Invasive grasses in South Texas rangelands: historical perspectives and future directions

Authors: Wied, Justin P., Perotto-Baldivieso, Humberto L., Conkey, April A. T., Brennan, Leonard A., and Mata, José M.

Source: Invasive Plant Science and Management, 13(2) : 41-58

Published By: Weed Science Society of America

URL: https://doi.org/10.1017/inp.2020.11

The BioOne Digital Library (https://bioone.org/) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (https://bioone.org/subscribe), the BioOne Complete Archive (https://bioone.org/archive), and the BioOne eBooks program offerings ESA eBook Collection (https://bioone.org/esa-ebooks) and CSIRO Publishing BioSelect Collection (https://bioone.org/csiro-ebooks).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commmercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Invasive-Plant-Science-and-Management on 21 May 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Invasive Plant Science and Management

www.cambridge.org/inp

Invasive grasses in South Texas rangelands: historical perspectives and future directions

Justin P. Wied[1], Humberto L. Perotto-Baldivieso[2], April A. T. Conkey[2], Leonard A. Brennan[3] and José M. Mata[4]

[1]Graduate Research Assistant, Caesar Kleberg Wildlife Research Institute, Texas A&M University–Kingsville, Kingsville, TX, USA; [2]Assistant Professor and Research Scientist, Caesar Kleberg Wildlife Research Institute, Texas A&M University–Kingsville, Kingsville, TX, USA; [3]C.C. "Charlie" Winn Endowed Chair for Quail Research, Professor, and Research Scientist, Caesar Kleberg Wildlife Research Institute, Texas A&M University–Kingsville, Kingsville, TX, USA and [4]Research Associate, Department of Ecosystem Science and Management, Texas A&M University, College Station, TX, USA

Review

Cite this article: Wied JP, Perotto-Baldivieso HL, Conkey AAT, Brennan LA, and Mata JM (2020) Invasive grasses in South Texas rangelands: historical perspectives and future directions. Invasive Plant Sci. Manag **13**: 41–58. doi: 10.1017/inp.2020.11

Received: 15 August 2019
Revised: 3 January 2020
Accepted: 3 April 2020
First published online: 13 April 2020

Associate Editor:
Kelly Lyons, Trinity University

Keywords:
Bermudagrass; buffelgrass; guineagrass; Lehmann lovegrass; Old World bluestems; remote sensing; tanglehead; unmanned aerial vehicles

Author for correspondence:
Humberto L. Perotto-Baldivieso, Caesar Kleberg Wildlife Research Institute, Texas A&M University–Kingsville, 700 University Boulevard, MSC 218, Kingsville, TX 78363.
(Email: humberto.perotto@tamuk.edu)

Abstract

South Texas is home to a high diversity of species due to its location at the confluence of subtropical, desert, and coastal ecoregions. Historical overgrazing of South Texas rangelands transformed the savanna and prairie to a landscape dominated by woody plants and shrubs interspersed with low seral grass species and bare ground. During the first half of the 20th century, exotic grass species, coupled with the application of industrial agricultural practices appeared to be the future of forage production in South Texas and elsewhere. Several of these exotic species, namely King Ranch bluestem [*Bothriochloa ischaemum* (L.) Keng], Kleberg bluestem [*Dichanthium annulatum* (Forssk.) Stapf], Angelton bluestem [*Dichanthium aristatum* (Poir.) C.E. Hubbard], buffelgrass [*Pennisetum ciliare* (L.) Link], guineagrass [*Urochloa maxima* (Jacq.) R. Webster], Lehmann lovegrass (*Eragrostis lehmanniana* Nees), and Bermudagrass [*Cynodon dactylon* (L.) Pers.], have escaped pasture cultivation. Additionally, the native grass tanglehead [*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult.] has begun displaying invasive behaviors. The monoculture growth habit of these species simplifies vegetation structure, reduces biodiversity, and decreases habitat for many species of wildlife. These grasses also alter natural fire regimes and nutrient cycling. This landscape-level transformation of vegetation composition and structure requires monitoring to quantify and assess the spatial and temporal distributions of invasive species as a basis to inform management practices. Current advances in remote sensing technologies, such as very high spatial resolution coupled with daily satellite imagery and unmanned aerial vehicles, are providing tools for invasive vegetation monitoring. We provide a synthesis of the natural history of these grasses, including their introductions, an overview of remote sensing applications in South Texas, and recommendations for future management practices.

Introduction

Throughout the world, invasive plant species decrease biodiversity and alter ecological processes such as nutrient cycling, hydrology, and disturbance regimes, cumulatively decreasing the proper function of ecosystems (D'Antonio and Vitousek 1992; Richardson et al. 2000; Simberloff et al. 2013; Vitousek 1990). Some species are accidental introductions, but many have been introduced for agronomic and erosion control purposes before becoming a nuisance in their new environments (Fulbright et al. 2013; Simberloff et al. 2013). Drought tolerance and high productivity make species attractive candidates for introduction and are the same traits that promote invasiveness (Fulbright et al. 2013).

