

# Effects of prescribed burning on gulf cordgrass, *Spartina spartinae* (Trin.) Merr. ex Hitchc.

## Abstract

Gulf cordgrass is a perennial bunchgrass native to North and South America. In the United States and Mexico, it is found in coastal prairies and marshes along the coast of the Gulf of Mexico, and occasionally further inland in low-lying areas. In South America, it is found along the Caribbean coast and inland in Argentina and Paraguay. Gulf cordgrass can remain green year-round making it an important source of forage in dormant and dry seasons. However, it is coarse and unpalatable when mature. In this paper, we review effects of prescribed burning on gulf cordgrass forage production and quality as well as plant community dynamics. The literature indicates burning is an economical way to rejuvenate gulf cordgrass by improving its palatability and accessibility and by increasing its protein content. Grazing can be used after burning to prolong the effects of fire, preventing young forage from maturing quickly into senescence. Season of burning may be less important than rainfall received after burning for forage regrowth.

**Keywords:** grasslands, gulf cordgrass, livestock, prescribed burning, protein, range management, season of burn

Volume 3 Issue 2 - 2018

Victoria L Haynes, Jose S Avila-Sanchez, Sandra Rideout-Hanzak, David B Wester, J Alfonso Ortega-S

Department of Animal, Rangeland and Wildlife Sciences, Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, USA

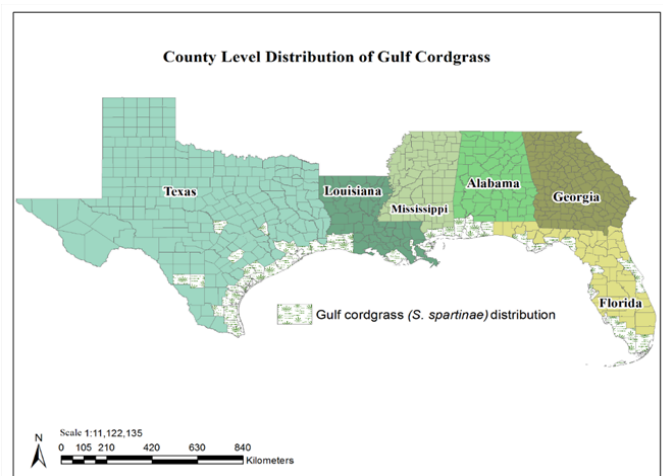
**Correspondence:** Sandra Rideout-Hanzak, 700 University Blvd, MSC 218, Texas A&M University-Kingsville, TX 78363, USA, Tel 361-593-4546; Fax 361-593-3788  
Email [sandra.rideout-hanzak@tamuk.edu](mailto:sandra.rideout-hanzak@tamuk.edu)

**Received:** February 01, 2018 | **Published:** April 25, 2018

## Introduction

Gulf cordgrass (*Spartina spartinae* (Trin.) Merr. ex Hitchc. [Trin.] Hitchc.) is a highly productive, C4 warm season perennial bunchgrass able to tolerate a large range of climatic conditions in both hemispheres.<sup>1,2</sup> It is found in the United States along the coast of the Gulf of Mexico from Florida to Texas (Figure 1), and south into eastern Mexico. It also can be found, although less commonly, inland in marshes and seasonally-flooded prairies. Additionally, it grows in South America along the Caribbean coasts and inland in Argentina and Paraguay.<sup>3</sup> Also known as “sacahuista” (from the Nahuatl, an Uto-Aztecan language indigenous to Central Mexico, “zacahuitzli,” from “zacatl” meaning grass or hay and “huitztl” meaning thorn<sup>4</sup>), gulf cordgrass grows 1–2 m tall with short peripheral subrhizomes; true rhizomes are absent. Culms are numerous, up to 2 m long and 2.4 mm thick, broad at the base, and closely involute essentially the entire length. It has 10 to 75 spikes per panicle, closely appressed and overlapping, and 16 to 40 spikelets per spike. The lower glume is nearly as long as the spikelet and hispid on keels.<sup>5,6</sup> Gulf cordgrass thrives in various soils that are typically above sea level, but occasionally submerged.<sup>7</sup> It has been reported to occur in soils ranging from sandy loams to clays and heavy clays with its greatest standing crop yield in fertile clay loams and clays because of higher moisture-holding capabilities in these soil textures.<sup>8,9</sup> Oefinger and Scifres<sup>10</sup> reported that cordgrass occurs on soils relatively high in sodium on the coastal prairie, and that its dominance in areas of high salinity may be attributable to the fact that other halophytes are unable to successfully compete with it. In southern Texas, the greatest herbage yield for gulf cordgrass occurs during rainy spring months and during September and October when tropical storms bring additional moisture.<sup>11</sup> Gulf cordgrass can maintain green tissue year-round in coastal prairies,<sup>1,8,12</sup> making it an important range forage species in the Coastal Prairies and Marshes ecoregion of Texas since the beginning of cattle raising there in the mid-1880s.<sup>13</sup> However, although gulf cordgrass can maintain green tissue year-round, mature plants are not grazed to an appreciable extent by livestock if other forages are available.

