	4	0.54	0.18		After	CG	4	0.12	0.05	
Perennial threeawn						Tumblegrass					
Before	HSD	4	0.08	0.02	0.16	Before	HSD	4	0.02	0.01	0.14
Before	CG	4	0.04	0.01		Before	CG	4	0.06	0.02	
After	HSD	4	0.05	0.02	0.18	After	HSD	4	0.02	0.01	0.25
After	CG	4	0.02	0.01		After	CG	4	0.01	0.01	
Sand dropseed						Other					
Before	HSD	4	0.20	0.03	0.09	Before	HSD	4	0.02	0.01	0.83
Before	CG	4	0.10	0.04		Before	CG	3	0.01	0.01	
After	HSD	4	0.19	0.04	0.11	After	HSD	4	<0.01	<0.01	0.39
After	CG	4	0.09	0.04		After	CG	3	<0.01	<0.01	

Table 2.5 Differences in standing biomass removal (kg · ha^{-1}) and BAI_{weight} between continuously grazed (CG) and high stocking density (HSD) treatment groups when grazed during the dormant season from January 12-Feb 13. HSD animals were moved daily with the same mean daily herbage allowance but with mean stocking densities that were ~33x that of the continuously grazed treatment. BAI_{weight} = weight after ÷ weight before grazing. Because all negative numbers are within the SEM, growth during the dormant season is less likely than experimental error. BAI was not calculated for Other due to a composition of zero at majority of observations in either treatment.

	trt	n	mean	SEM	p		trt	n	mean	SEM	p
Total						Sand dropseed					
Removal	HSD	4	875	524	0.82	Removal	HSD	4	218	40	0.32
Removal	CG	4	1095	749		Removal	CG	4	88	114	
						BAI	HSD	4	0.70	0.04	0.70
						BAI	CG	4	0.82	0.27	
Blue grama						Side oats grama					
Removal	HSD	4	332	230	0.48	Removal	HSD	4	6	93	0.86
Removal	CG	4	150	71		Removal	CG	4	-15	67	
BAI	HSD	4	0.69	0.15	0.93	BAI	HSD	4	0.98	0.16	0.53
BAI	CG	4	0.68	0.07		BAI	CG	4	1.11	0.10	
Old world bluestem						Tumble windmill grass					
Removal	HSD	4	-2	188	0.35	Removal	HSD	4	84	87	0.60
Removal	CG	4	476	442		Removal	CG	4	-6	141	
BAI	HSD	4	0.95	0.29	0.84	BAI	HSD	4	0.93	0.12	0.43
BAI	CG	4	1.03	0.27		BAI	CG	4	1.16	0.24	
Perennial threeawn						Tumblegrass					
Removal	HSD	4	113	81	0.83	Removal	HSD	4	49	24	0.11
Removal	CG	4	141	91		Removal	CG	4	213	86	
BAI	HSD	4	1.04	0.56	0.93	BAI	HSD	4	0.48	0.17	0.06
BAI	CG	4	1.15	1.01		BAI	CG	4	0.08	0.06	
Other											
Removal	HSD	4	69.03	62.41	0.77						
Removal	CG	4	47.97	26.72							

Table 2.6 Differences in species composition and BAI_{comp} between continuously grazed (CG) and high stocking density (HSD) treatment groups when grazed during the dormant season from January 12-Feb 13. HSD animals were moved daily with the same mean daily herbage allowance but with mean stocking densities that were ~33x that of the continuously grazed treatment. BAI_{comp} = % composition by weight at the end of the grazing period ÷ % composition by weight at the end of the grazing period. Negative values denote an increase in estimated standing biomass composition.

	trt	n	mean	SEM	p		trt	n	mean	SEM	p
Blue grama						Side oats grama					
Change	HSD	4	0.04	0.04	1.00	Change	HSD	4	-0.04	0.04	0.72
Change	CG	4	0.04	0.03		Change	CG	4	-0.06	0.02	
BAI	HSD	4	0.88	0.14	0.98	BAI	HSD	4	1.26	0.26	0.28
BAI	CG	4	0.89	0.27		BAI	CG	4	2.27	0.82	
Old world bluestem						Tumble windmill grass					
Change	HSD	4	-0.01	0.03	0.51	Change	HSD	4	-0.05	0.02	0.53
Change	CG	4	-0.04	0.04		Change	CG	4	-0.03	0.02	
BAI	HSD	4	1.08	0.20	0.52	BAI	HSD	4	1.23	0.07	0.88
BAI	CG	4	1.32	0.30		BAI	CG	4	1.26	0.16	
Perennial threeawn						Tumblegrass					
Change	HSD	4	0.03	0.02	0.72	Change	HSD	4	0.01	0.00	0.04
Change	CG	4	0.02	0.01		Change	CG	4	0.05	0.02	
BAI	HSD	4	1.39	0.88	0.80	BAI	HSD	4	0.74	0.27	0.09
BAI	CG	4	1.05	0.88		BAI	CG	4	0.09	0.06	
Sand dropseed						Other					
Change	HSD	4	0.01	0.01	0.87	Change	HSD	4	0.02	0.01	0.92
Change	CG	4	0.00	0.01		Change	CG	3	0.01	0.01	
BAI	HSD	4	0.97	0.06	0.47						
BAI	CG	4	0.82	0.19							

Table 2.7 Proportional Utilization Index by species and defoliation severity classification. PUI was developed to compare species defoliation patterns to all defoliation patterns. PUI $=P_{sd}/P_d$ Where; P_{sd} = (count within a defoliation category for a species/count of that species) $\cdot 100$ and P_d = (count of all plants in a defoliation category/total plants observed) $\cdot 100$.

Species	Treatment	Defoliation	PUI	Species	Treatment	Defoliation	PUI
Old World Bluestem	CG	(SEVERE)	0.93	Side Oats Grama	CG	(SEVERE)	0.60
		(MODERATE)	1.34			(MODERATE)	1.25
		(LIGHT)	0.97			(LIGHT)	1.48
		(UNGRAZED)	0.59			(UNGRAZED)	1.27
	HSD	(SEVERE)	1.06		HSD	(SEVERE)	0.87
		(MODERATE)	1.01			(MODERATE)	1.06
		(LIGHT)	1.16			(LIGHT)	1.56
		(UNGRAZED)	0.49			(UNGRAZED)	0.76
Blue grama	CG	(SEVERE)	1.78	Sand dropseed	CG	(SEVERE)	1.59
		(MODERATE)	0.37			(MODERATE)	0.55
		(LIGHT)	0.49			(LIGHT)	0.75
		(UNGRAZED)	0.29			(UNGRAZED)	0.30
	HSD	(SEVERE)	1.20		HSD	(SEVERE)	1.25
		(MODERATE)	0.98			(MODERATE)	0.88
		(LIGHT)	0.74			(LIGHT)	0.80
		(UNGRAZED)	0.43			(UNGRAZED)	0.36
Tumble windmillgrass	CG	(SEVERE)	0.65	Other	CG	(SEVERE)	0.11
		(MODERATE)	0.67			(MODERATE)	0.16
		(LIGHT)	1.56			(LIGHT)	0.20
		(UNGRAZED)	2.16			(UNGRAZED)	*6.20
	HSD	(SEVERE)	0.97		HSD	(SEVERE)	0.10
		(MODERATE)	1.37			(MODERATE)	0.19
		(LIGHT)	1.02			(LIGHT)	0.50
		(UNGRAZED)	0.31			(UNGRAZED)	*7.83

*Values for PUI are significantly different within a treatment ($p<0.05$) than expected value of 1, this indicates similar proportions of plants of that species in each category of defoliation

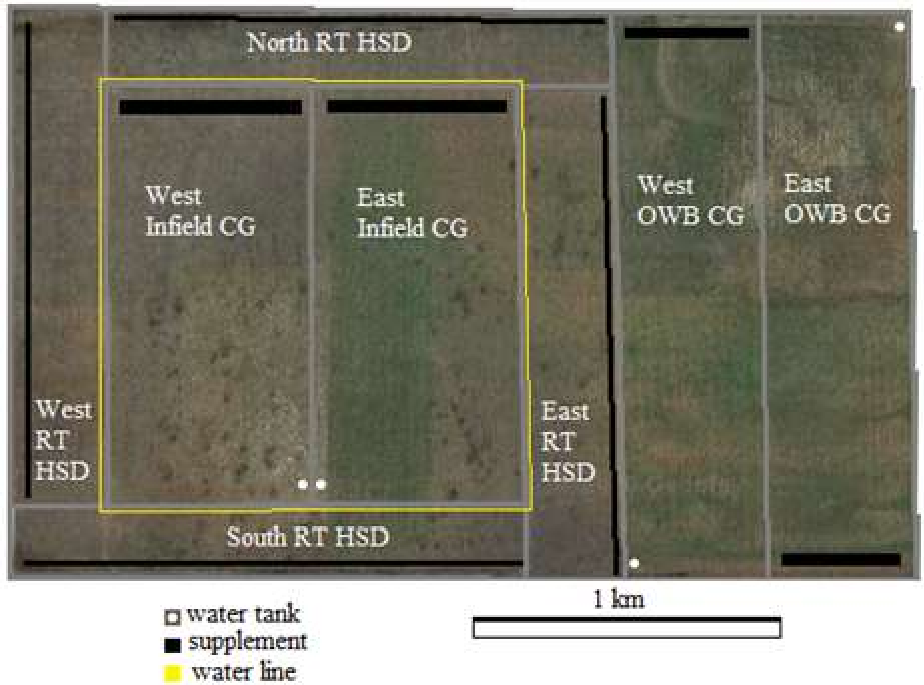

Fig. 2.1 Map of pasture layout with pasture names, water tanks (CG), water line with quick-connect valves (HSD) and supplement location. 2018.

CHAPTER III

GRAZING PATTERNS, DIET QUALITY, AND PERFORMANCE OF COW CALF PAIRS GRAZING GROWING SEASON SHORTGRASS PRAIRIE IN THE TEXAS PANHANDLE USING CONTINUOUS OR HIGH STOCKING DENSITY GRAZING

ABSTRACT

This study 1) measured differences in diet quality using fecal near-infrared reflectance spectroscopy and performance of cow-calf pairs; and 2) quantified and compared vegetation defoliation and regrowth patterns on native rangeland in the Texas Panhandle when cattle were managed using continuous or rotational grazing employing weekly moves at the same stocking rate and stocking intensity. Eighty lactating cow-calf pairs were weighed and assigned to two treatment groups among six native shortgrass-dominated rangeland pastures dominated by blue grama (*Chondrosum gracilis* Willd.), and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). Botanical composition was measured using the dry weight ranked method (DWR) before the study began to measure standing biomass, and after completion of the study in order to measure disappearance by species. Grazing distribution was measured using point transects out to 386 meters from the water tank. Weights of cows and calves and average daily gain were recorded and compared between treatments. Cattle in the CG treatment maintained higher ($p<0.05$) mean dietary DOM and CP levels even though major species (blue grama and gummy lovegrass) had the same TDN and CP levels. Patterns of total defoliation intensity (y intercept of the line predicting probability of defoliation, (β_1) were different ($p<0.05$)

between treatments in periods 1, 5, 6, and 7. Standing biomass of gummy lovegrass was lower ($p<0.05$) at the end of the grazing season in HSD than CG. Standing biomass and composition of cool season annual grasses were lower ($p<0.05$) at the end of the grazing season in CG than HSD. The potential for improving warm season species composition over time and the options for winter grazing may be improved under HSD grazing compared to CG, while maintaining acceptable animal performance if stocking intensity remains at or below that of CG.

INTRODUCTION

Grazing patterns are a result of animal preferences among areas of a landscape and plants (Bailey and Brown, 2011; Galyean and Gunter, 2016). Cattle graze around focal points associated with water (Irving et al. 1995; Roath and Krueger, 1982), thermal comfort and/or areas where plants maintain longer periods of growth (Senft et al. 1985). For example, Irving et al. (1995) observed that within a grazing period, utilization of available forage radiates out from a water tank and did not differ spatially between grazing treatments with different stocking densities and grazing periods at the same stocking rate. Hart et al. (1993) found that drastically reducing pasture size with the same nominal stocking rate improved cow and calf gains because poorer distribution in the large pasture increased the effective stocking rate.

Preferences also change in time and space (Bailey and Provenza, 2008). Senft et al. (1985) found that favored portions of the landscape changed between the growing and dormant seasons. Preference changes occur in time because of plant phenological (Rittenhouse and Roath, 1987) or species compositional changes in the plant community (Bailey and Brown, 2011).

Plant and landscape preferences can affect plant species performance and competitive relationships. Mueggler (1971) tested the effects of both defoliation severity and of competition from neighboring plants. Yield of bluebunch wheatgrass (*Pseudoroegneria spicatum* [Pursh] Á. Löve) clipped to remove 50% of herbage weight just before emergence of seedheads with partial competition (clipping surrounding plants within 90 cm at ground level) was not different from unclipped plants under full competition from unclipped surrounding plants. Yield of extreme clipped plants (removal of 50% of herbage weight and a second clipping to 8-cm stubble height at dough stage) with no competition was also not different from unclipped plants at full competition (Mueggler, 1971). So both the intensity of defoliation on a plant, and the uniformity of defoliation among plants affect total yield and composition of herbage.

However, improved performance of desirable forage species must be balanced with the risk of reduced animal performance. In Zimbabwe (annual precipitaion 60 cm), Barnes and Denny (1991) measured steer gains when grazing 8 paddocks with 5 day grazing periods, 4 paddocks with 10 day grazing periods, and continuous grazing at two stocking rates for each strategy (0.94AU · ha^{-1} · $year^{-1}$ and 0.65AU · ha^{-1} · $year^{-1}$). Steer gains were greatest ($p<0.05$) for continuous grazing at low stocking rates, with no differences among treatments at high stocking rates, though high stocking rates yielded greater gains per ha than low stocking rates. Therefore, an operation trying to optimize production per unit area (Ash and Stafford Smith, 1996) by increasing stocking rate will likely see little difference in livestock performance between grazing strategies if stocking intensity is held constant, though the vegetation outcomes respond favorably to adequate recovery between grazing periods (Earl and Jones, 1996; Jacobo et al, 2006; Peiper et al, 1991); Peterson et al, 2013).