South Texas (Figure 1) includes the area south of the Edwards Plateau from the Rio Grande at Del Rio east to San Antonio and southeast to the Gulf of Mexico at the mouth of Lavaca Bay (Carter 1958; Fulbright and Bryant 2002). The region historically consisted of midgrass coastal plains and inland savanna with the now-prevalent honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) relegated to riparian areas, washes, and other upland sites (Griffith et al. 2007; Jahrsdoerfer and Leslie 1988). South Texas's variation in edaphic, geologic, and climatic factors, as well as the convergence of subtropical, eastern deciduous, and Chihuahuan desert species, creates a hyperdiverse region (Fulbright and Bryant 2002). The South Texas plains, exclusive of the coastal counties, are home to 514 resident native vertebrate species: 40 amphibians, 109 reptiles, 283 birds, and 82 mammals (Holt et al. 2000). Alone, the 76,006 ha of the South Texas Refuge Complex in the Lower Rio Grande Valley host 31 species of fish, 115 species of herpetofauna, 429 species of bird, and 44 species of mammal at some time during the year (Leslie 2016).

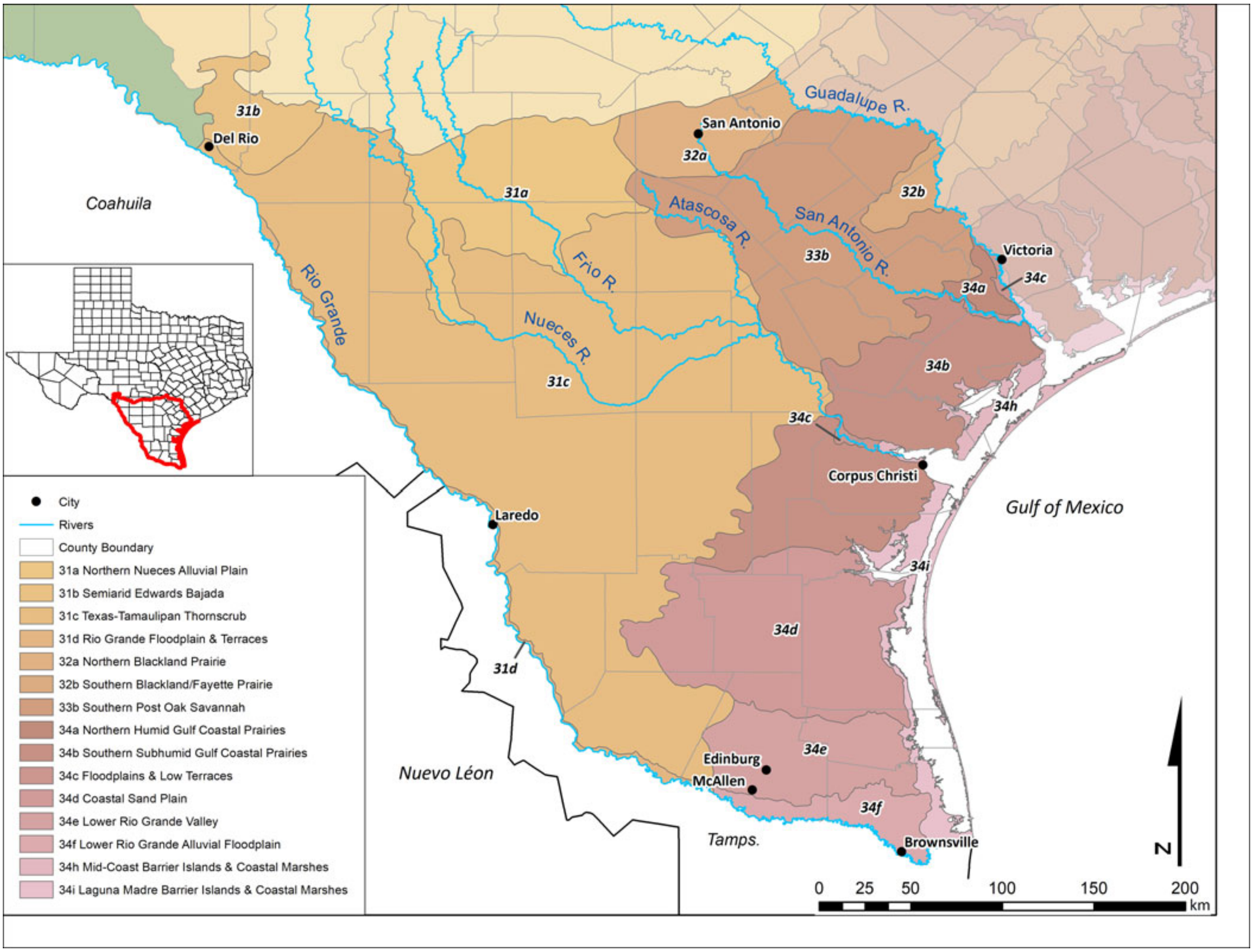

Figure 1. South Texas ecoregions based on Griffith et al. (2007).