Mature growth produces coarse, stiff, and spine-like leaf blades with low palatability and nutritional quality, making it less valuable for livestock and wildlife.<sup>8,12,14</sup>



**Figure 1** County-level distribution of gulf cordgrass (*Spartina spartinae* [Trin.] Merr. ex Hitchc.) in the United States. Based on NRCS map (<https://plants.usda.gov>) retrieved 11 January 2018.

## Discussion

In general, temperate grasslands are adapted to frequent disturbances because they evolved under a regime of frequent defoliation by burning and grazing animals.<sup>15</sup> Because growing points in grasses are below or just above the soil surface, often little harm is inflicted on graminoids during aboveground disturbances.<sup>16</sup> The historical interaction of fire and nomadic grazers played a vital role in shaping heterogeneous grassland landscapes in North America and elsewhere.<sup>17</sup> Prior to anthropogenic ignitions, indigenous fires along the Texas Gulf Coastal Prairies originated from lightning

strikes and spontaneous combustions, which were most common in mid to late summer.<sup>18</sup> Native Americans used fire on the landscape quite frequently, and extended the season of burning into winter as well.<sup>19</sup> Native herbivores such as bison (*Bison bison* [Linnaeus, 1758]) freely roamed grasslands, and their nomadic patterns modified vegetative communities by promoting open areas following grazing. These patterns of herbivory often are what affected the probability and pattern of fire because the occurrence of fire partially depends upon fuel accumulation and availability.<sup>20</sup> Following fire suppression in North America from the early 1900s to the present, prairies protected from periodic fires began experiencing brush encroachment, invasion by non-native species, slower nutrient cycling, and a loss in biodiversity.<sup>21</sup> As the ecological worth of fire became evident after decades of suppression, rangeland managers began re-applying fire to these landscapes with the intention of integrating fire into their livestock grazing operations.<sup>19</sup> Traditional rangeland techniques to increase forage utilization and livestock production have consisted of annual burning; strategic placement of fencing and water; and in some cases use of herbicides to eliminate forbs. This traditional rangeland management is based on a paradigm of managing for uniform grazing distributions and homogeneous grass-dominated habitats suitable for cattle production and a narrow range of wildlife species.<sup>22</sup> Because of present-day landowners' rising interest in wildlife recreation for economical purposes, practices to adjust homogeneous landscapes toward greater plant diversity for both domestic and wildlife species are on the rise.<sup>23</sup>

### Management of gulf cordgrass for livestock

In grasslands, prescribed burning can increase forage nutritive value, palatability, availability, and yield.<sup>24</sup> According to White et al.<sup>25</sup> variable fire conditions lead to varying plant responses. Plant response after a fire is influenced by intensity of the fire, condition of the plants, and weather conditions. There also are other factors that can either positively or negatively affect plant survival and regrowth production following burning such as soil temperature, soil moisture, and season of the burn.<sup>26</sup> Stubbendieck et al.<sup>24</sup> concluded that when burning is performed at the right time and soil moisture is adequate, grass yields will increase because of ash darkening the soil surface and absorbing radiant heat from the sun causing the soil to warm quickly, stimulating earlier grass growth and suppressing competing forbs. Management techniques to improve palatability of gulf cordgrass have included prescribed fire and mechanical shredding treatments.<sup>14</sup> When applying either of these treatments to gulf cordgrass, nutritional value is enhanced and production of inflorescences and live standing crop is augmented.<sup>1,10,14,27</sup> Tender shoots that emerge after tillers have been burned or shredded are heavily utilized by livestock.<sup>9</sup> Therefore, gulf cordgrass has traditionally been burned at the convenience of the land manager for use as reserve feed during cool months, dry summers, or any time forage is limited.<sup>14</sup>