The objectives of this study were to: 1) quantify and compare vegetation defoliation and regrowth patterns on native rangeland; and 2) measure differences in diet quality using fecal near-infrared reflectance spectroscopy and performance of cow-calf pairs in the

Texas Panhandle when cattle were managed using continuous or rotational grazing employing weekly moves at the same stocking rate and stocking intensity.

MATERIALS AND METHODS

Site description

The study was conducted during the 16 week interval from July 10 through October 30, 2019 on the West Texas A&M University Nance Ranch, located 11 km east of Canyon in Randall County, TX from July 10- October 30, 2019. The site has a semi-arid climate, with an average annual precipitation of 49 cm, an average annual high temperature of 21˚ C, and an average low temperature of 6.5˚ C. The site experiences an average frost-free period of 186 days (USDA-NRCS, 2020a). First frost (< 0˚ C) occurs earlier than October 4th one year in ten and earlier than October 21, five years in ten (USDA-NRCS, 2020a). Interannual average daily high is 29.8˚ C, and interannual daily low is 14.6˚ C for the months of July-October, with an average cumulative precipitation for the months of July-October of 22.7 cm. Forty-four percent of plant community growth is expected to occur from July 1 to October 31 (USDA-NRCS, 2020a). Actual precipitation during the trial was 13.1 cm, and the average daily high and low temperatures were 30˚ C ± 0.8˚ C and 15˚ C ± 0.78˚ C, respectively (NOAA, 2020a). Actual precipitation for the 2020 calendar year was 58.2 cm (Table 3.1).

The study site was dominated (95.1% of area) by Deep Hardland ecological sites with 0-5% slopes (USDA-NRCS, 2020b) that had never been cultivated, composed of the Pullman, Olton, and Acuff series (fine, loamy or mixed superactive thermic Aridic or Torrertic Paleustolls) supporting native shortgrass-dominated rangeland communities dominated by blue grama (*Chondrosum gracilis* Willd.), and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). Table 3.2 contains a list of the species encountered on the study site over the course of the study. Other minor soil series in the study area included Lofton clay loam (fine, mixed superactive thermic Vertic Agiustoll) and Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs). The area is in seral state 1.2 (Degraded Shortgrass Community) and has been maintained to graze cow/calf pairs prior to the study since at least the 1950s (USDA-NRCS, 2020b). None of the pastures had been grazed since the previous dormant season.

Infrastructure development

In the context of this study, the word pasture refers to the area in each treatment that the cattle used for the length of the study, while a paddock is a subdivision within a HSD pasture used for a grazing period. Each individual pasture was created by dividing an existing pasture in half with either a single strand of high-tensile electrified wire (Home CG and Home HSD; Mesa CG and Mesa HSD) or a four strand barbwire fence (Foggy CG and Foggy HSD). The size of the pastures (N=6) were as follows: 96.8 ha (Mesa HSD and Mesa CG), 83.4 ha (Foggy HSD and Foggy CG), 51.2 ha (Home HSD and Home CG) (Fig. 3. 1). High tensile electric fencing was erected on at least 1 side of every HSD paddock to carry current from an AC powered 16 joule fence charger. Each HSD pasture (Mesa HSD, Foggy HSD, and Home HSD) was further subdivided into 16 equal sized paddocks as discussed in the section entitled Care and Management (Fig. 3. 2).

The cattle in the CG treatments had *ad libitum* access to fresh water in a permanent water trough as indicated on Fig. 3. 2. Water was supplied to cattle in the HSD treatment *ad libitum* using 25.4 mm high density polyethylene (HDPE) pipe with ball valves located near alternate paddock subdivision fence lines in a HSD grazing cell. The distance from water to the back of each paddock or pasture was no farther than 1180 m and no less than 890 m from a water tank in any treatment. All water tanks were located near (<20m) a permanent fence in each treatment. In HSD water was supplied by 2.4 m diameter galvanized or fiberglass tanks mounted on simple sleds made from 7.3 cm well stem. Floats were wall type and attached to 1.9 cm hoses connected to the ball valves.

Care and management

Following procedures approved by the West Texas A&M University Institutional Animal Care and Use Committee (Proposal #030218), 80 mature (average age; 4.5 years, range 3-10 yrs. of age) cows with an average weight of 579 kg ± 8.5 kg (std. dev.) and their calves weighing 94 kg ± 2.2 kg (std. dev.) were stratified by cow and calf weight and assigned to six treatment groups. There were 3 replicates of a continuously grazed treatment (CG) and 3 replicates of the rotationally grazed treatment assigned to pastures apportioned as previously described. Each cow with her calf was considered an animal unit (AU), and the forage that an animal unit consumed in a day was defined as an animal-unit day (AUD). Forty pairs were allotted to the CG replicates, and 40 pairs to the HSD replicates to achieve a stocking rate of 18.04 AUD $\cdot$ ha^{-1} for each grazing treatment pasture over the 112 day grazing season in each replicate. The stocking intensity of the rotationally grazed paddocks – defined by Gammon (1984) as the forage demand per unit area in a paddock for the length of a grazing period – was also 18.04 AUD $\cdot$ ha^{-1} for each paddock in the HSD treatments, since they were moved consecutively through 16 paddocks in a single herd 1 time over the course of the grazing season. The size of the herd for each replicate of a treatment was different because of the different pasture sizes, but was the same for each pasture with the same name. Stocking density was 16x higher (2.56 AU $\cdot$ ha^{-1}) in the HSD pastures than CG pastures (0.16 AU $\cdot$ ha^{-1}).

The CG cattle entered the CG pastures on July 10 and exited October 30. The HSD cattle were moved into the first paddock in their 16-paddock pastures on July 10 and were removed from the last paddock on October 30. Paddock subdivisions were constructed using a single polypropylene braided twine with 12 stainless steel wires interwoven to conduct electric current (polywire) and suspended on 10mm diameter plastic-coated fiberglass posts to minimize the possibility of shorts. The polywire could then be connected directly to the high tensile wire to provide sufficient power to keep the HSD cattle on the proper side of the fence.

Three polywire fences were used in each HSD replicate. In that way, one was on each side of a paddock where the cattle were grazing between two permanent fences, and one delineated the boundary of the next paddock in the rotation. The HSD cattle were moved to another paddock every seven days.

On the day of a move, a piece of 2.5 cm PVC pipe with a notch in the end was inserted under the wire and stood on its end to raise the polywire so the cattle could move through to the next paddock. The advantage of using the PVC pipe in this way is that stockmen can travel to the cattle and allow them to cross anywhere along the fence, minimizing the trampling that would occur at permanent gates. One stockman was adequate for the first moves with small herds like these. Once the cattle had all moved to the next paddock, the pipe was removed. The back fence was then rolled up, posts pulled, and the former back fence was moved to make the paddock where the cattle would next move. The polywire reels and small diameter posts enabled one person to easily move three groups of cattle and remove and install three fences totaling about 3250 meters, in total, in a day with a small ATV. The sled and tank were moved when the cattle were moved to another paddock.

One bull was allotted to each replicate herd from July 10 – October 14 (17, 18 and 10 cows/bull). The bulls were not weighed before introduction to the study.

Measurements

<u>Defoliation with distance from water</u>

Spatial grazing distribution data were collected at 38 points along four transects within an actively grazed pasture or paddock at intervals of 10 meters up to 0.39 km from the water tanks using a hodometer. These data were collected at 16 day intervals during the 112 day grazing period in CG and the nearest corresponding day of the week in HSD. The plant nearest the lowest point on the left side of the wheel at each 10 meter interval (point) was identified by species. Each point was observed as either grazed (evidence of defoliation) or ungrazed (no evidence of defoliation) to estimate progressive spatial distribution of defoliation at similar points during the grazing period for each treatment – i.e. CG sampling period 1 was 16 days after the grazing period and HSD sampling period 1 was taken in the actively grazed HSD paddocks 24 hours after the cattle were moved into the paddock within a week of CG sampling period 1.

Species standing biomass and composition by weight

At the beginning of the grazing season, (BOGS, July 8), just before the cattle began grazing, the Dry Weight Rank method (DWR) (Mannetje and Haydock, 1963 as revised by Dowhower et al. 2001) was used to estimate the standing biomass and species composition by weight of the plant community in each pasture (20 · $pasture^{-1}$, across two transects 200 ±30 meters from water and 400 ±30 meters from water in Foggy CG, Mesa CG, Home CG, Foggy HSD, Mesa HSD, Home HSD) before grazing began. Briefly, when performing the DWR method, a quadrat frame of sufficient size to have no more than 3 species in the majority of frames is used. In this study, a 0.25 m^2 quadrat frame was appropriate. The quadrat frame is placed randomly, and the observer then determines which three species in the quadrat have the greatest standing herbage, by weight, in the quadrat frame. These species are given rankings of 1, 2, and 3 with 1 having the most biomass and 3 having the least. If > 3 species are found, all other species in the quadrat frame are ignored. If only two species are present in a quadrat, one species is given multiple ranks e.g. 1 and 2, 2 and 3, or 3 and 1. If only one species is present in a quadrat, all three rankings are assigned to the one species and the composition of that plant is estimated as 100% composition. A rank of 1 corresponds to 70% composition by weight, rank 2 is 20% while rank 3 is 10%. If 2 rankings are assigned to one species, the values associated with those rankings are added.

After ranking, all standing herbage in the quadrat was clipped to ground level, placed in a bag, dried at 60˚ C for 24 hours and weighed. The mean of the ranked composition of all quadrats in a treatment was calculated for each treatment and the standing biomass was compared between treatments. The mean composition or weight of 20 quadrats within a treatment replicate was recorded as one DWR observation. A student t-test for differences in standing biomass between treatments revealed no difference ($p>0.05$) between treatments (Table 3.3).

DWR measurements were taken again after a killing frost as soon as possible after cattle had been removed at the end of the grazing season (EOGS) in CG (20 pasture^{-1}, across two transects 200 ±30 meters from water and 400 ±30 meters from water) and in HSD paddocks 1, 4, 8, and 12 (20 paddock^{-1}, across two transects 200 ±30 meters from water and 400 ±30 meters from water). In HSD paddocks were sampled more intensely in order to stratify DWR sampling by recovery period (52.5 days ± 52.5). Standing herbage refers to dry (dried at 60 °C for 24 hours) weight of herbage.

F.NIR

A fresh composite fecal sample (approximately 0.5 liter) from three cows was collected in each replicate of both treatments on Fridays (Day 3 of HSD paddock grazing period) of weeks 3, 6, 9, 12, and 16. The following Tuesday (HSD paddock grazing day 7) composite samples were collected in only the HSD paddocks in the same way. The samples were then sent to the Grazing Animal Nutrition lab (GANlab, 720 East Blackland Rd., Temple, TX, 76502) to be analyzed for dietary CP, and DOM using near-infrared reflectance spectroscopy.

Forage quality

Composite, whole-plant forage samples of primary forage species consumed by cattle, no fewer than four individual plants of the same species per actively-grazed paddock or pasture, were clipped at ground level (blue grama, gummy lovegrass, 1 composite sample of each species, n = 3 pastures · trt^{-1} · $species^{-1}$ · sampling $period^{-1}$) over six sampling periods 28 days apart, total; 3 pastures · trt^{-1} · $species^{-1}$ · sampling $period^{-1}$ · actively grazed pasture or $paddock^{-1}$ over two sampling periods 28 days and 56 days from the conclusion of the study). Little barley was also clipped at ground level and analyzed for forage quality (56 days and 28 days before the conclusion of the study) in only HSD (n= 3 rested paddocks) because there was inadequate sampling material in the actively grazed areas. Samples were then analyzed for CP and Total Digestible Nutrients (TDN) at Servitech Laboratory (6921 Bell St. Amarillo, TX, 79109).

Cattle performance

Cows and calves were weighed individually in a squeeze chute June 25 (BOGS) and November 1 (EOGS). Weight gained and average daily gain (ADG; weight gain ÷ 129 days) were calculated. Weights were collected 17 days before the grazing period in order to stratify treatments by cow and calf weight. Cow weight refers to the mean weight of a cow within a given pasture on each of those sampling dates. Calf weight refers to the mean weight of a calf within a given pasture. Pair weight refers to the sum of cow weight and calf weight within a given pasture. All cows were pregnancy checked November 1 and reported as either pregnant or open (not pregnant). Additionally, live animal ultrasound measurements recorded were: four independent images collected laterally across the 12th and 13th ribs to estimate percentage intramuscular fat within the *longissimus dorsi* muscle (marbling), a cross-sectional image taken between the 12th and 13th ribs to obtain and *longissimus dorsi* depth (ribeye depth) and subcutaneous fat thickness (backfat), and a longitudinal image taken between the hook and pin bones perpendicular to the shaft of the ileum to measure subcutaneous fat depth at the intersection of the biceps femoris and gluteus medias muscles (rump fat).

Analysis

All data was analyzed using SAS 9.4 (SAS Institute, 2019) .

Defoliation with distance from water

For each distance from water, the probability of defoliation was calculated as observed bitten plants ÷ number of observations at that distance within a pasture. Linear regression was then used to calculate the probability that a plant would be defoliated as distance from water increased. The slopes ($ß_1$) and y intercepts ($ß_0$) of the mean of these lines by treatment were compared across treatments on a given sampling period using t-tests.

Species standing biomass and composition by weight

Student t-tests were used to compare BOGS and EOGS standing biomass and percent composition by weight of functional groups (C3 annual forbs, C3 annual grasses, C4 perennial grasses and C4 annual forbs), and for blue grama and gummy lovegrass (separately from functional groups) between treatments (HSD and CG).

F.NIR

Student t-tests were used to compare grazing season mean DOM, and grazing season mean CP between HSD and CG treatments.

Forage quality

Student t-tests were used to compare grazing season TDN, and grazing season CP by species between HSD and CG treatments.