Overstocking of sheep during the second half of the 19th century degraded range conditions and contributed to woody plant encroachment (Fulbright 2001; Lehmann 1969). Cattle ranching replaced sheep, but low carrying capacities required large tracts of rangeland (Fulbright 2001; Griffith et al. 2007). In the early 20th century, a search for grass species for forage and erosion control on degraded rangelands led to the introduction of several grass species to southern Texas (Fulbright et al. 2013). The extended droughts in the 1930s and 1950s in particular drove this search (Todd and Ogren 2016). Today, conservation of natural resources in South Texas is critical for property owners who increasingly earn their livelihood through outdoor recreation and are interested in wildlife management (Brennan et al. 2007; Fulbright and Bryant 2002; Smith 2010). Management strategies include brush management, decreased stocking rates, and restoration of pastures with native grass species. The increase of several invasive species (Table 1), such as tanglehead [*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult.], King Ranch bluestem [*Bothriochloa ischaemum* (L.) Keng; also known as yellow bluestem] (NRCS 2019), Kleberg bluestem [*Dichanthium annulatum* (Forssk.) Stapf], Angleton bluestem [*Dichanthium aristatum* (Poir.) C.E. Hubbard], buffelgrass [*Pennisetum ciliare* (L.) Link], guineagrass [*Urochloa maxima* (Jacq.) R. Webster], Lehmann lovegrass (*Eragrostis lehmanniana* Nees), and Bermudagrass [*Cynodon dactylon* (L.) Pers.], has become problematic for outdoor enthusiasts and conservationists (Smith 2010). *Pennisetum ciliare* and *C. dactylon* remain commonly planted exotic pasture grasses; however, the greater economic returns provided by fee-lease hunting are prompting landowners to provide suitable areas for wildlife habitat through conservation and ecological restoration. Restoration of native shrub species on abandoned cropland is impeded by the colonization of these grass species; this can be exacerbated by oil and gas infrastructure such as pad sites, pipelines, and rights-of-way (Cobb et al. 2016; Goertz 2013). Existing research has shown that grass invasions are likely to occur within 60 m of the abovementioned infrastructure. Changes in herbaceous vegetation restoration strategies with native ecotypic seed can provide resistance to exotic ingress (Falk et al. 2013; Twedt and Best 2004). In this review, we outline how these species have spread across South Texas. For each, we describe its natural history, uses, and impacts on rangelands and wildlife. Finally, we describe how we can use remote sensing methods to quantify the amount and spatial distribution of these species and monitor their spread across the landscape, as well as their potential effects on wildlife management in rangelands.

Table 1. Summary of key biological and ecological characteristics of the most common invasive grass species in South Texas.

Scientific name	Common synonymy	Common name(s)	Provenance	Life history	Growth form	Key ecological features	References
Bothriochloa ischaemum (L.) Keng	None	King Ranch bluestem, yellow bluestem	Temperate and subtropical Eurasia	Perennial	Caespitose	Fire-tolerant, highly grazing tolerant, drought resistant, associated with ecological disturbance	Celarier and Harlan 1955; Fulbright et al. 2013; Gabbard and Fowler 2007; Ortega-S et al. 2007; Shaw 2012
Cynodon dactylon (L.) Pers.	None	Bermudagrass	Subtropics and tropics of southeastern Africa and southern Asia	Perennial	Stoloniferous, rhizomatous	Moderately drought tolerant, grazing tolerant, little freeze tolerance, adaptable to many soil types, flooding tolerant	Anderson et al. 2002; Burton 1948; Fulbright et al. 2013; Shaw 2012; Tan et al. 2010; Way 2014
Dichanthium annulatum (Forssk.) Stapf	None	Kleberg bluestem	Tropical and subtropical eastern and southeastern Asia, tropical Africa	Perennial	Caespitose, weakly stoloniferous	Fire tolerant, highly grazing tolerant, moderately drought tolerant	Bhat et al. 2011; Celarier and Harlan 1955; Fulbright et al. 2013; Gabbard and Fowler 2007; Ortega-S et al. 2007; Shaw 2012
Dichanthium aristatum (Poir.) C.E. Hubbard	None	Angleton bluestem	Tropical and subtropical eastern and southeastern Asia	Perennial	Caespitose	Highly grazing tolerant, moderately drought tolerant	Bhat et al. 2011; Celarier and Harlan 1955; Fulbright et al. 2013; Shaw 2012
Eragrostis lehmanniana Nees	None	Lehmann lovegrass	Southern Africa	Annual, perennial	Caespitose	Fire tolerant, grazing tolerant, drought tolerant, adaptable to wide temperature range	Bock et al. 2007; Cox et al. 1988a; Fulbright et al. 2013; McGlone and Huenneke 2004; Shaw 2012; Williams and Baruch 2000
Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.	None	Tanglehead	Cosmopolitan tropics and subtropics	Perennial	Caespitose	Slow nutrient uptake, fire tolerant, grazing tolerant	Bielfelt and Litt 2016; Shaw 2012; Tothill and Hacker 1976; Wester et al. 2018
Urochloa maxima (Jacq.) R. Webster	*Panicum maximum* Jacq. *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs	Guineagrass	Tropical and subtropical Africa	Perennial	Caespitose	Shade tolerant, resistant to short drought, fire tolerant, not freeze hardy, adaptable to many soil types	Fulbright et al. 2013; Langeland et al. 2008; Parsons 1972; Shaw 2012; Williams and Baruch 2000
Pennisetum ciliare (L.) Link	*Cenchrus ciliaris* L.	Buffelgrass	Tropics and subtropics of Africa and southwestern Asia	Perennial	Caespitose	Fire adapted, grazing resistant, drought resistant, not freeze hardy, intolerable to heavy soils	Fulbright et al. 2013; Marshall et al. 2012; Pinkerton and Hussey 1985; Shaw 2012; Williams and Baruch 2000