Fire rarely has a negative effect on gulf cordgrass production; rather it revitalizes stands by removing excessive mulch and standing dead tissues. The yield produced also depends largely on soil water availability.<sup>8</sup> The degree of water stress and nutrient availability also affect the seasonal variation in carbohydrate reserves.<sup>28</sup> McAtee and colleagues studied effects of burning or shredding on gulf cordgrass standing crop<sup>14</sup> and forage quality<sup>1</sup> on the Rob and Bessie Welder Wildlife Refuge (WWR) in southern Texas with treatments applied in April, July or December. Short-term (90-day) standing

crop responses differed from long-term (11-month) responses. For example, green cordgrass biomass averaged 2835 kg/ha prior to treatment in April; burned and shredded plots had 2693 and 4366 kg/ha, respectively, 90 days after treatment, and 5642 and 6379 kg/ha, respectively, 11 months after treatment. Plots averaged 1778 kg/ha prior to treatment in July; burned and shredded plots had 1031 and 1173 kg/ha, respectively, 90 days after treatment, and 2969 and 2863 kg/ha, respectively, 11 months after treatment. Plots averaged 2062 kg/ha prior to treatment in December; burned and shredded plots had 556 and 701 kg/ha, respectively, 90 days after treatment, and 2804 and 3980 kg/ha, respectively, 11 months after treatment. Thus, short-term biomass responses to burning were neutral (April) to negative (July or December) but long-term responses were positive; short-term responses to shredding were positive in April but negative in July and December, and long-term responses were positive. Differences in effects of burning and shredding likely are because burning removed a protective mulch layer from the soil surface whereas this layer remained intact in shredded plots. Digestible energy (DE) content in gulf cordgrass prior to the April treatment averaged 1974 kcal/kg of green leaves; 90 days post-treatment, DE content was 2485 and 2136 kcal/kg in burned and shredded plots, respectively, compared to 1910 in non-treated plots; and 7 months post-treatment, DE content averaged 1911 and 1912 kcal/kg in burned and shredded plots, respectively, compared to 1651 kcal/kg in non-treated plots.<sup>1</sup> Crude protein content 90 days following treatment averaged 7 and 6.4%, in burned and shredded plots, respectively, compared to 4.6% in non-treated plots. DE content 30 days after July treatment averaged 2521 and 2274 kcal/kg in burned and shredded plot, respectively, compared to 1855 kcal/kg in non-treated plots; and crude protein averaged 11.4 and 8.7% in burned and shredded plots, respectively, compared to 4.6% in non-treated plots. Both McAtee et al. studies<sup>1,14</sup> indicated shredding is effective in improving gulf cordgrass nutritive value; however, economic considerations such as equipment, labor, and fuel costs need to be considered when mechanical techniques such as shredding are applied. Prescribed fire may be more feasible than mechanical methods for managing gulf cordgrass rangelands because of its economic advantage, its effectiveness at improving forage quality, and its historical presence on the landscape as a natural disturbance.<sup>1,14,21,29</sup>

### Benefits of using fire on gulf cordgrass rangelands

Presently in prairies along the coast of the Gulf of Mexico in the U.S., fire often is applied to meet multiple objectives for livestock and wildlife management such as increasing herbage yields and availability of forages, controlling various parasites, stimulating early growth of grasses, removing old growth, and improving coarse grasses for animal consumption.<sup>19</sup> Excessive amounts of litter and senescent standing tissue negatively affect primary production of plants by restricting nutrient recycling.<sup>8,30</sup> The blackened, exposed soil following fire is helpful in stimulating quickened germination and production of forbs, annual grasses, and perennial grasses on the coastal prairies because it encourages the absorption of warm temperatures that improve growing conditions.<sup>10</sup> Before a spring (April) burn within a gulf cordgrass community on the WWR, McAtee et al.<sup>14</sup> observed that, of the total fine fuel load (11,584 kg/ha), only 24% was live, standing gulf cordgrass. Typically, senescent leaves have lower photosynthetic potential than young grass leaves, which reduces overall productivity potential.<sup>31,32</sup> Rangelands cattle rely on microorganisms found within the rumens to effectively break