Cattle performance

Student t-tests were used to compare CG and HSD treatments for beginning and ending cow weights, calf weights, pair weights, cow ADG, calf ADG, and pair ADG, and pregnancy rates. Student t-tests were also used to compare CG and HSD treatments for marbling, ribeye depth, back fat, and rump fat.

RESULTS

The slope of the line depicting the probability of a plant being bitten with increasing distance from water ($ß_{1)}$ was not significantly different ($p \geq 0.05$) between treatments during any grazing period sampled (Table 3.3). However, the Y intercept for the line ($ß_0$) was significantly different between treatments during some sampling periods, being higher ($p<0.05$) early in the grazing season for the CG treatment in period 1, but was higher ($p<0.05$) in HSD than CG toward the end of the grazing season for periods 5, 6, and 7 (Table 3.4).

Standing biomass was not different ($p>0.05$) between treatments at BOGS, but at EOGS, total standing biomass in HSD was lower ($p<0.05$) than CG (Table 3.5) Standing biomass ($kg \cdot ha^{-1}$) and composition by weight of selected species (blue grama and gummy lovegrass), functional groups, and total standing biomass ($kg \cdot ha^{-1}$) were not significantly different ($p>0.05$) between treatments at the beginning of the grazing season (Table 3.6-3.7). Cool season annual grass standing biomass and composition by weight was greater, while warm season perennial grass and gummy lovegrass standing crops were lower ($P<0.05$) in HSD than CG at EOGS (Table 3.6).

Mean F.NIR estimates of both CP and DOM were higher ($p<0.05$) in CG than HSD (Table 3.8) while forage quality was not different for blue grama and gummy lovegrass, Table 3.9). However, higher diet quality did not translate to greater ($p>0.05$) gain or ADG for the cows, calves or pairs in CG compared to HSD treatments (Table 3.10). Increased dietary DOM and CP also did not translate to significantly greater ($p>0.05$) subcutaneous fat, intramuscular fat or ribeye depth at any measured location (Table 3.11), nor did pregnancy rates differ significantly ($p>0.05$) between treatments (Table 3.9).

DISCUSSION

This study indicated that the probability of defoliation decreases at a similar rate with distance from water in either grazing strategy i.e. the slope of the line (β_1) is not different ($p>0.05$) between treatments for any period. A consistently negative slope (fewer plants are likely to be defoliated as distance from water increases) corroborates the findings of Irving et al. (1995) and Hart et al. (1993) as the slope measures the observed grazing in waves radiating from the tank. It also demonstrates that, regardless of grazing strategy, these patterns are the same i.e. cattle are more likely to defoliate plants that are nearer the water tank.

The more intense (β_0 is greater, $p<0.05$) total defoliation (period 1) observed in CG compared to HSD were overcome and then surpassed by the end of the study i.e. the cattle in HSD had more intense (β_0 is greater, $p<0.05$) defoliation patterns toward the end of the grazing period (periods 5 through 7) in the HSD compared to CG. The greater intensity, but with similar decreases in defoliation probability with distance from water is also corroborated by the lower ($p<0.05$) total standing biomass and composition of gummy lovegrass at the end of the growing season in HSD compared to CG, and may indicate less expression of selectivity in the HSD.

However, it is unclear how defoliation patterns and intensity of defoliation are confounded by the difference in geometry between the paddocks in the HSD and CG treatments. Because of the long, narrow configuration of the HSD paddocks, more area (and biomass) is within a given distance of water in the CG. In the long, narrow HSD paddocks (Fig. 2.2), consuming the same amount of plant material would necessitate grazing further out from the water point, possibly explaining the higher Y intercept seen for the HSD paddocks later in the season. As observations in HSD approach 0 meters from water, there are progressively fewer plants available to bite as a result of pasture geometry (a hypothetical continuous transect at a given distance from water is longer as distance increases in CG treatments). In HSD pastures, where paddocks were long and narrow (Fig. 2.2), the opportunity to graze different plants does not change once the distance from water reaches a critical point (a hypothetical continuous transect at that distance from water intersects both polywire fences).

After practical observation and management experience Peterson et al. (2013) hypothesized that reduced expression of selective grazing in rotational grazing schemes is not a result of 'starving' cattle to eat less palatable plants but rather a result of "developing either a taste, or a need" (Peterson et al. 2013) for plants that are typically considered less palatable.

The increased expression of selectivity among CG cattle may have contributed to greater composition of gummy lovegrass compared to the HSD treatment. Decreased weight and composition of cool season annual grasses in CG compared to HSD at EOGS may also be a result of greater ability to select the cool season grasses for the CG cattle coupled with the increased opportunity for these grasses to germinate, establish and grow in pastures that were recovering from previous grazing periods in the HSD treatments. The high quality of little barley for instance (CP = 15.05 ± 0.57, TDN = 63.88 ± 1.37) likely made cool season grasses like little barley more desirable by grazing cattle when they began to produce until the study ended (Villalba and Provenza, 2009). But the biomass was likely so small that they quickly exhausted all that was available, decreasing standing crop to such an extent that there was insufficient availability for a forage sample in any sampling period late in the season.

Because of the increased cool season plant standing biomass, HSD has more potential for higher quality forage production than the CG during middle and late stages of pregnancy and calving (December 1- March 15 and March 15-April 30 in the context of this production system), because actively growing cool season plants would be established going into winter, and could then be rationed out with the smaller paddocks grazed rotationally throughout the winter if the HSD strategy was continued.

The higher composition of warm season annual forbs in HSD compared to CG can be explained two ways, either or both of which may be in effect. One explanation is that the cattle in CG were allowed to consume warm season forbs as they grew and maintained a phenologically younger stand (Rittenhouse and Roath, 1987) that had a greater concentration of cell solubles (Blank et al. 2011), thereby maintaining a smaller (by weight per unit area) stand of warm season forbs that were more palatable and nutritious while suppressing their recruitment and growth. Another explanation is that the lower ($p<0.05$) composition of warm season perennials, particularly gummy lovegrass, in HSD compared to CG may have led to the change in composition, i.e. the standing biomass of forbs was not different, but the effect of decreased standing biomass differences for both total standing biomass and warm season perennials (CG is greater than HSD at EOGS) made the percentage composed of forbs significantly higher.

Reporting pregnancy rates for this study was appropriate, since the majority of the breeding season occurred during the study period. However, management before the trial may have contributed to the acceptable pregnancy rate in both treatments (>90%) if most calves were conceived during the period when they were managed as one herd.

The consistently higher arithmetic values for all CG performance measures should not be automatically dismissed, despite the lack of statistical significance, because of small sample size (n=3 per treatment) and the fact that the study did not span a full growing season. The general improvement in performance for the CG cattle may be a result of selective grazing during the growing season on warm season grass regrowth, and cool season annual grasses late in the season. The lower standing biomass at the end of the grazing season for both categories of these grasses, despite similar standing biomass at the beginning of the study between treatments provides corroboration for such an explanation. A longer study over at least an entire growing season might provide greater differences in performance, if the trends in diet quality seen in this study held true over the longer time span.

Warm season perennial grass and gummy lovegrass biomass were lower at EOGS in the HSD treatment than in the CG treatment. However, there was no significant difference in standing biomass between treatments at the end of the study for the other major warm season perennial grass, blue grama, considered to be a very palatable and nutritious species. While gummy lovegrass is considered an unpalatable plant, the lower standing biomass in HSD compared to CG, despite similar standing biomass at the beginning of the study indicates some form of mechanical removal, whether from consumption or trampling. The reduction may lead to decreased competition for other species and affect the species composition of actively growing warm season plants in years to come (Mueggler, 1971; Stephenson et al. 2015). Additionally, it may lead to production of gummy lovegrass that is maintained in a phenologically less mature, and therefore, more digestible stage of growth (Rittenhouse and Roath, 1987). But the process outlined in the previous sentence must be initiated by removal of mature gummy lovegrass. Reducing the expression of selectivity may have modified acceptability of gummy lovegrass – i.e. management improved relative palatability and the cattle 'learned' that gummy lovegrass was acceptable feed (Provenza et al. 2015). The subsequent value of each of these effects is potentially positive with regard to forage quality and quantity on the site, but further long-term research is needed to record composition changes and diet quality following extended use of different grazing treatments.

CONCLUSIONS AND IMPLICATIONS

Knowing how animals use landscapes and plants in relation to focal points like water allows producers to use cattle as landscape management tools. Defoliation patterns change in similar ways with distance from water between different grazing strategies, and differences in defoliation intensity relative to distance from water may have been due to differences in expression of selectivity, or possibly associated with paddock configuration.

Knowing ways to manage animal distribution, temporally and spatially to improve landscapes without detrimental effects on livestock production allows producers to evaluate management strategies in light of labor and financial constraints, as well as potential benefits regarding risk management, business resilience, and resource improvement. Managers can then implement a strategy that best suits their landscape goals while maintaining or improving productivity and profitability.

Further research at different spatial and temporal scales that more precisely illuminate mechanisms driving landscape use by animals is needed. Different pasture configurations should be designed and compared to develop principles of paddock and pasture design that optimize livestock distribution, grazing behavior, and performance to achieve landscape goals in semi-arid environments.

Table 3.1 High and low temperatures and precipitation, by month, for the study period NOAA, 2020a

Month	Average max (℃)	Average min (℃)	Actual precipitation (cm)
July	35	19	1.9
August	36	20	1.11
September	32	17	3.03
October	18	3	6.06
Season	30	15	12.1

Table 3.2 Species found in the study area classified into functional groups

Warm season perennial	Warm season annual
Grasses	
Blue grama *Chondrosum gracilis* Willd.	
Gummy lovegrass *Eragrostis curtipedicellata* Buckley	
Sand dropseed *Sporobolus cryptandrus* Hitchc	
Perennial threeawn *Aristida purpurea* Nutt.	
Vine mesquite *Hopi obtusa* Kunth	
Forbs	
Fringed sagewort *Artemisia frigida* Willd.	Marestail *Conyza Canadensis* L.
Silverleaf nightshade *Solanum elaeagnofolium* Cav.	Annual buckwheat *Eriogonum anuum* Nutt.
Yellowspine thistle *Cirsium ochrecentrum* Gray	Russian thistle *Salsola iberica* Sennen & Pau.
Cool season perennial	**Cool season annual**
Grasses	
Western wheatgrass *Pascopyrum smithii* Kunth.	Little barley *Critesian pusillum* [Nutt.] Á. Löve
	Cheatgrass *Anisantha tectorum* L.
Forbs	
	Filaree *Erodium cicutarium* L.
	Tallow weed *Plantago patagonica* Jacq.
	Yellow salsify *Tragapogon dubieus*

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Table 3.3 Results of t-tests comparing the slope (β_1) of regression lines predicting the probability of plants being grazed as distance from a water point increases between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis* Willd.) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment.

trt	mean	SEM	p	trt	mean	SEM	p
period 1				period 2			
CG	-0.2492	0.2473	0.42	CG	-0.0026	9.00E-05	0.06
HSD	-0.001	0.000186		HSD	-0.0022	9.00E-05	
period 3				period 4			
CG	-0.0021	0.000551	0.33	CG	-0.0014	0.0002	0.33
HSD	-0.0014	0.0003		HSD	-0.001	0.0002	
period 5				period 6			
CG	-0.0006	0.00047	0.81	CG	-0.0026	0.0022	0.43
HSD	-0.0007	0.0002		HSD	-0.0004	0.0003	
period 7							
CG	0.0003	0.000265	0.22				
HSD	-0.0002	0.000186					

Table 3.4 Results of t-tests comparing the Y intercept (β_0) of regression lines predicting the probability of plants being grazed as distance from a water point increases between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis*) and gummy lovegrass (*Eragrostis curtipendicillata*). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment.

	trt	mean	SEM	p		trt	mean	SEM	p
period 1					period 2				
	CG	0.8995	0.0326	0.01		CG	1.1433	0.00311	0.11
	HSD	0.6349	0.0538			HSD	1.0228	0.0442	
period 3					period 4				
	CG	1.0882	0.0692	0.19		CG	1.0460	0.0285	0.18
	HSD	0.9663	0.0332			HSD	0.9944	0.0134	
period 5					period 6				
	CG	0.7359	0.079	0.05		CG	0.7164	0.00434	<0.01
	HSD	0.9840	0.0429			HSD	0.9391	0.0214	
period 7									
	CG	0.6724	0.0459	0.01					
	HSD	0.9678	0.0731						

Table 3.5 Differences in total standing biomass at the beginning of the grazing season (July 10) and at the end of the grazing season (October 30) between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis*) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment.

		trt	n	Mean	SEM	P
TOTAL						
	BOGS	CG	3	1771	49	0.56
	BOGS	HSD	3	1846	110	
	EOGS	CG	3	1430	157	0.05
	EOGS	HSD	12	1077	73	

Table 3.6 Results of t-tests comparing the standing biomass of selected species and functional groups at the beginning (BOGS) and end (EOGS) of the grazing season between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis*) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment.

	trt	n	Mean	SEM	p		trt	n	Mean	SEM	p
Blue Grama						Gummy lovegrass					
BOGS	CG	3	745	165	0.67	BOGS	CG	3	417	132	*0.94
BOGS	HSD	3	649	127		BOGS	HSD	3	375	36	
EOGS	CG	3	738	61	0.24	EOGS	CG	3	475	152	0.02
EOGS	HSD	12	607	50		EOGS	HSD	12	167	43	
Warm Season perennial grasses						Warm season perennial forbs					
BOGS	CG	3	1215	22	0.78	BOGS	CG	3	67	14	0.15
BOGS	HSD	3	1255	134		BOGS	HSD	3	145	41	
EOGS	CG	3	1231	131	0.01	EOGS	CG	3	69	33	0.08
EOGS	HSD	12	802	57		EOGS	HSD	12	23	10	
Cool season perennial grasses						Warm season annual forbs					
BOGS	CG	3	0	0	0.19	BOGS	CG	3	414	119	0.56
BOGS	HSD	3	51	26		BOGS	HSD	3	316	97	
EOGS	CG	3	0	0	0.06	EOGS	CG	3	24	5	0.09
EOGS	HSD	12	10	5		EOGS	HSD	12	65	22	
Cool season annual grasses						Cool season annual forbs					
BOGS	CG	3	0	0	0.32	BOGS	CG	3	74	45	0.93
BOGS	HSD	3	10	8		BOGS	HSD	3	69	35	
EOGS	CG	3	0	0	<0.01	EOGS	CG	3	107	20	0.35
EOGS	HSD	12	100	22		EOGS	HSD	12	77	14	