Natural Histories of Invasive Grasses

Heteropogon contortus (Tanglehead)

Heteropogon contortus is described as native in the southern Texas plains where midgrass prairies were common (Carter 1958; Johnston 1963). Its worldwide distribution is pantropical, with clusters in the southwestern United States, Central America, Hawaiʻi, the Indonesian archipelago, Australia, the Indian subcontinent, Madagascar, and southern Africa, which has led some to question its native status within North America (Correll and Johnston 1970; Tothill and Hacker 1976). Tothill and Hacker (1976) consider it a successful species based on its ability to thrive across varying habitats.

Heteropogon contortus is a C_4 perennial bunchgrass of the Andropogoneae tribe with erect culms typically growing to 1 m (Reilly et al. 2002; Soreng et al. 2015). Leaves occur along the length of culms, which end in inflorescences of spikate racemes. A long, twisted awn arises from each upper floret (Everitt et al. 2011). These awns collectively twist together along the raceme, giving the grass its common name. The florets are easily detachable, and the stiff awns attach to fur, clothing, and vehicles, which transport the seeds and facilitate dispersal. Reproduction is primarily apomictic, although sexual reproduction is known to occur (Reilly et al. 2002; Tothill and Hacker 1976). Flowering typically occurs from summer to early fall in southern Texas (Johnston 1963), but Tothill and Hacker (1976) suggested that flowering response may be adaptive due to the instability in subtropical climates. Because it takes in soil nutrients at a slower rate than other associated plant species, *H. contortus* can spread into areas with lower soil productivity (Bielfelt and Litt 2016). Slow absorption also allows established stands of *H. contortus* growing on more nutritive soils to persist longer than other herbaceous species that deplete soil nutrients more quickly (Bielfelt and Litt 2016). Thus, where *H. contortus* has become invasive, it is associated with a monoculture growth of closed canopy (Figure 2), which may decrease bare ground and light availability for other plants (Bielfelt and Litt 2016).

Heteropogon contortus has been considered a good native forage for livestock production during its growth phase; however, upon maturity, the coarse culms and decreased palatability reduce its preference among grazers (Reilly et al. 2002). Additionally, the stiff tangle of awns may cause physical injury to animals. Historically, *H. contortus* was a minor component of rangeland in southern Texas (Carter 1958), and likely not a major component of livestock diets. Johnston's (1963) data show a marked decrease in *H. contortus* abundance on grazed sites, indicating palatability to livestock. The decrease in grazing within South Texas has likely led to the proliferation of *H. contortus* (Wester et al. 2018). Many ranchers in South Texas have observed declining grazing preference by cattle when the plants reach maturity, which contrasts to other areas in western Texas and worldwide, where increasing grazing pressure decreases *H. contortus* abundance, regardless of its growth stage (Tjelmeland 2011).

Wester et al. (2018) proposed that changing land-use practices contributed to an increase of *H. contortus*. Early research on grazing reduction in southern Arizona likewise showed an increase in *H. contortus* production after removal of grazing pressure (Canfield 1948). Prescribed fire is a common tool for improving range through herbaceous renewal and brush removal, but *H. contortus* is naturally fire tolerant (Goergen and Daehler 2001; Tjelmeland 2011). Prescribed fire studies conducted in Jim Hogg County, TX, showed that small patches ($<6.97\ \mathrm{m}^2$) of *H. contortus* increased in both burned and unburned patches 1 yr following a spring fire, but the increase was faster (50%) on burned sites compared with unburned plots (17%) (Wester et al. 2018). The resulting regrowth of surviving plants increased in crude protein 16% and decreased in crude fiber a month after burning, before decreasing with 52% livestock utilization in the burned patches compared with 1.8% in unburned patches (Wester et al. 2018). The use of prescribed burning can therefore make *H. contortus* a more desirable forage. However, Grace et al. (2016) found that fire can promote output up to 1,500 seedlings m^{-2}.