down structural carbohydrates and supply them with both energy and microbial protein. This process requires an adequate supply of nitrogen, which comes from plant protein. Reported crude protein maintenance requirements for a non-lactating and lactating beef cow are 6–8% and 9–12%, respectively. Microbial activity in the rumen is hampered when dietary crude protein falls below 7%; this causes a reduction in microbial protein production, and forage digestion and intake. During the dormant season, rangelands often lose their nutritional value because of inadequate supply of protein in the forage. This decline in protein also occurs in warm season perennial forages as they mature (e.g.,<sup>33</sup>). Senescent gulf cordgrass foliage on the WWR Aransas National Wildlife Refuge (ANWR) contained crude protein levels that ranged from 4 to 5%.<sup>1,8</sup> Following burning in April, June, July, September, or December, gulf cordgrass crude protein increased and persisted for 30 to 90 days with no grazing (see above,<sup>1</sup>). Crude protein levels in new shoots reached 9.3 to 11.8% within a month of regrowth after these burns. However, the highest percentage of crude protein was only maintained in the first 30 days after burning in at both WWR and ANWR with no grazing. By 5 months after burning, crude protein levels were roughly only 2% higher than in untreated gulf cordgrass.<sup>1</sup> Oefinger et al.<sup>10</sup> suggested that continuous grazing could effectively maintain high crude protein levels for 4 to 5 months after burning because it promotes young available tissue, which in turn increases the volume of high quality forage. Without constant periodic defoliation, crude protein levels dropped to 7.4–8.9% at 90 days following a burn.<sup>9</sup> At the WWR, crude protein levels generally were higher ~0.5 to 4% in plants continuously clipped monthly at 10 cm than those clipped at 20 cm for 18 months. These results indicated gulf cordgrass could withstand removal of herbage to a height of 10 cm on a monthly basis without adverse effects as long as sufficient moisture is received.<sup>34</sup>

### Herbivore attraction to burned areas

Many herbivores in semi-arid and arid rangelands are selective grazers as they do not graze evenly across the landscape.<sup>35,36</sup> Variable forage quality combined with biotic and abiotic disturbances cause herbivores to search for profitable locations that enhance their fitness relative to time and energy costs.<sup>36</sup> The marginal value theorem (MVT), proposed by Charnov,<sup>37</sup> suggests that the optimal time a herbivore will forage within an area before moving on to the next depends on foraging efficiency, which is influenced by resource uptake (value) and the investment (cost) in resource acquisition. In theory, when the intake rate in any area drops to the average rate for the habitat, the animal should leave that area and travel to another to maximize rate of resource intake because more energy would be spent than gained by remaining.<sup>37</sup> As an environment becomes richer in high-quality forages, foraging efficiency increases wherein foraging time is minimized and higher fitness gains are achieved.<sup>38</sup> When an herbivore's foraging efficiency is enhanced, higher rates of weight gain, better body condition, increased survival rates, and improved reproductive success can be expected.<sup>39</sup> Time since fire influences how animals distribute themselves on the landscape.<sup>40</sup> When natural fires occur, nomadic large herbivores prefer vegetation regrowth within burned portions of the landscape.<sup>41</sup> Domestic herbivores also have been observed utilizing recently burned areas to proportionately greater extents than previously burned and non-burned areas.<sup>42,43</sup> Following a fire, there is an improvement in the nutritional value of emerging herbaceous as compared to plants available burning. This nutritional improvement often is advocated as the primary reason for

a “magnet effect” or attraction to burned areas<sup>44,45</sup>. The preference for recently burned areas, however, is only temporary because forage quality decreases as plants mature.<sup>41</sup> Previous studies indicate that fire can be used as a tool to alter grazing behavior, shifting grazing from a selective scale to a landscape scale because plants that previously were underutilized by herbivores become increasingly more palatable with fire.<sup>17,41,46</sup> Prior to prescribed burning in southwestern Idaho, U.S., cattle distributions tended to focus on foraging patches containing higher nutritional quality than surrounding areas. Following burning, there was an increase in the number and density of high-quality foraging patches relative to pre-fire<sup>40,46</sup>. Because of the increase in density of high-quality patches, herbivores exhibited longer foraging durations in burned sites as foraging activity was interrupted less frequently by traveling and searching activities.<sup>46</sup> A study conducted in the Serengeti National Park Serengeti National Park (SNP) in Tanzania, Africa, observed that preference for burned areas was directly linked to body size and metabolic requirements.<sup>47</sup> In visual counts following burning, smaller ungulate species more commonly were found utilizing burned areas while larger ungulates spent more of their time in non-burned sites. Researchers at SNP Serengeti National Park concluded that because burned areas had less production immediately following burning, larger species spent more time in the non-burned areas to maximize intake. Yet, small ungulates fed in burned sites that provided higher quality forage to fulfil their high metabolic requirements.<sup>47</sup>