* variable was squared transformed to fit normal distribution and then transformed back to report means

Table 3.7 Results of t-tests comparing the composition by weight of dominant species and functional groups at the beginning (BOGS) and end (EOGS) of the grazing season between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis* Willd.) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment.

	trt	n	Mean	SEM	p		trt	n	Mean	SEM	p
Blue grama						Gummy lovegrass					
BOGS	CG	3	0.43	0.11	0.57	BOGS	CG	3	0.23	0.0708	[1]0.91
BOGS	HSD	3	0.35	0.06		BOGS	HSD	3	0.21	0.0025	
EOGS	CG	3	0.53	0.0613	0.57	EOGS	CG	3	0.32	0.0725	[2]0.91
EOGS	HSD	12	0.56	0.0261		EOGS	HSD	12	0.16	0.0361	
Warm Season perennial grasses						Warm season perennial forbs					
BOGS	CG	3	0.69	0.0296	0.73	BOGS	CG	3	0.04	0.0088	0.2
BOGS	HSD	3	0.67	0.0388		BOGS	HSD	3	0.08	0.026	
EOGS	CG	3	0.86	0.0186	0.02	EOGS	CG	3	0.05	0.0213	0.1
EOGS	HSD	12	0.74	0.0225		EOGS	HSD	12	0.02	0.007	
Cool season perennial grasses						Warm season annual forbs					
BOGS	CG	3	0	0	0.18	BOGS	CG	3	0.23	0.0608	0.46
BOGS	HSD	3	0.03	0.0636		BOGS	HSD	3	0.17	0.0467	
EOGS	CG	3	0	0	0	EOGS	CG	3	0.02	0.0017	0.03
EOGS	HSD	12	0.01	0.0057		EOGS	HSD	12	0.06	0.0164	
Cool season annual grasses						Cool season annual forbs					
BOGS	CG	3	0	0	0.3	BOGS	CG	3	0.04	0.0268	0.93
BOGS	HSD	3	0.01	0.0064		BOGS	HSD	3	0.05	0.0235	
EOGS	CG	3	0	0	0.03	EOGS	CG	3	0.07	0.006	0.92
EOGS	HSD	12	0.09	0.0142		EOGS	HSD	12	0.07	0.0118	

[1] variable was square transformed to fit normal distribution
[2] variable was square root transformed to fit normal distribution.

Table 3.8 Results of t-tests comparing differences in mean fecal near-infrared reflectance spectroscopy estimates of digestible organic matter (DOM) and crude protein CP between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis* Willd.) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment. Samples were collected in weeks 3, 6, 9, 12, 16 during the study period from July 10 to October 30, 2019.

	treatment	n	Mean	SEM	p
DOM					
	CG	15	62.16	0.37	*0.05
	HSD	30	61.27	0.25	
CP					
	CG	15	8.07	0.20	0.01
	HSD	30	7.37	0.14	

* variable was squared to fit normal distribution

Table 3.9 Results of t-tests comparing average quality of primary forage grasses over the course of a 16 week grazing season (July10-Oct 0) between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe. HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment. Blue grama and gummy lovegrass was taken at 28 day intervals throughout the growing season. Little Barley samples were taken 56 days before the end of the grazing season and 28 days before the end of the grazing season. Summary statistics of HSD are shown due to inadequate sampling material in CG.

	treatment	n	Mean	SEM	p
Blue grama (*Chondrosum gracilis* Willd.)					
TDN					
	CG	12	50.25	0.60	0.57
	HSD	12	49.65	0.84	
CP					
	CG	12	8.71	0.51	0.63
	HSD	12	8.38	0.42	
Gummy lovegrass (*Eragrostis curtipedicellata* Buckley)					
TDN					
	CG	12	51.08	0.91	0.28
	HSD	12	49.80	0.71	
CP					
	CG	12	7.41	0.34	0.96
	HSD	12	7.43	0.31	
*Little Barley (*Critesian pusillum* [Nutt.] Á. Löve)					
TDN					
	HSD	6	63.88	1.37	
CP					
	HSD	6	15.05	0.52	

*summary statistic of HSD are shown due to inadequate sampling material available in CG

Table 3.10 Results of t-tests comparing mean cow and calf performance by treatment between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis* Willd.) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment. Weights were taken 17 days days before introduction to grazing treatments (June 25) and again one day after the end of the grazing season. (October 31). Average daily gains are based on those weights. Pregnancy detection was done using ultrasound on October 31.

	treatment	Mean	SEM	p
Cow				
gain (kg)	CG	45	16	0.69
gain (kg)	HSD	38	3	
ADG ($kg \cdot d^{-1}$)	CG	0.35	0.13	0.69
ADG ($kg \cdot d^{-1}$)	HSD	0.30	0.03	
Calf				
gain (kg)	CG	166	8	0.27
gain (kg)	HSD	156	2	
ADG ($kg \cdot d^{-1}$)	CG	1.30	0.1	0.26
ADG ($kg \cdot d^{-1}$)	HSD	1.22	0.01	
Pair				
gain (kg)	CG	210	25	0.58
gain (kg)	HSD	194	4	
ADG (kg)	CG	1.64	0.2	0.58
ADG (kg)	HSD	1.52	0.03	
Pregnancy rate (%)				
	CG	0.98	0.02	0.40
	HSD	0.94	0.04	

Table 3.11 Results of t-tests comparing cattle body composition parameters between continuously grazed (CG) and high stocking density (HSD) treatments on shortgrass steppe dominated by blue grama (*Chondrosum gracilis* Willd.) and gummy lovegrass (*Eragrostis curtipedicellata* Buckley). HSD treatments were moved weekly with the same stocking rate and stocking intensity as the CG treatment, but with mean stocking densities that were ~16X that of the CG treatment. Marbling, rib eye depth, and backfat were measured between the 12th and 13th rib of mature cows measured. Rump fat was measured over the gluteus muscle on the rump, at the intersection of a line through the pin bone parallel to the chine and its perpendicular through the third sacral crest.

Marbling	trt	Mean	SEM	p
% composition	CG	7.71	0.26	0.88
% composition	HSD	7.79	0.35	
Rib eye depth				
cm	CG	6.14	0.13	0.06
cm	HSD	5.69	0.11	
Backfat				
cm	CG	0.66	0.12	0.43
cm	HSD	0.52	0.10	
Rumpfat				
cm	CG	1.06	0.18	0.49
cm	HSD	0.87	0.19	

Ultrasound was used to estimate all parameters.

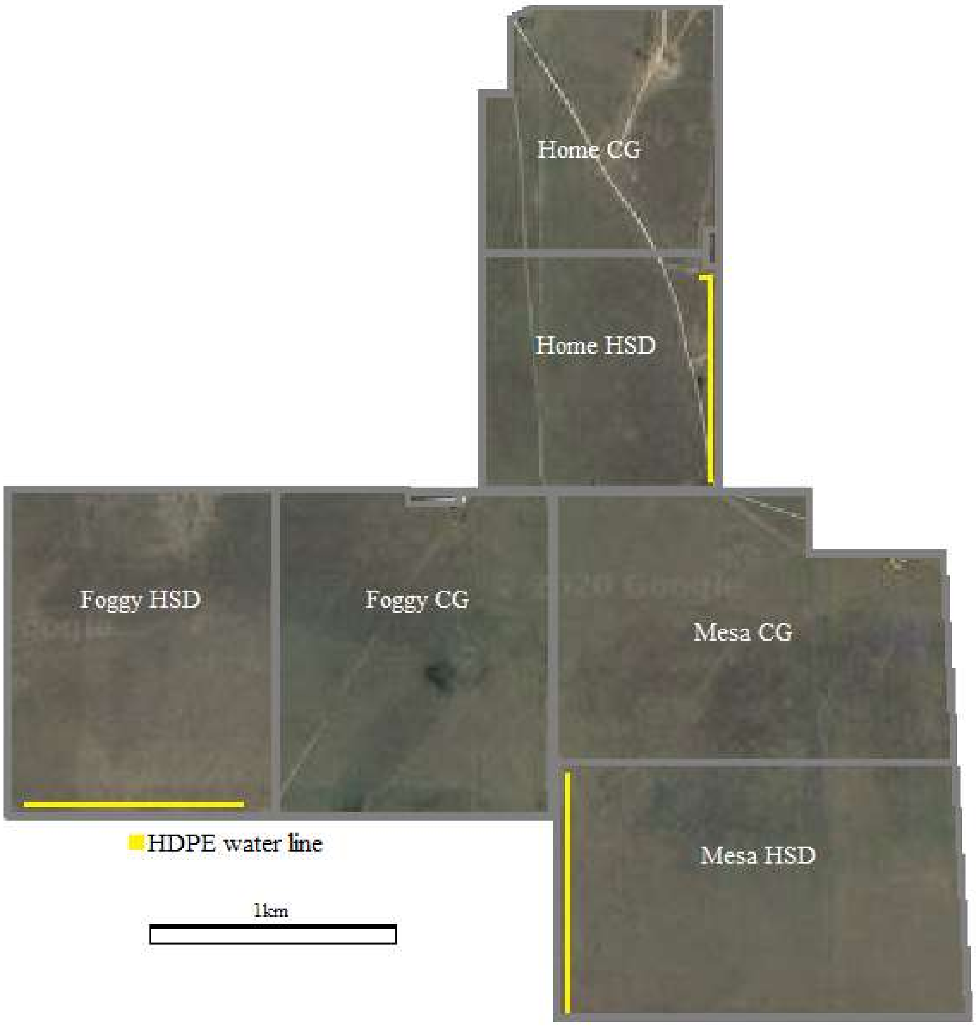

Fig. 3.1 Pasture names and layout with above ground HDPE water line locations 2019.

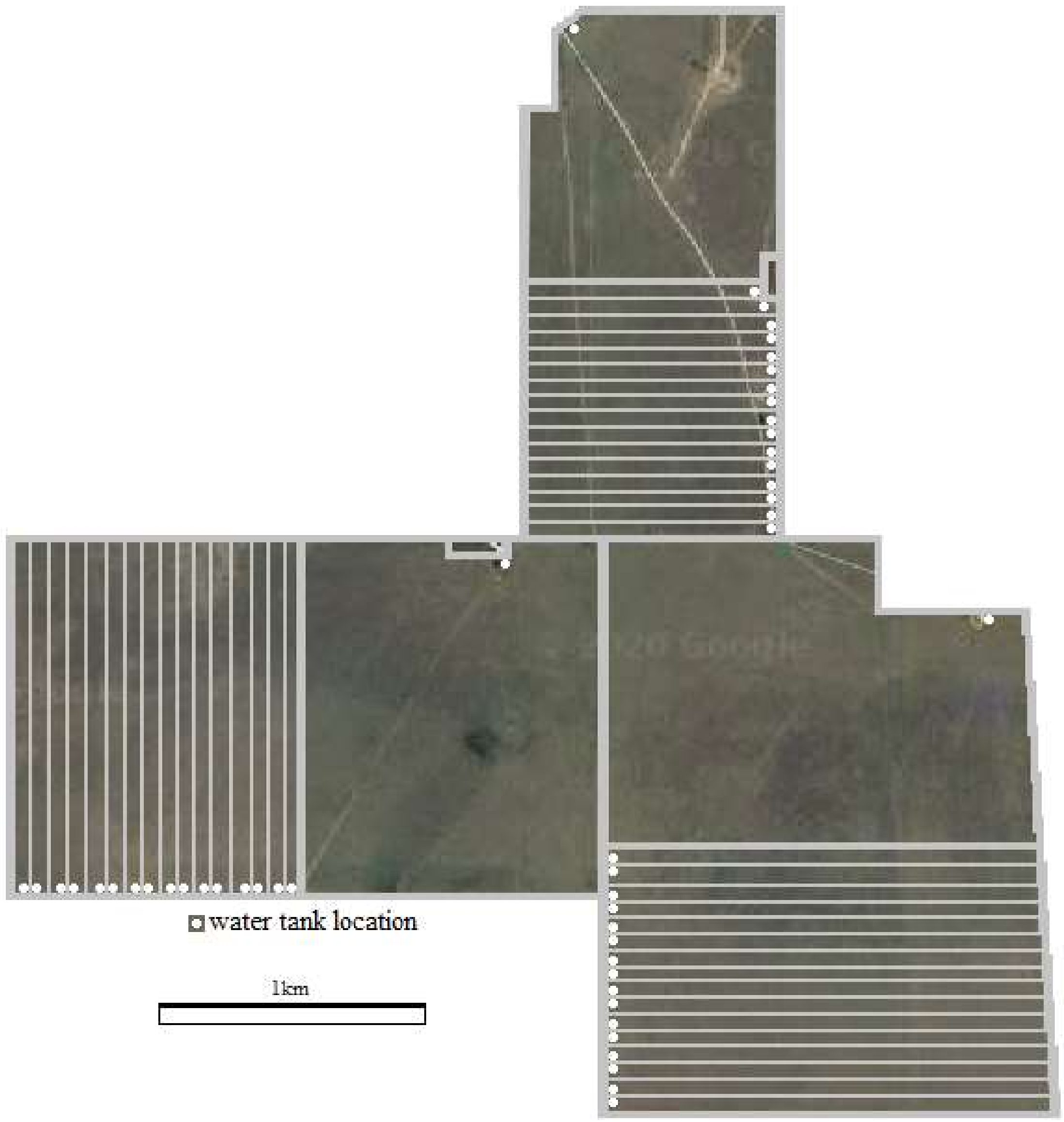

Fig. 3.2 Water tank locations (HSD and CG) and pasture subdivisions (HSD) 2019.