Figure 2. Monoculture of *Heteropogon contortus* in a ranch pasture in Jim Hogg County, TX.

Few studies have been conducted on the effects of *H. contortus* on wildlife in southern Texas. Bielfelt (2013) reported that increasing density of *H. contortus* increased density of breeding pairs among three obligate grassland species: Cassin's sparrow (*Peucaea cassinii* Woodhouse), Eastern meadowlark (*Sturnella magna* Linnaeus), and grasshopper sparrow (*Ammodramus savannarum* J. F. Gmelin). Mourning dove (*Zenaida macroura* Linnaeus) density increased with rising *H. contortus* density, though the presence of scissor-tailed flycatchers (*Tyrannus forficatus* Gmelin) decreased. The growth form of *H. contortus* likely provides some ground-foraging and ground-nesting bird species improved protection from predation (Bielfelt 2013). Buelow et al. (2011) found that northern bobwhite (*Colinus virginianus* Linnaeus) used sites dominated by *H. contortus* for nesting in similar proportion (i.e., without preference) to available patches across the landscape; however, they avoided *H. contortus* patches during times spent off-nest. Presumably, the dense nature of *H. contortus* monocultures hampers the movement of ground foragers and may decrease the availability of a diverse diet (Buelow et al. 2011). Similarly, Edwards et al. (2017) detected fewer coveys of *C. virginianus* where invasive grasses, including *H. contortus*, reached >20% canopy cover. This correlated to areas of decreased bare ground and forb production. Where *H. contortus* is prevalent, grassland birds seem to be trapped in a trade-off between improved nesting conditions and less diverse food resources.

Old World Bluestems

The term "Old World bluestems" is applied to agronomic grasses in the Americas imported from Eurasia and Africa. These species belong to a monophyletic, agamic complex of species within the genera *Bothriochloa*, *Dichanthium*, and *Capillipedium* (Harlan et al. 1958; Mathews et al. 2002; Soreng et al. 2015). Specifically, the species encountered in South Texas are *B. ischaemum* (King Ranch bluestem, also known as yellow bluestem), *D. annulatum*

(Kleberg bluestem), and *D. aristatum* (Angleton bluestem) (NRCS 2019). They are distantly related to the native bluestem species within the *Andropogon* and *Schizachyrium* genera with which they form sister clades (Arthan et al. 2017; Mathews et al. 2002). The native range of *B. ischaemum* is temperate and subtropical Eurasia (Celarier and Harlan 1955; Todd and Ogren 2016). *Dichanthium annulatum* and *D. aristatum* are both found from India to southeast and eastern Asia, with *D. annulatum* also occurring in tropical Africa (Celarier and Harlan 1955; Bhat et al. 2011; Todd and Ogren 2016).

The Old World bluestems are C_4 perennial species (Soreng et al. 2015). Hybridization can occur between species in *Dichanthium* and *Bothriochloa* (Singh 1965). Diploids of each species reproduce sexually, whereas polyploids are facultative or obligate apomicts (Harlan and de Wet 1963). Apomictic reproduction is common within both genera and among their hybrids, though vegetative reproduction by stolons occurs (Gould and Shaw 1983; Harlan et al. 1964; Hatch et al. 1999). A plasticity in growth form coupled with hybridization makes identification to the species level difficult, though a groove on the pedicellate spikelets is a defining character of *Bothriochloa* (Best 2006; Celarier and Harlan 1955).

In the United States, several species of *Dichanthium* and *Bothriochloa* were investigated for use in forage production beginning in the early 20th century. *Dichanthium aristatum* and hurricane grass [*Bothriochloa pertusa* (L.) A. Camus] appear to have been accidental introductions to the Western Hemisphere, via the Caribbean Islands (Celarier and Harlan 1955). *Dichanthium annulatum* also appears to have been an accidental introduction (Alderson and Sharp 1994; Novosad and Pratt 1959). Caucasian bluestem [*Bothriochloa bladhii* (Retz.) S.T. Blake] and *B. ischaemum* arrived in the New World for use as potential forage producers (Celarier and Harlan 1955).

Bothriochloa ischaemum is usually recorded as an accidental introduction to the United States (Harlan 1951). The earliest record of *B. ischaemum* in the United States was traced back to a shipment from the U.S. consulate in Amoy (modern Xiamen), Fujian, China, to the California Agriculture Experiment Station in Berkeley (Alderson and Sharp 1994; Celarier and Harlan 1955). Similar material was shipped to the Texas Agriculture Experiment Station in Angleton in 1914 by the U.S. Bureau of Plant Industry (Alderson and Sharp 1994). This species was found growing unexpectedly in a pasture of the King Ranch (Nueces County, TX) by Soil Conservation Service agronomist Nick Díaz in 1939 (Lea 1957). From this material, 34 kg of seed was sent to the Soil Conservation Service nursery in San Antonio, TX, for production investigations (Nixon 1949). Commercial release of *B. ischaemum* began in 1949 (Alderson and Sharp 1994). This year also marks the first accession to a herbarium of a *B. ischaemum* sample collected in Kleberg County (South Texas) and not associated with experiment stations or grass nurseries (Gabbard and Fowler 2007).