### Utilization of gulf cordgrass after burning

As with other grasslands, after fire has been applied to a gulf cordgrass pasture and herbaceous recovery commences, cattle will choose the young regrowth.<sup>1</sup> Young gulf cordgrass regrowth is more palatable and tender to herbivores than old growth because new growth contains more digestible cell solubles relative to cell wall constituents.<sup>10</sup> Generally, yearling cattle grazing on recently-burned gulf cordgrass also outperform cattle grazing on non-burned gulf cordgrass rangelands because higher weight gains are achieved in burned gulf cordgrass rangelands.<sup>27</sup> Following fall burning on the WWR gulf cordgrass pastures afforded mature cattle sufficient nutrition during winter to maintain weight. Growing livestock, however, had a difficult time maintaining and gaining weight during midwinter, and supplemental feeding was recommended for growing livestock because immature animals require a higher quality diet to meet nutrient requirements as compared to adults.<sup>27</sup> Following a spring burn in gulf cordgrass rangelands on the WWR, carrying capacity was increased for 6 months because more AUD/ha existed on burned areas than on non-treated mature areas.<sup>14</sup> Following several burns in different seasons on the WWR, age of regrowth was recognized as the cause for change in nutritional levels and degree of utilization, rather than season of treatment.<sup>1,12</sup> However, when other desirable grasses and forbs become available during spring, recently-burned communities of gulf cordgrass are only utilized by cattle for a short period allowing gulf cordgrass to mature after grazing pressure ceased.<sup>8,10</sup>

### Recommended timing for burning gulf cordgrass

Generally, grasses are fuels with low volatile oil content.<sup>48</sup> Although gulf cordgrass contains volatile oils<sup>29</sup> and could be burned year-around, historically, cattle ranchers have burned gulf cordgrass and managed it only as a reserve source of forage to alleviate stress during winter dormancy, forage shortages, or droughts when high-

quality forage is scarce.<sup>8,10,12,14</sup> Typically, the most difficult time of the year for cattle enterprises is the winter dormant season when primary forage production is low. Yet, threat of drought is another concern that is omnipresent in rangelands. During these difficult times, landowners often supply their herd with supplemental feed, which is a major expense.<sup>49</sup> Carbohydrate reserves are the total nonstructural carbohydrates (TNC) that are stored in roots, rhizomes, stolons, stem bases, and haplocorms of grasses. Plants use TNC as a readily metabolizable source of energy needed for growth, respiration, reproduction and survival. In other words, they are used as an energy source to initiate new growth until photosynthesis is sufficient to sustain plant respiration.<sup>13,28,50</sup> The major constituents in TNC reserves are glucose, fructose, sucrose, fructosans, and starches. Predominant carbohydrate reserves stored by temperate–origin or cool season grasses (C3 plants) are sucrose and fructosans; those from subtropical–tropical or warm season grasses (C4 plants) are sucrose and starches.<sup>28</sup> Applying fire to gulf cordgrass rangelands in warm, moist periods and prior to seasonal reduction of other available forage is recommended to promote sufficient recovery and higher quality and utilization of gulf cordgrass.<sup>10</sup> In order to obtain higher yields of gulf cordgrass,<sup>14</sup> advised that burning be conducted in the spring because soil moisture is higher, providing favorable conditions for growth. Yet, conducting a burn during early fall is perhaps the most logical timing because of the critical need for green forage along the Gulf Coast prairies during the winter months.<sup>1,10,27</sup> During fall to early spring, high quality forage often becomes dormant and impracticable for grazing.<sup>14</sup> Livestock in pastures with deficiencies in high–quality cool–season forage can suffer from weight loss, if forced to survive on low–quality cool–season annuals.<sup>1</sup> A similar recommendation to burn in the fall was suggested by<sup>34</sup> to ensure that nonstructural carbohydrate reserves and moisture would be present to stimulate regrowth. A short deferment between burning and grazing of gulf cordgrass is sometimes recommended to allow for initial vigorous herbaceous recovery but not plant maturity as grass and forb quality declines with plant maturity.<sup>8,36</sup> In a study by Angell et al.<sup>27</sup> cattle were stocked into pastures 30 days after burning. Management should be flexible when determining grazing periods and intensity based on ever–changing rangeland conditions. Ranchers are advised to rest a pasture from grazing before a subsequent burn to allow enough fuel to accumulate.<sup>8</sup> Annual burning in gulf cordgrass communities may not allow for sufficient senescent top–growth to carry a fire uniformly.<sup>27</sup> Thus, to achieve a complete burn, rangelands consisting of gulf cordgrass should be burned every two to three years.<sup>8</sup> Gulf cordgrass has the potential to be a valuable, alternative grazing component under proper management to improve diet quality of livestock.