CHAPER IV

CONCLUSIONS AND IMPLICATIONS

The observations in each study indicate that cattle behavior exerts an influence on their landscape use and biomass composition, and that the expression of behaviors can affect dietary intake. Both experiments dealt directly with defoliation patterns between continuous grazing and high stocking density grazing strategies. Additionally, the patterns in defoliation intensity, standing biomass, and species composition explain differences and similarities in estimated diet quality, forage quality, and livestock performance measured in the second study. This study also provides information that livestock and landscape managers may use in their decision making process. The expression of livestock selectivity as a product of management strategy likely led to the differences and similarities we see between treatments in both studies. Further research is needed to quantify behavior at different temporal and spatial scales and the effects of paddock configurations on grazing behavior that may be deleterious or beneficial to animal performance and plant communities.

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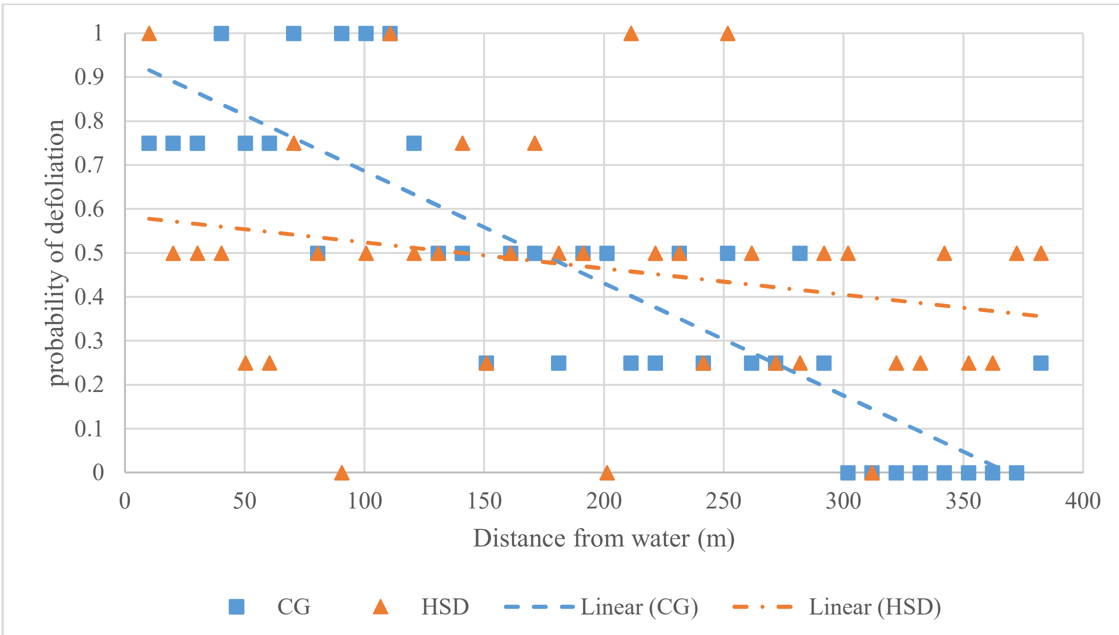
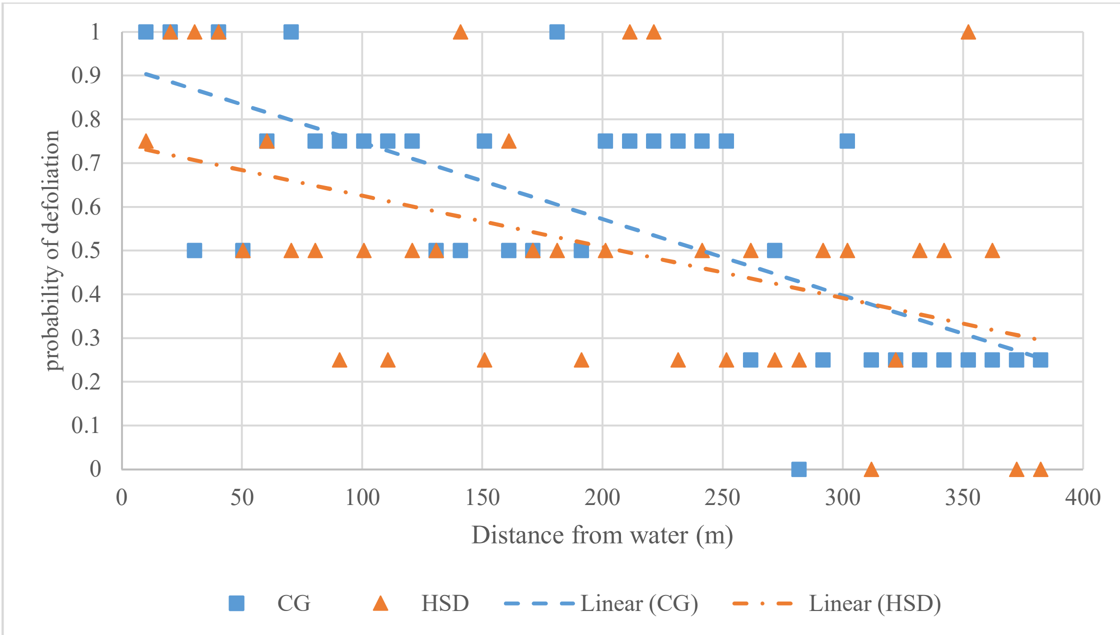
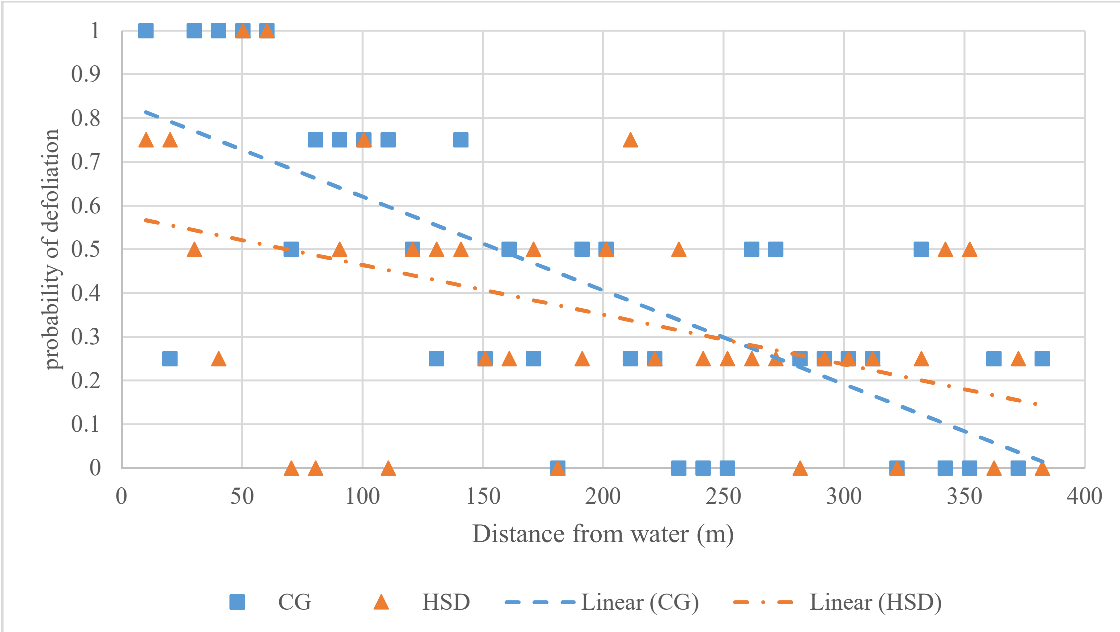
APPENDIX



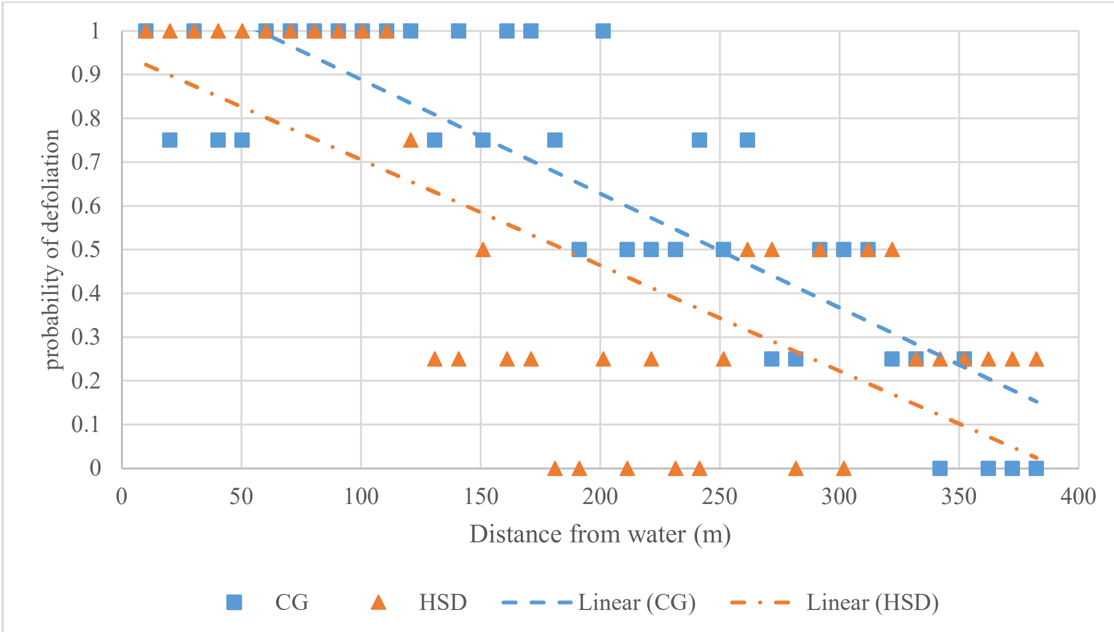
Appendix Fig. a.1 Regression analysis for Foggy period 1 HSD: $\beta_1 = -0.0006$, $\beta_0 = 0.5839$, $r^2 = 0.065$ CG: $\beta_1 = -0.0026$ $\beta_0 = 0.9417$, $r^2 = 0.7437$.



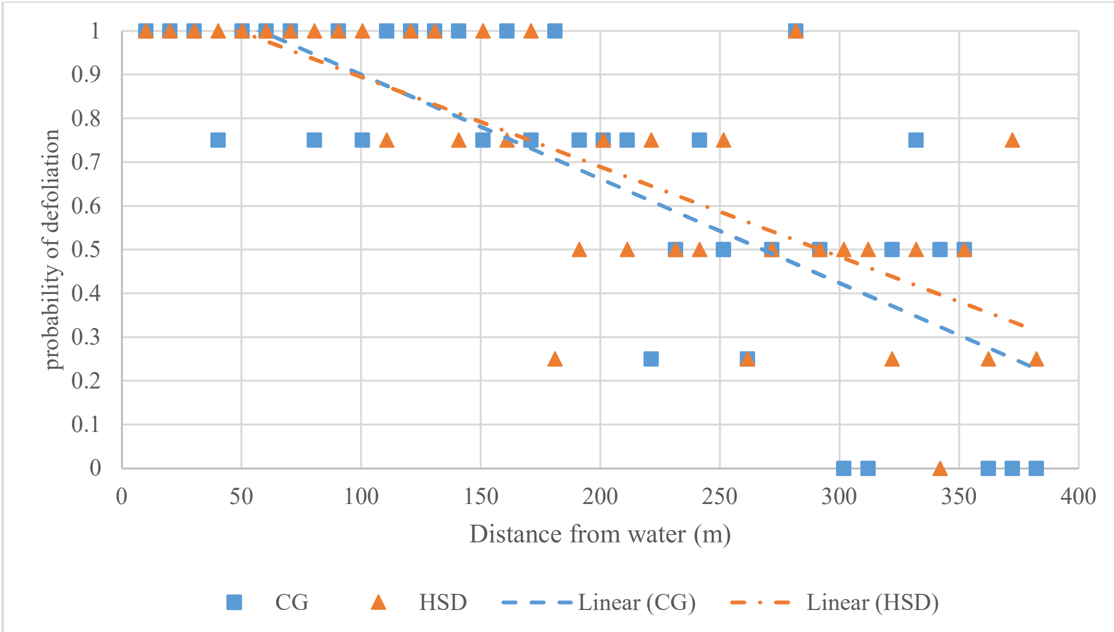
Appendix Fig. a.2 Regression analysis for Home period 1 HSD: $ß_1$ = -0.0017, $ß_0$ = 0.9214, r^2 = 0.5101 CG: $ß_1$ = -0.0012 $ß_0$ = 0.7425, r^2 = 0.1949.