Dichanthium annulatum was noticed growing on King Ranch by agronomist Nick Díaz (Lea 1957). The original source of this population is unknown. Beginning around 1915, the King Ranch began experimental plantings of Rhodes grass (*Chloris gayana* Kunth) with an eventual 12,282 ha in production by 1940 (Lea 1957). It is possible seeds or stolons of *D. annulatum* were accidentally mixed with the *C. gayana* material, as both occur in South Africa. Seeds were collected from this population and sent to the Soil Conservation Service nursery in San Antonio, where the grass was increased for production with an informal release of grass seed to producers in the 1940s (Alderson and Sharp 1994).

Dichanthium aristatum plants were donated to the Texas Agriculture Experiment Station in Angleton in 1915 by the USDA Office of Forage-Crop Investigation from materials sent from the Poona Agriculture College (modern Pune Agriculture University) in India (Hafner 1926; Novosad and Pratt 1959). By the 1950s, two cultivars of *D. aristatum*, 'Gordo' and 'Medio', were created from source plants from South Africa and Bee County, TX, respectively, at the Soil Conservation Service nursery in San Antonio. A third cold-hardy cultivar named 'T-587' was released in 1981 from worldwide-sourced stock in the 1950s (Alderson and Sharp 1994).

By the late 1940s, the desire for improved pasture grasses grew, and Old World bluestem production increased, with nearly 55,000 kg of *B. ischaemum* seed harvested for sale in Texas and Oklahoma (Nixon 1949). The Old World bluestems were seen as superior to the native bluestem species due to their grazing resistance and ability to thrive under high fertilizer regimens (Ahring et al. 1978). In the 1950s, work to create improved varieties was undertaken by the Oklahoma Agriculture Experiment Station (Celarier and Harlan 1956). King Ranch instituted a seeding program of planting *B. ischaemum* and *D. annulatum*, among other introduced grasses such as *P. ciliare* and *C. dactylon*, in pastures cleared of brush (Lea 1957; Schnupp and DeLaney 2012). By the 1970s, Old World bluestems were investigated for erosion and weed control along highway rights-of-way by the Texas Highway Department (later Texas Department of Transportation; McCully et al. 1970). In addition, trials were conducted on *B. ischaemum* to test its use as a reclamation grass on former oil well reserve pits in the 1980s (McFarland et al. 1987). An estimated 1 million ha of Texas and Oklahoma rangeland has been seeded with nonnative bluestems since the mid-1980s (Ruffner and Barnes 2012).

Ecosystem disturbances appear to have neutral to positive feedbacks to the spread of these grass species. Root growth is deep, especially in *B. ischaemum*; Allred and Nixon (1955) note that roots reached a depth of 2 to 3 m in a heavy clay soil with roots comprising two times the vegetation growth, improving drought resistance. The exotic bluestems are highly tolerant of grazing, especially in comparison to native grass species (Gabbard and Fowler 2007; Ortega-S et al. 2007). *Bothriochloa bladhii*, *B. ischaemum*, and *D. annulatum* appear to tolerate prescribed fire applications (Gabbard and Fowler 2007; Grace et al. 2001). Fires occurring in the mid-growing season have shown negative effects on *B. ischaemum*, notably when tillers are composed of prereproductive and reproductive tillers (Ruckman et al. 2012; Simmons et al. 2007). Similarly, postdrought fires during the growing season were found more successful than dormant-season fires in promoting growth of native forbs without increasing spread of *B. ischaemum* (Twidwell et al. 2012). Encroachment of woody plants appears to indirectly facilitate establishment of *B. ischaemum* by creating disturbances, and thus pathways for invasion within the landscape (Alofs and Fowler 2013).

Shaw (2012) classified *D. annulatum* as poor livestock forage, and Pacheco et al. (1983) found it has a low nutritive value with low protein content and high levels of fiber and silica. It is palatable to cattle and important in late summer when other grasses become dormant (Meyer and Brown 1985). *Bothriochloa ischaemum* is listed as fair forage for livestock and wildlife (Shaw 2012). Palatability of this species is high, though stems cure quickly late in the growing season, thus deterring grazing (Davis 2011; Powell 1994). Old World bluestem forage is capable of supporting gains in livestock weight early in the summer, but this capability declines by August (Coleman and Forbes 1998). Crude protein content

Figure 3. Characteristic yellow color of reproductive stage of *Bothriochloa ischaemum* in Nueces County, TX.

of *B. ischaemum* can decrease from 19% with immature growth to 3.7% with mature growth (National Research Council 1971). Crude protein can be increased in Old World bluestems by maintaining pasture at a short height and applying nitrogen fertilizer (McCollum 2000).