### Consequences of burning gulf cordgrass

Benefits of using fire as a management tool are numerous, yet one must consider that vegetation response following burning depends on a plant's physiological or morphological state, seasonal timing of burning, and environmental conditions prior to as well as after a fire.<sup>15</sup> During the growing season, the flowering process demands energy from carbohydrate resources<sup>32,51</sup>. Once the flowering process is completed but before the plant enters dormancy, perennial grasses redirect carbohydrates to their crowns and stem bases to be used for tiller growth in the subsequent growing season. During this

period, following flowering and before dormancy, rest from grazing defoliation is important for health and vigor of perennial grasses.<sup>32,51</sup> Conducting a burn during this period could have negative impacts on perennial grass plants. Inadequate soil moisture during dry periods slows recovery from fire, reduces forage quality, and causes rangeland degradation.<sup>52,53</sup> The lowest regrowth yield following burning at WWR occurred after burning in December. This result was attributed to low rainfall received throughout the 90 days after burning (1.9cm). Regrowth yield 90 days following spring burning treatments had equaled or surpassed pre–treatment standing crop with 8.6 cm of rainfall received each month following treatment.<sup>1</sup> Rainfall following summer burning was similar to the amount following the spring burning; however, standing crop regrowth was lower than after the spring burn. This was attributed to high summer temperatures accelerating loss of soil moisture. Although plant recovery is affected by soil moisture, soil moisture availability is affected by soil texture. The WWR treatments produced a faster standing crop and higher yield of gulf cordgrass than at ANWR because the Aransas–Victoria clay at WWR has a higher moisture holding capacity than ANWR's Galveston fine sand.<sup>14</sup> Additionally McAtee et al.<sup>14</sup> found that 1 AU required fewer hectares for 6 months after burning in clay soils than<sup>10</sup> had reported in sandy loam soils.

### Conclusion

Prescribed burning is an effective tool for removing mature and senescent growth in gulf cordgrass rangelands to promote regrowth with improved nutrition for livestock. However, the recommended seasonal timing for burning communities along the Texas coast to improve overall utilization by livestock is unclear. Proper grazing management—whether of gulf cordgrass or other rangeland forages—should be designed with stocking rate calculated to prevent damage to vegetation by overgrazing, yet continue to stimulate succulent regrowth through grazing disturbance after burning<sup>8</sup>. Management Intensive Grazing (MIG) is essential for maintaining long–term sustained forage quality and utilization of gulf cordgrass by livestock because light grazing allows gulf cordgrass to progress into a mature stage and become less palatable for livestock.<sup>34</sup> A rotational, naturally–deferred grazing system controlled by burning could provide year–long grazing of gulf cordgrass rangelands by treating pastures at different times<sup>12</sup>.

### Acknowledgements

The authors wish to thank the Caesar Kleberg Wildlife Research Institute and the Department of Animal, Rangeland and Wildlife Sciences at Texas A&M University–Kingsville, the East Foundation, and the Renè Barrientos scholarship fund. We also thank Fidel Hernández, Randy Stanko, Rich Machen and 2 anonymous reviewers for reviewing and improving this paper. This is Caesar Kleberg Wildlife Research Institute manuscript number 18–123, Texas A&M University–Kingsville, TX, and East Foundation manuscript number 026.

### Conflict of interest

Authors have no financial interest or conflict of interest.