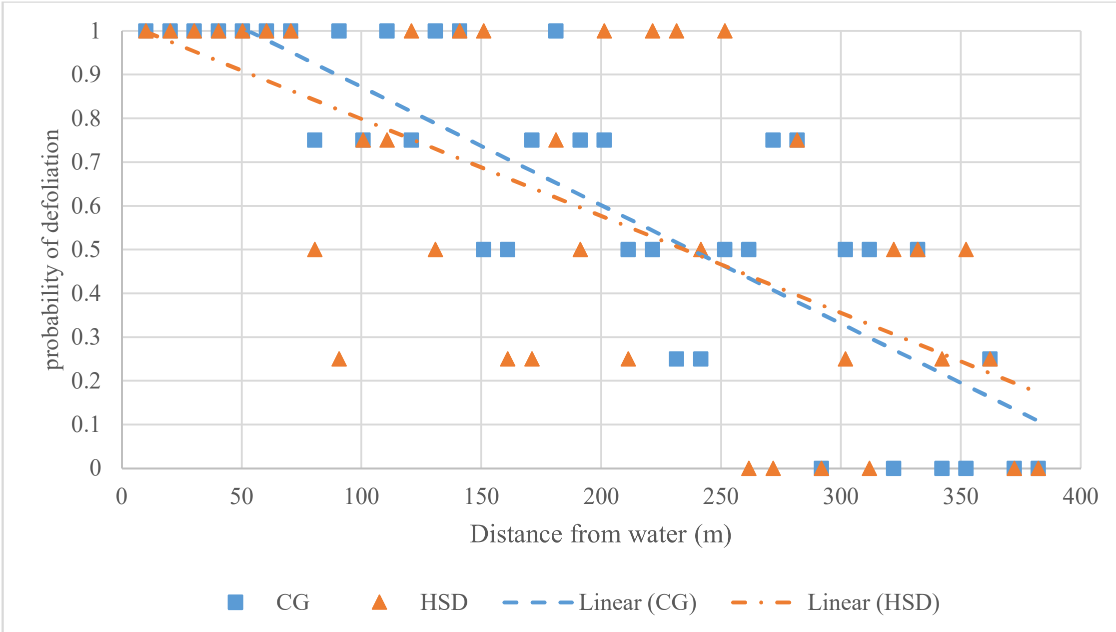
Appendix Fig. a.3 Regression analysis for Mesa period 1 HSD: $ß_1$ = -0.0021, $ß_0$ = 0.8353, r^2 = 0.5276 CG: $ß_1$ = -0.0011 $ß_0$ = 0.5782, r^2 = 0.2112.



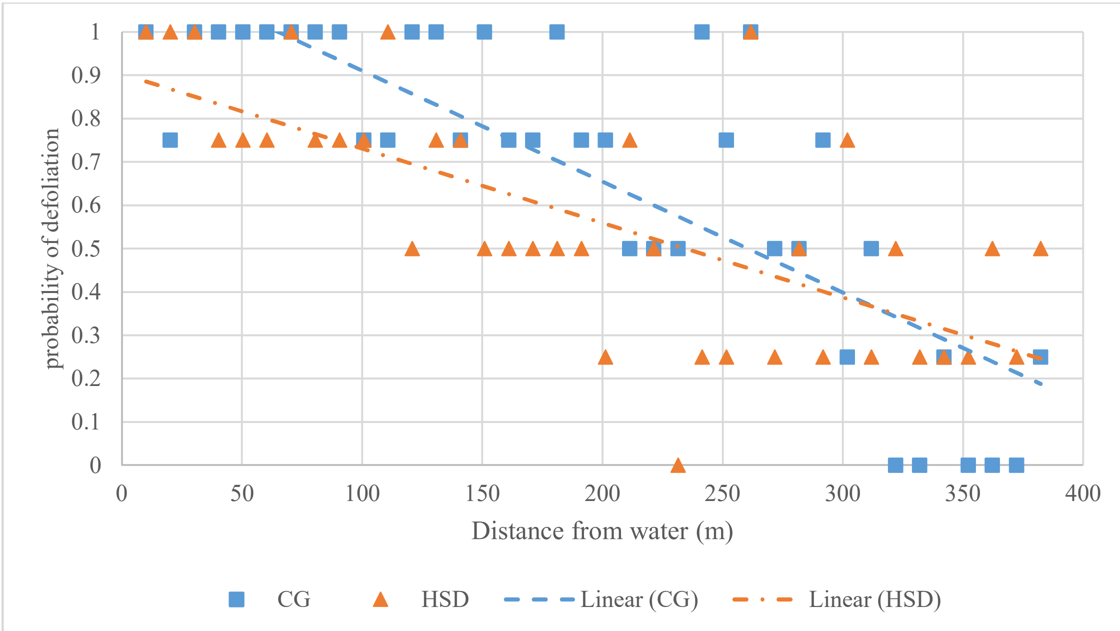
Appendix Fig. a.4 Regression analysis for Foggy period 2 HSD: $ß_1$ = -0.0024, $ß_0$ = 0.9474, r^2 = 0.5041 CG: $ß_1$ = -0.0026, $ß_0$ = 1.1497, r^2 = 0.7251.



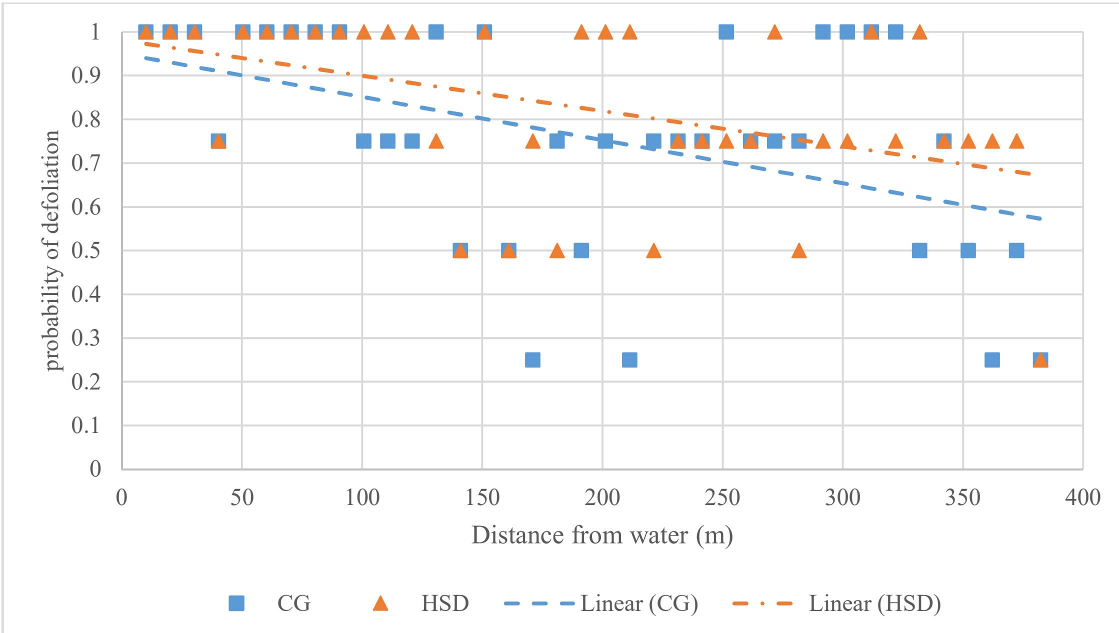
Appendix Fig. a.5 Regression analysis for Home period 2 HSD: $ß_1$ = -0.0021, $ß_0$ = 0.1.1006, r^2 = 0.5977 CG: $ß_1$ = -0.0024 $ß_0$ = 1.1383, r^2 = 0.598.



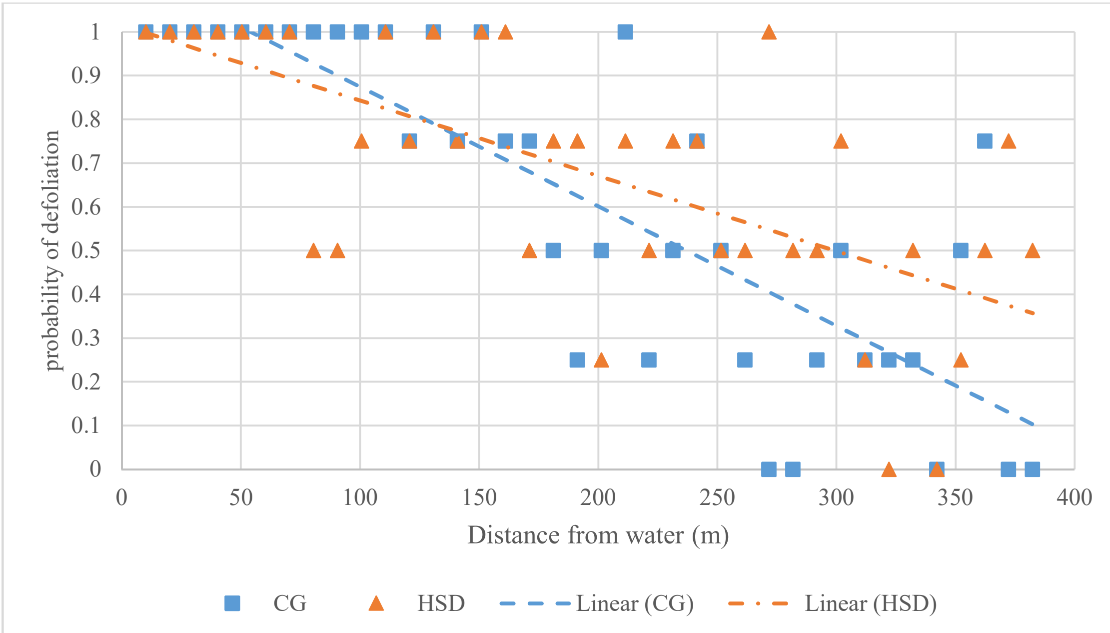
Appendix Fig. a.6 Regression analysis for Mesa period 2 HSD: $ß_1$ = -0.0022, $ß_0$ = 1.0203, r^2 = 0.4199 CG: $ß_1$ = -0.0027, $ß_0$ = 1.1426, r^2 = 0.77184.



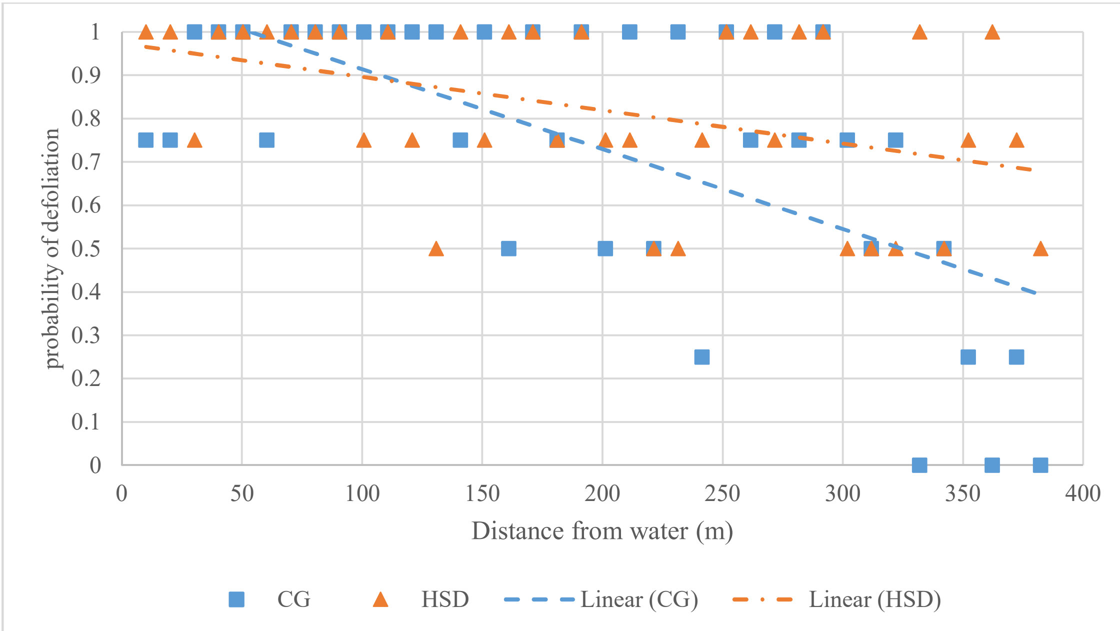
Appendix Fig. a.7 Regression analysis for Foggy period 3 HSD: $ß_1$ = -0.0017, $ß_0$ = 0.9029, r^2 = 0.4817 CG: $ß_1$ = -0.0026, $ß_0$ = 1.1664, r^2 = 0.6677.



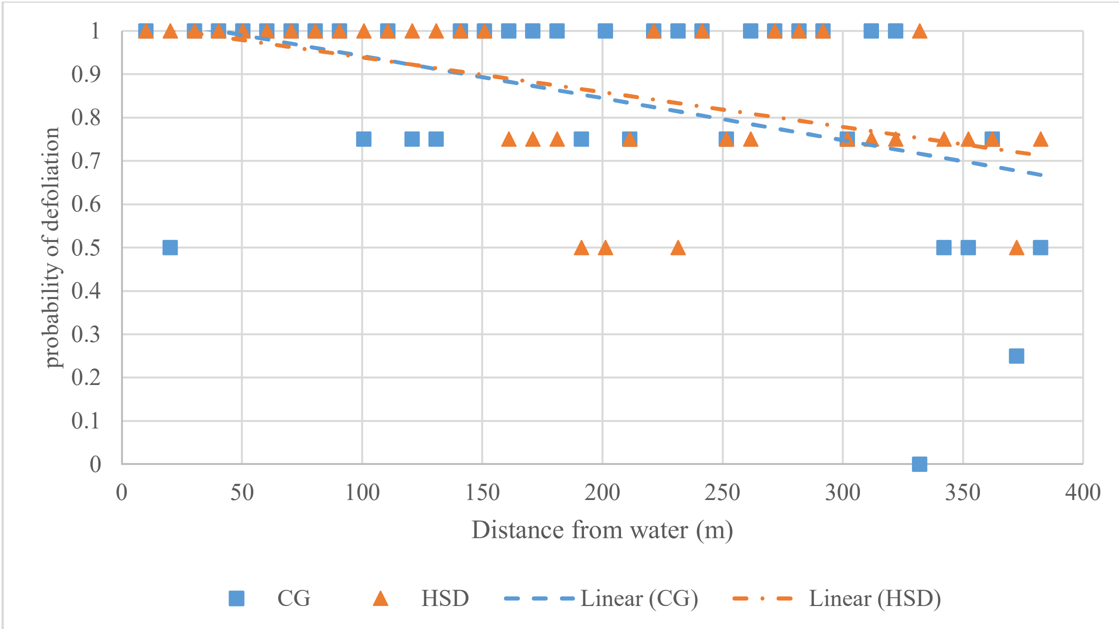
Appendix Fig. a.8 Regression analysis for Home period 3 HSD: $ß_1$ = -0.0008, $ß_0$ =0.9808, r^2 = 0.2026 CG: $ß_1$ = -0.0010, $ß_0$ = 0.9502, r^2 = 0.1950.