The effects that Old World bluestems have on wildlife have been studied for a wide variety of species and topics. As a component of herbivore diets, *B. ischaemum* and *D. annulatum* have been analyzed for white-tailed deer (*Odocoileus virginianus* Zimmermann) in Texas. *Odocoileus virginianus* are primarily browsing animals, but use of grass increases when the quality of other components decrease or when fresh regrowth occurs after grazing by livestock (Arnold and Drawe 1979; Bryant et al. 1979; Chamrad and Box 1968; Everitt and Drawe 1974). Bryant et al. (1981) confirmed this seasonal use of *B. ischaemum* in central Texas *O. virginianus*. *Bothriochloa ischaemum* is consumed by *O. virginianus* as succulent growth or when woody browse is not preferred, but its preference index values are low compared with other available grass species. Similarly, Meyer et al. (1984) found *O. virginianus* used *D. annulatum* in the summer, accounting for 14% of their seasonal diet. Despite the high usage, the in vitro digestible energy of *D. annulatum* was among the lowest at 1.85 kcal g^{-1} which would require 246 g to provide a daily maintenance level of digestible energy of 3,252 kcal g^{-1} to a 55-kg lactating doe (Meyer et al. 1984). Mean percent crude protein values of *D. annulatum* samples are 6.7% (SE = 0.7%) and only provide sufficient protein >13% for *O. virginianus* growth and reproduction during spring and autumn (Meyer and Brown 1985). These results indicate a low utility of these exotic bluestem grasses by *O. virginianus*.

The tendencies (Figure 3) of *Bothriochloa* and *Dichanthium* to develop monocultures create changes in habitat suitability for various wildlife species. For example, mounds of maritime pocket gophers (*Geomys personatus maritimus* Davis) are less likely to be found on sites containing *D. annulatum* (Cortez et al. 2015). A study of *B. ischaemum* impacts on rodent communities in the Edwards Plateau of Texas found hispid cotton rat (*Sigmodon hispidus* Say and Ord) densities to be similar between native vegetation and invaded sites, but fulvous harvest mice (*Reithrodontomys fulvescens* J.A. Allen) and northern pygmy mice (*Baiomys taylori* Thomas) were only captured in native vegetation (Sammon and Wilkins 2005). Similarly, the species richness of a rodent community decreased in north-central Oklahoma grasslands with 40% to 60% Old World bluestem cover compared with native grassland controls, with *S. hispidus* again becoming the most prevalent species (Greer et al. 2014). Kamler et al. (2003) and Pavur (2016) hypothesized that swift foxes (*Vulpes velox* Say) avoided Conservation Reserve Program grasslands seeded to Old World bluestems where taller and denser vegetation decreased prey abundance and reduced vision, which increases susceptibility to predation by coyotes (*Canis latrans* Say).

Lesser prairie-chicken (*Tympanuchus pallidicinctus* Ridgway) hens require areas of abundant bare ground for brood rearing, while males require short vegetation for lek sites, both of which can be lacking within Old World bluestem–dominated grasslands (Ripper et al. 2008). As with *V. velox*, Conservation Reserve Program fields planted with exotic species did not provide more benefit to *T. pallidicinctus* over native prairie (Wolfe et al. 2016). Where the structure and plant diversity between native prairie and Conservation Reserve Program grassland greatly differs, a smaller abundance of grassland songbirds are benefited (Chapman et al. 2004). *Ammodramus savannarum* are one of the few grassland songbirds whose breeding density increased in Old World bluestem fields, though high breeding densities have been negatively correlated with individual reproductive success (George et al. 2009, 2013a). The vegetation structure between native prairie and *B. ischaemum*–dominated grasslands were similar enough to support dickcissel (*Spiza americana* J. F. Gmelin) and *S. magna* nesting sites (George et al. 2009). While wintering birds may use Old World bluestem fields for structural cover, there may exist a trade-off for lower food abundance in these fields (George et al. 2013b). Dense growth of Old World bluestems on Conservation Reserve Program fields provided scaled quail (*Callipepla squamata* Vigors) with some cover, but they avoided dense vegetation and favored more diverse structure and plant species composition (Kuvlesky et al. 2002). Similarly, *C. virginianus* was less abundant in Conservation Reserve Program fields (George et al. 2013a), although, Arredondo et al. (2007) found that *C. virginianus* did use *D. annulatum* for nesting cover, though at lower percentages compared with other grass species.