## References

- McAtee J, Scifres C, Drawe D. Digestible energy and protein content of gulf cordgrass following burning or shredding. *J Range Manage.* 1979a;32(5):376–378.
- Aincouche M, Baumel A, Salmon A, Yannic G. Hybridization, polyploidy and speciation in *Spartina* (*Poaceae*). *New Phytol.* 2003;161(1):165–172.
- USDA, NRCS. Gulf Cordgrass *Spartina spartinae* (Trin.) Merr. ex A.S. Hitchc., Plant Fact Sheet. Kika de la Garza Plant Materials Center, Kingsville, TX; 2003. 2 p.
- Academic. Dictionnaire de la Langue Nahuatl Classique. Huitztlil. www.fracademic.com, USA; 2017.
- Correll D, Johnston M. Manual of the Vascular Plants of Texas. Richardson, Texas, USA: University of Texas at Dallas. 1979. p.1881.
- Shaw R. Guide to Texas Grasses. TX. USA: Texas A&M University Press. College Station; 2011:1096.
- Hatch S, Gandhi K, Brown L. Checklist of the Vascular Plants of Texas. Texas A&M Agricultural Experiment Station, Miscellaneous Publication, USA; 1990.
- Scifres C, Drawe D. Gulf cordgrass: distribution, ecology and responses to prescribed burning. In: Hanselka CW, editor. Prescribed range burning in the Coastal Prairie and Eastern Rio Grande Plants of Texas, Texas Agr Exp Sta Bull, USA; 1980. p. 83–92.
- Scifres C, McAtee J, Drawe D. Botanical, edaphic and water relationships of gulf cordgrass. *Southwest Nat.* 1980;25(3):397–409.
- Oefinger R, Scifres C. Gulf cordgrass production, utilization and nutritional value following burning. Texas Agr Exp Sta Bull. 1977. 19 p.
- Garza A, Drawe D. Herbage yield, protein content, and carbohydrate reserves in Gulf cordgrass (*Spartina spartinae*). *J Range Manage.* 1997;47(1):16–21.
- Hanselka C. Improving gulf cordgrass range. Texas Agricultural Extension Service, Texas Agricultural Experiment Station, College Station, TX, USA; 1981.
- Garza AJ. Carbohydrate reserve patterns in gulf cordgrass [*Spartina spartinae* (Trin.) Hitchc.]. Texas A&M University–Kingsville. 1980. 59 p.
- McAtee J, Scifres C, Drawe D. Improvement of gulf cordgrass range with burning or shredding. *J Range Manage.* 1979b;32(5):372–375.
- Anderson R. The historic role of fire. University of Oklahoma Press; 1990.191 p.
- Anderson R. An evolutionary model summarizing the roles of fire, climate and grazing animals in the origin and maintenance of grasslands: An end paper. University of Oklahoma Press; 1982. p. 297–308.
- Scasta JD, Thacker ET, Hovick TJ, et al. Patch–burn grazing (PBG) as a livestock management alternative for fire–prone ecosystems of North America. *Renew Agr Food Syst.* 2015;31(6):550–567.
- Samson F, Knopf F. Prairie conservation: preserving North America's most endangered ecosystem. Washington DC. 1996. 351 p.
- Hanselka C. The historical role of fire on South Texas rangelands. In: Hanselka CW, editor. Prescribed range burning in the coastal prairie and Eastern Rio Grande Plains. Texas Agricultural Extension Service. 1980:2–18.
- Leonard S, Kirkpatrick J, Mardsen–Smedley J. Variation in the effects of vertebrate grazing on fire potential between grassland structural types. *J Appl Ecol.* 2010;47(4):876–883.
- Drawe D. The role of fire in the coastal prairie. In Hanselka CW, editor. Prescribed range burning in the coastal prairie and Eastern Rio Grande Plains. Texas Agricultural Extension Service. 1980:101–113.
- Churchwell RC, Davis CS, Fuhlendorf S, et al. Effects of patch–burn management on dickcissel nest success in a tallgrass prairie. *J Wildlife Manage.* 2008;72(7):1596–1604.
- Hanselka C. Integrating livestock production systems with white–tailed deer management in South Texas. Proceedings. Beef Cattle Production Systems on Northeastern Mexico and Southern Texas Workshop. 1998. 215 p.
- Stubbenieck J, Volesky J, Ortmann J. Grassland Management with Prescribed Fire. The Board of Regents of the University of Nebraska. 2007; 6 p.
- White L, Hanselka C. Prescribed Range Burning in Texas. Dept. Rangeland Ecology and Management, Texas A&M University, Bryan. 1994. 9 p.
- Hulbert L. Fire effects on tallgrass prairie. In: Clambey GK, Pemble R, editors. The Prairie: Past, Present and Future, Proceedings of the Ninth North American Prairie Conference. Tri–College University Center of Environmental Studies, Fargo, North Dakota/Moorhead, Minnesota. 1986. p.138–142.
- Angell R, Stuth J, Drawe D. Diets and liveweight changes of cattle grazing fall burned gulf cordgrass. *J Range Manage.* 1986;39(3):233–236.
- White L. Carbohydrate reserves in grasses: a review. *J Range Manage.* 1973;26(1):13–18.
- Grace J, Allain L, Baldwin H, et al. Effects of prescribed fire in the coastal prairies of Texas. U.S. Geological Survey Open File Report. 2005;1287:46.
- Pieper R. Ecological implications of livestock grazing. In: Varva M, Laycock WA, Pieper RD editors. Ecological Implications of Livestock Herbivory in the West. Society for Range Management. Denver, CO. 1994. p.13–68.
- Briske D, Richards J. Plant responses to defoliation: A physiological, morphological and demographic evaluation. In: Bedunah DJ, Sosebee RE, editors. Society for Range Management. 1995. p. 635–710.
- Sosebee R, Wester D, Villalobos J, et al. How grasses grow–How plant growth relates to grazing management. *Acta Prataculturae Sinica.* 2004;14(1):117–125.
- Holechek JR, Pieper RC, Herbel C. Range management: Principles and practices. Boston, USA: Prentice Hall; 2001.
- Garza A, McLendon T, Drawe D. Herbage yield, protein content, and carbohydrate reserves in Gulf cordgrass (*Spartina spartinae*). *J Range Manage* 1994;47(1):16–21.
- Jourdonnais C, Bedunah D. Prescribed fire and cattle grazing on an elk winter range in Montana. *Wildlife Soc B.* 1990;18(3):232–240.
- Teague R, Provenza R, Kreuter U, et al. Multi–paddock grazing on rangelands: why the perceptual dichotomy between research results and ranch experience? *J Environ Manage.* 2013;(128):699–717.
- Charnov E. Optimal foraging, the marginal value theorem. *Theor Popul Biol.* 1976;9(2):129–136.