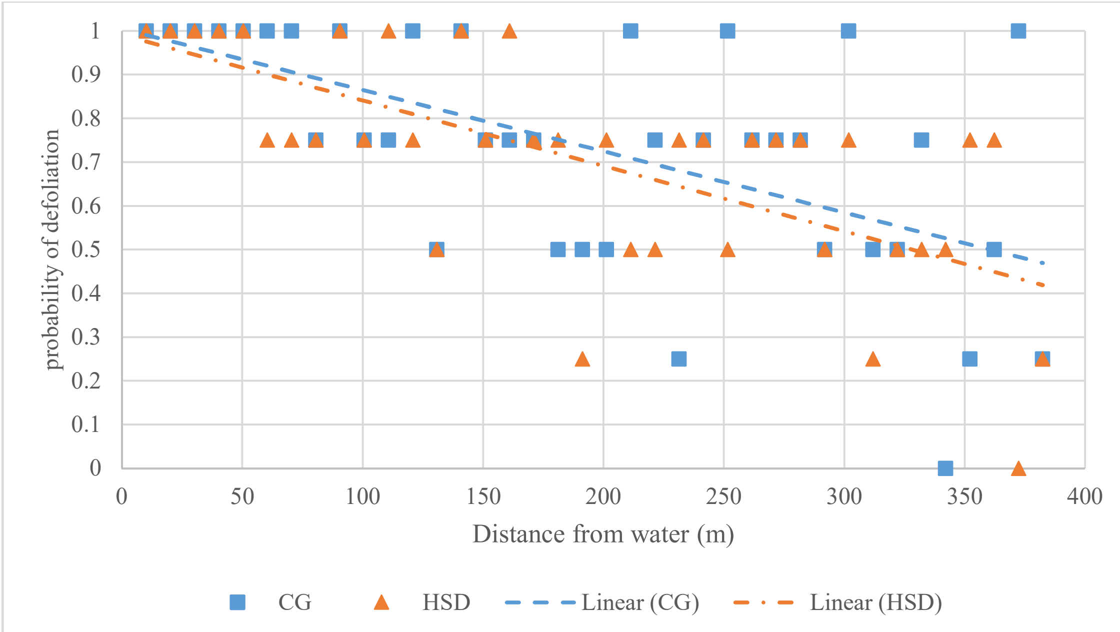
Appendix Fig. a.9 Regression analysis for Mesa period 3 HSD: $ß_1 = -0.0017$, $ß_0 = 1.0153$, $r^2 = 0.4401$ CG: $ß_1 = -0.0027$, $ß_0 = 1.1479$, $r^2 = 0.6789$.



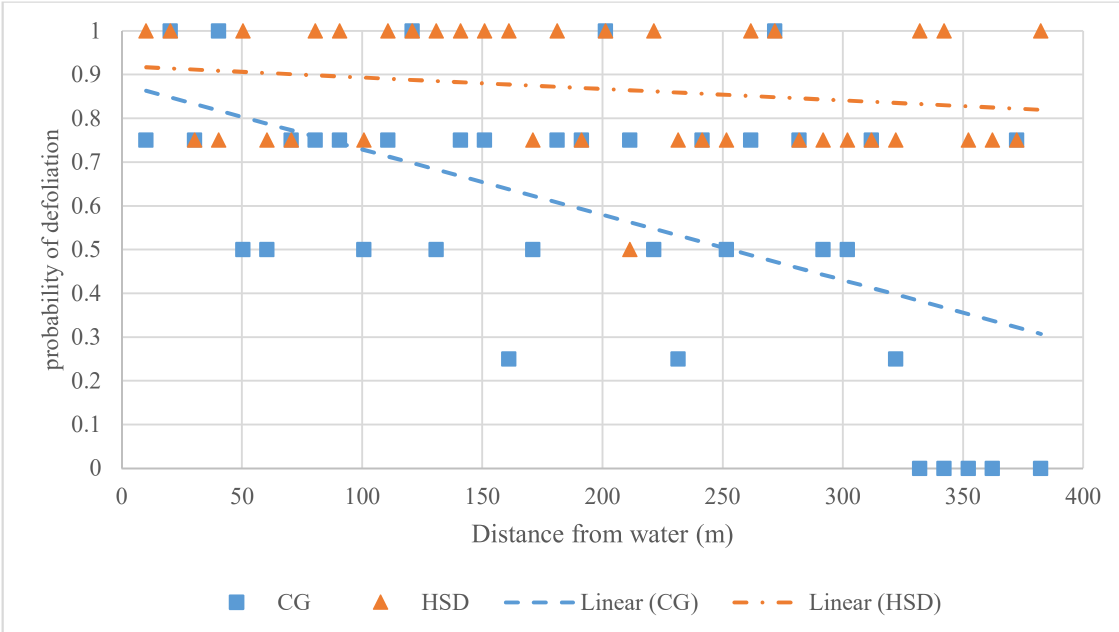
Appendix Fig. a.10 Regression analysis for Foggy period 4 HSD: $ß_1 = -0.0008$, $ß_0 = 0.9733$, $r^2 = 0.184$ CG: $ß_1 = -0.0018$, $ß_0 = 1.0985$, $r^2 = 0.4063$.



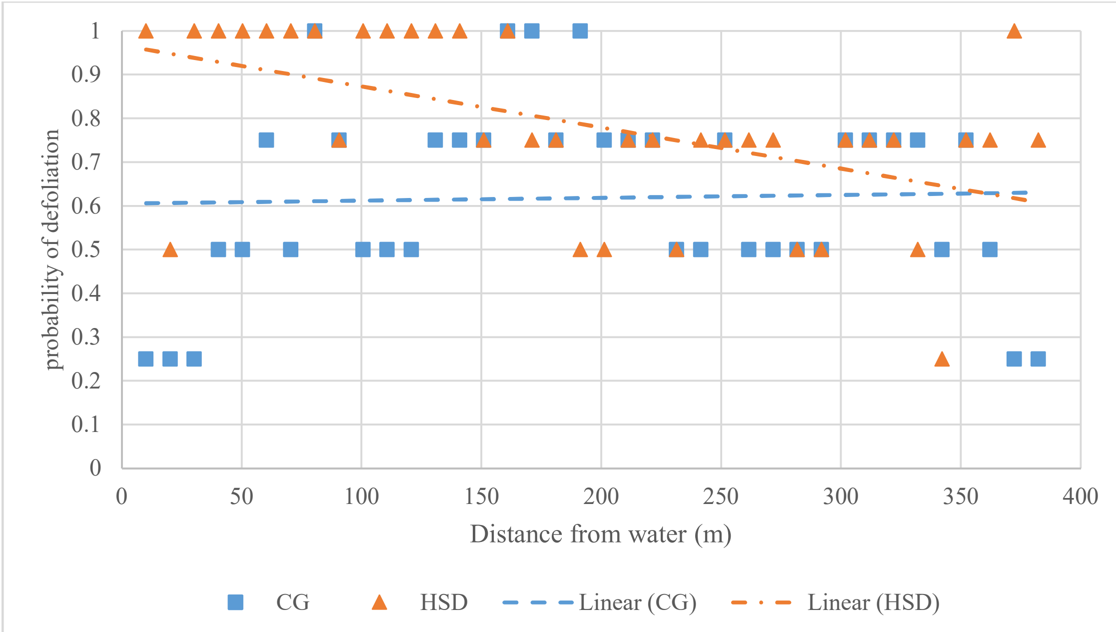
Appendix Fig. a.11 Regression analysis for Home period 4 HSD: $ß_1 = -0.0008$, $ß_0 = 1.0192$, $r^2 = 0.2737$ CG: $ß_1 = -0.0010$, $ß_0 = 1.0391$, $r^2 = 0.1988$.



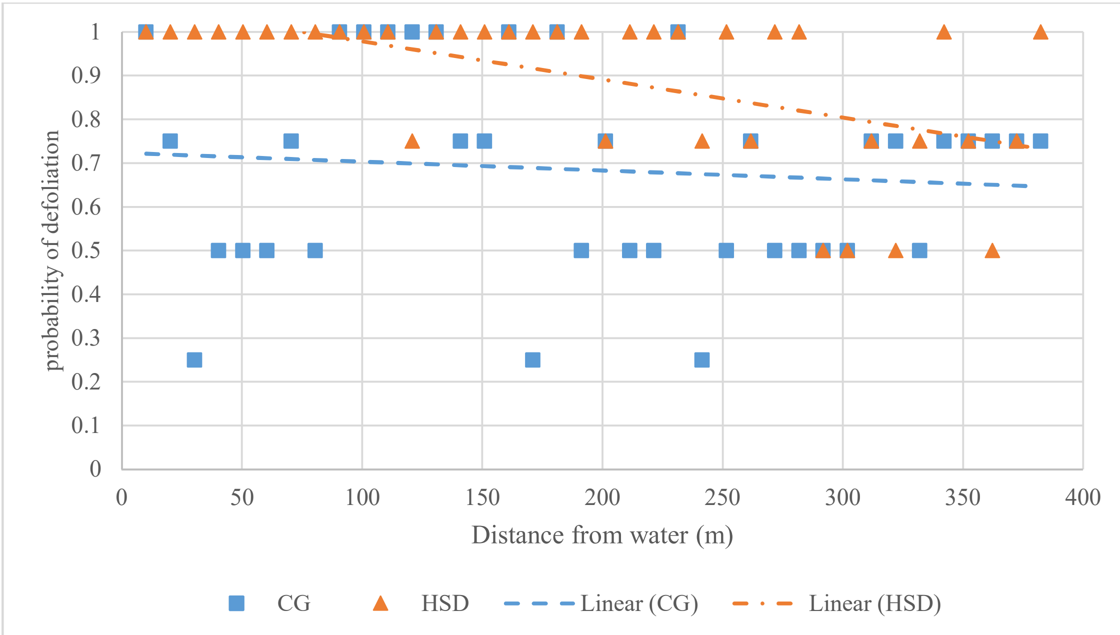
Appendix Fig. a.12 Regression analysis for Mesa period 4 HSD: $ß_1$ = -0.0015, $ß_0$ = 0.9908, r^2 = 0.4557 CG: $ß_1$ = -0.0014, $ß_0$ = 1.005, r^2 = 0.3393.



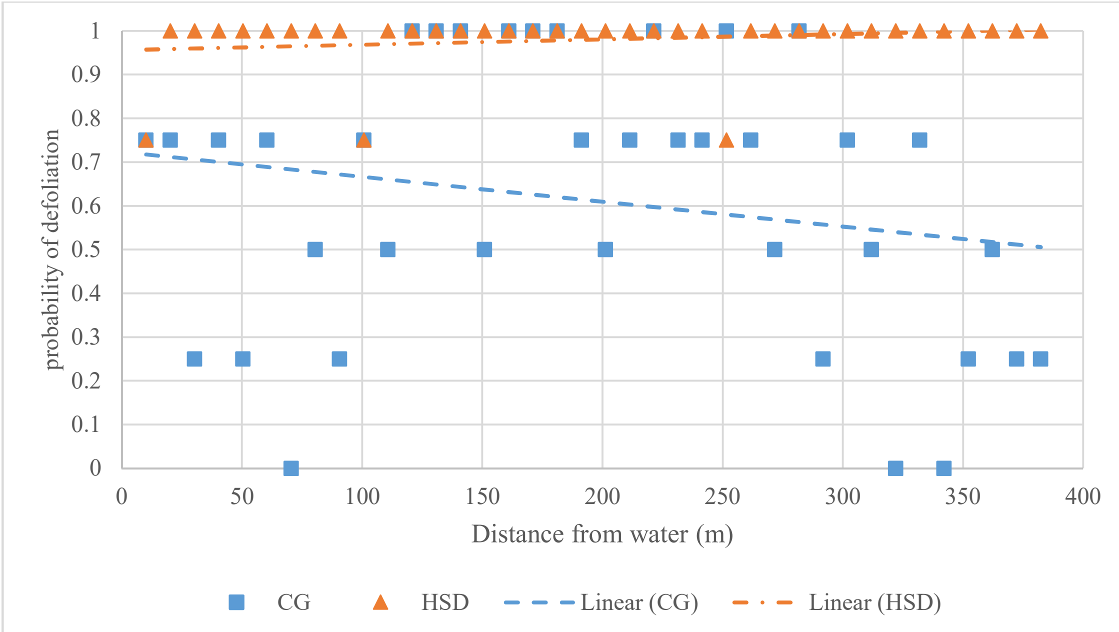
Appendix Fig. a.13 Regression analysis for Foggy period 5 HSD: $ß_1 = -0.0003$, $ß_0 = 0.9196$, $r^2 = 0.0439$ CG: $ß_1 = -0.0015$, $ß_0 = 0.8784$, $r^2 = 0.3023$.