38. Winterhalder B. Opportunity–cost foraging models for stationary and mobile predators. *Am Nat.* 1983;122(1):73–84.
39. Parker K, Gillingham M, Hanley T, et al. Energy expenditure versus energy gain in free–ranging black–tailed deer. *Can J Zool.* 1996;74(3):442–450.
40. Allred B, Fuhlendorf S, Engle D, et al. Ungulate preference for burned patches reveals strength of fire–grazing interaction. *Ecol Evol.* 2013;1(2):132–144.
41. Coppedge B, Shaw J. Bison grazing patterns of seasonally burned tallgrass prairie. *J Range Manage.* 1998;51(3):258–264.
42. Fuhlendorf S, Engle D. Restoring heterogeneity on rangelands: ecosystems management based on evolutionary grazing patterns. *Bioscience.* 2001;51(8):625–632.
43. Fuhlendorf S, Engle D, Fuhlendorf S, et al. Application of a fire–grazing interaction to restore a shifting mosaic on tallgrass prairie. *J Appl Ecol.* 2004;41(4):604–614.
44. Archibald S, Bond W, Stock W, et al. Shaping the landscape: fire–grazer interactions in an African savanna. *Ecol Appl.* 2005;5(1):96–109.
45. Brockway D, Gatewood R, Paris R. Restoring fire as an ecological process in shortgrass prairie ecosystems: initial effects of prescribed burning during the dormant and growing seasons. *J Environ Manage.* 2002;65(2):135–152.
46. Clark P, Nielson R, Lee J, et al. Prescribed fire effects on activity and movement of cattle in mesic sagebrush steppe. *Rangeland Ecol Manage.* 2017;70(4):437–447.
47. Wilsey B. Variation in use of green flushes following burns among African ungulate species: the importance of body size. *Afr J Ecol.* 1996;34(1):32–38.
48. Wright H, Bailey A. Fire Ecology, United States and Southern Canada. *Wiley Interscience.* 1982.
49. McCuiston K, Grigar M, Wester D, et al. Can we predict forage nutritive value with weather parameters? *Rangelands.* 2014;36(1):2–9.
50. Butler G, Bailey R. Chemistry and Biochemistry of Herbage. USA: Academic Press; 1973.
51. Collins S, Wallace L. Fire in North American tallgrass prairies. Norman, Oklahoma: University of Oklahoma Press. 1990.
52. Sharrow S, Wright H. Effects of fire, ash, and litter on soil nitrate, temperature, moisture and tobosagrass production in the Rolling Plains. *J Range Manage.* 1977;30(4):266–270.
53. Teague W, Duke S, Waggoner J, et al. Rangeland ecosystem response to summer patch fires under continuous grazing. *Arid Land Res Manage.* 2008;22(3):328–241.