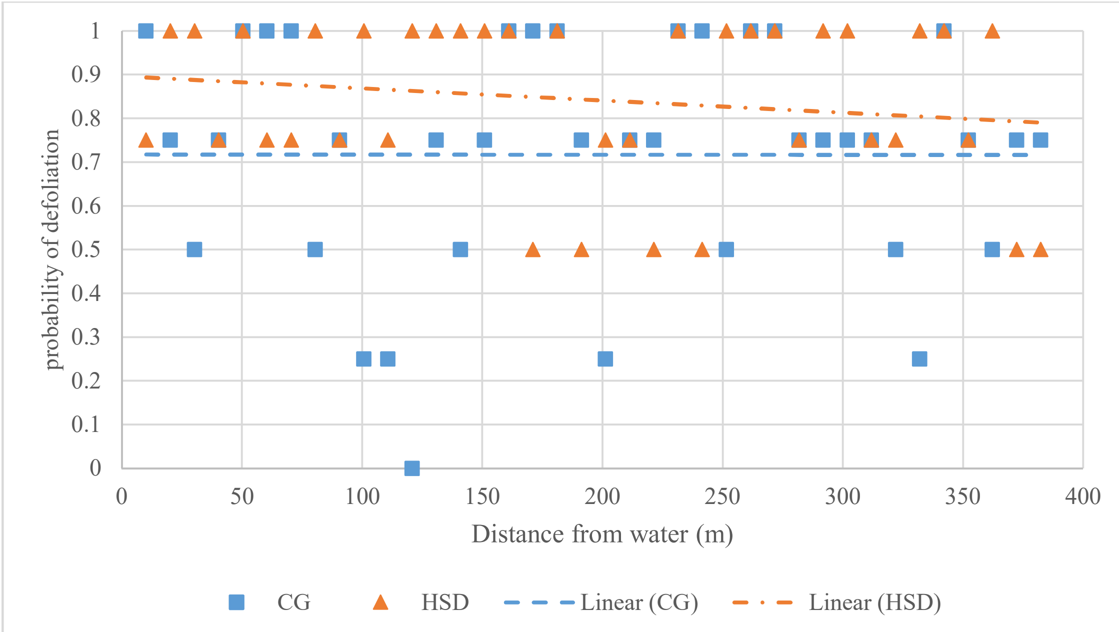
Appendix Fig. a.14 Regression analysis for Home period 5 HSD: $ß_1$ = -0.0009, $ß_0$ = 0.9669, r^2 = 0.2675 CG: $ß_1$ = 0.0000005, $ß_0$ = 0.6056, r^2 = 0.0011.



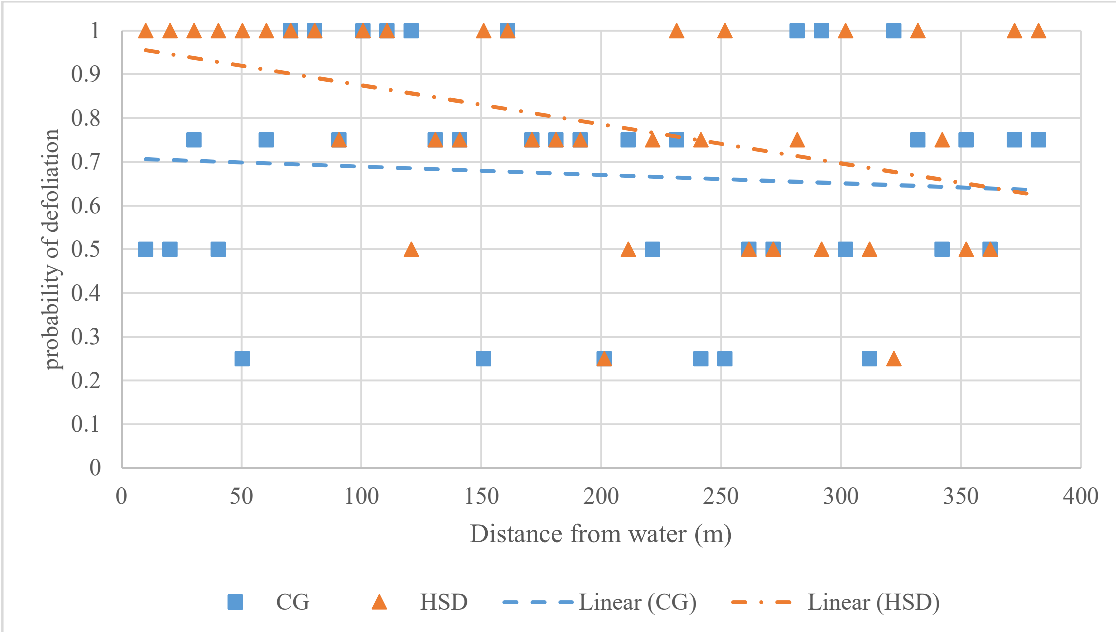
Appendix Fig. a.15 Regression analysis for Mesa period 5 HSD: $ß_1$ = -0.0009, $ß_0$ = 1.0654, r^2 = 0.3245 CG: $ß_1$ = -0.0002, $ß_0$ = 0.7237, r^2 = 0.0096.



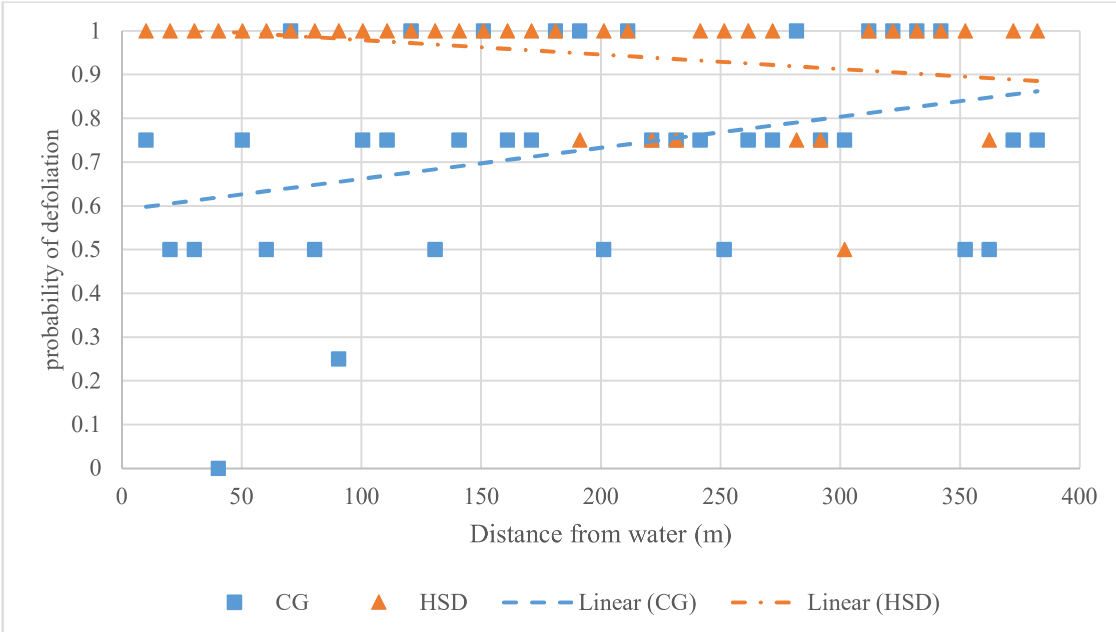
Appendix Fig. a.16 Regression analysis for Foggy period 6 HSD: $ß_1$ = -0.0001, $ß_0$ = 0.9563, r^2 = 0.0401 CG: $ß_1$ = -0.0006, $ß_0$ = 0.7233, r^2 = 0.0402.



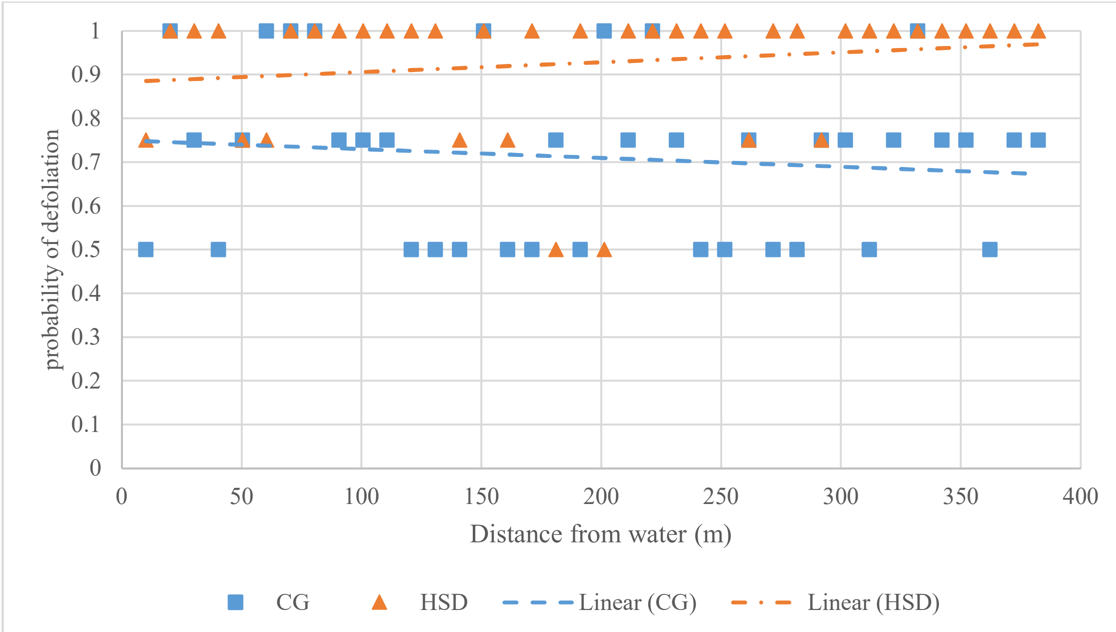
Appendix Fig. a.17 Regression analysis for Home period 6 HSD: β_1 = -0.0003, β_0 = 0.8965, r^2 = 0.0273 CG: β_1 = -0.000003, β_0 = 0.7176, r^2 = 0.0006.



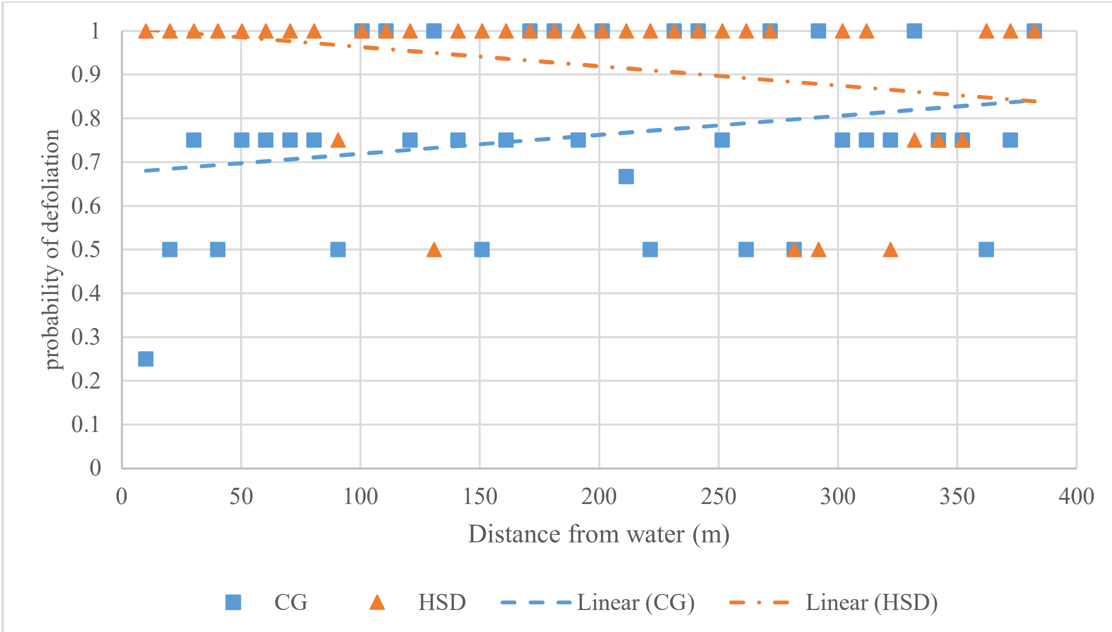
Appendix Fig. a.18 Regression analysis for Mesa period 6 HSD: $\beta_1 = -0.0009$, $\beta_0 = 0.9644$, $r^2 = 0.1781$ CG: $\beta_1 = -0.0002$, $\beta_0 = 0.7084$, $r^2 = 0.007$.



Appendix Fig. a.19 Regression analysis for Foggy period 7 HSD: $ß_1 = 0.0003$, $ß_0 = 0.1.0124$, $r^2 = 0.0979$ CG: $ß_1 = 0.0007$, $ß_0 = 0.591$, $r^2 = 0.1138$.



Appendix Fig. a.20 Regression analysis for Home period 7 HSD: $ß_1 = 0.0002$, $ß_0 = 0.8834$, $r^2 = 0.0319$ CG: $ß_1 = -0.0002$, $ß_0 = 0.7500$, $r^2 = 0.0142$.



Appendix Fig. a.21 Regression analysis for Mesa period 7 HSD: $ß_1 = 0.0004$, $ß_0 = 1.0075$, $r^2 = 0.0866$ CG: $ß_1 = 0.0004$, $ß_0 = 0.6761$, $r^2 = 0.0575$.

Appendix Table 1 Climate data for Randall county Texas. (USDA-NRCS, 2017)

	Temperature					Precipitation		
				2 years in 10 will have			2 years in 10 will have	
	Average daily maximum	Average daily minimum	Average	Maximum higher than	Minimum lower than	Average	Average Less than	Average More than
	℃	℃	℃	℃	℃	cm	cm	cm
January	11.22	-4.61	3.28	23.89	-17.78	1.17	0.25	1.96
February	14.33	-2.28	6.06	26.67	-16.67	1.32	0.13	2.44
March	18.78	1.39	10.06	30.56	-11.11	2.51	0.48	4.22
April	23.39	5.94	14.67	32.78	-4.44	2.74	0.64	4.60
May	27.72	11.39	19.56	36.67	1.11	7.34	2.84	11.63
June	32.28	16.44	24.33	40.56	8.89	7.52	3.10	12.07
July	33.61	18.89	26.22	40.00	13.33	6.05	2.39	9.73
August	32.28	18.00	25.17	38.33	12.78	7.21	2.24	11.79
September	29.17	13.89	21.56	37.22	2.78	5.00	1.09	9.19
October	24.00	7.61	15.78	33.33	-3.33	4.50	1.02	6.76
November	16.39	0.72	8.56	28.33	-11.11	1.75	0.33	3.28
December	11.67	-3.56	4.06	23.89	-17.22	1.57	0.18	2.74
Yearly:								
Average	22.89	7.00	14.94			---	---	---
Extreme	42.78	-23.89	---	41.11	-20.00	---	---	---
Total						48.74	40.31	56.72

(Recorded in the period 1971-2000 at CANYON, TX1430