Old World bluestems simplify arthropod diversity, which decreases nutrient cycling, prey abundance, and pollination services (Kuvlesky et al. 2012; Litt and Steidl 2010). Biomass of arthropods was significantly lower (Kruskal-Wallis $H = 307$, $P < 0.001$) in *B. ischaemum* sites (0.3 g $sample^{-1}$) compared with native prairies (1.3 g $sample^{-1}$; Hickman et al. 2006). Arthropod abundance in *D. annulatum* grasslands remained similar to that of native grasslands but differed by species richness (Cord 2011; Mitchell and Litt 2016; Woodin et al. 2010). The Shannon diversity index for insects on a native grassland site was 1.4 with evenness of 0.7, whereas these values were 1.0 and 0.5, respectively, on a *D. annulatum*–dominated site in Nueces County, TX (Woodin et al. 2010). Exotic bluestems had a simplifying effect on several arthropod functional guilds, including herbivorous, predatory, and detritivorous groups. Relative abundances of hemipteran and homopteran species increased relative to other herbivorous species such as orthopterans (Cord 2011; McIntyre and Thompson 2003; Mitchell and Litt 2016; Woodin et al. 2010). Detritivorous insects were least abundant among *D. annulatum* (Cord 2011), and isopods decreased on exotic grasslands, presumably due to changes in amounts and composition of litter (Mitchell and Litt 2016). The simplification of these arthropod groups appears to affect the distributions of predatory arthropod species, namely arachnids (Cord 2011; Woodin et al. 2010). Ants were absent from Old

World bluestem sites, particularly harvester ants (*Pogonomyrmex* spp. Mayr), which are a primary prey species for the threatened Texas horned lizard (*Phrynosoma cornutum* Harlan; McIntyre 2003). Grassland birds are typically granivorous but include arthropods in their diets, especially during breeding and brood rearing, with insects from the orders Lepidoptera, Orthoptera, and Coleoptera being most important to their diets (McIntyre and Thompson 2003; Wiens 1973). These orders decreased in abundance in Old World bluestem sites.

Pennisetum ciliare (Buffelgrass)

Pennisetum ciliare is native to tropical and subtropical Africa and southwestern Asia, with South Africa being the likely geographic origin of the species (Burson et al. 2012; Marshall et al. 2012). It was initially introduced to four sites in Texas for investigation as a pasture grass; however, soil conditions in Angleton and cold winters in Temple, Chillicoathe, and Tyler prevented survival of these plantings (Hanselka 1988; Pinkerton and Hussey 1985). A second accession of plant material, this time from the Turkana Basin of Kenya and Ethiopia, was successfully established at the Soil Conservation Service nursery in San Antonio in 1946 (Alderson and Sharp 1994; Cox et al. 1988a). The USDA Soil Conservation Service has success with field trials in southern Texas and informally released a variety for production in 1949 (Cox et al. 1988a; Hanselka 1988). Commercial production began in the 1950s, coinciding with a period of severe drought in Texas (Marshall et al. 2012). Several cultivars were developed during this period through the 1980s (Alderson and Sharp 1994). By 1985, *P. ciliare* was established on over 4 million ha in southern Texas, accounting for 90% of seeded pasture in the state south of San Antonio (Cox et al. 1988a; Mayeux and Hamilton 1983). Overall it is the dominant herbaceous cover on 10 million ha in southern Texas and northeastern Mexico (Williams and Baruch 2000). It was similarly promoted in Arizona and Sonora, Mexico, for improved pastures in the 1940s and 1950s, respectively (Franklin et al. 2006; Marshall et al. 2012; Martin-R et al. 1995). The spread in Sonora has reached more than 1 million ha (Arriaga et al. 2004).

Pennisetum ciliare is a perennial within the Paniceae taxonomic tribe that uses C_4 carbon fixation in photosynthesis (Marshall et al. 2012; Shaw 2012). Plants grow tufted to 120 cm in height with spikelets subtended by soft hairs on a spike-like panicle (Everitt et al. 2011). The species is highly plastic in its growth form (Marshall et al. 2012). It is an aposporous apomict, with tetraploidy being the most common genotype; sexual reproduction is known in some genotypes (Akiyama et al. 2005; Burson et al. 2012; Ozias-Akins and Van Dijk 2007). Seed dormancy appears to change according to the provenance of the parent material (Hacker and Ratcliff 1989). Winkworth (1971) found 10% of sown seed remained viable after 2 yr, while seed maintained in dry storage appeared to enter a second dormancy and emerge with 60% germination. *Pennisetum ciliare* can also reproduce vegetatitvely via rhizomes and stolon production (Marshall et al. 2012). Seed is spread via attachment to animal fur, vehicles, runoff, and wind (Ortega-S et al. 2013). Some studies suggest *P. ciliare* may have allelopathic qualities (Franks 2002; Fulbright and Fulbright 1990).

Persistence of *P. ciliare* stands requires frost-free winters and medium-textured, low-salinity soils (Hanselka 1988). Roots can grow to 2.4 m deep in the soil, but the low and high water-holding capacities of coarse- and fine-textured soils, respectively, retard growth, as do high water tables (Hanselka 1988; Marshall et al. 2012). There is comparable production of aboveground biomass on sandy- and loamy-textured soils, but *P. ciliare* becomes a predominant species and spreads more easily on loams and sandy clays (Johnson and Fulbright 2008). Establishment occurs more readily on more alkaline soils than acidic soils (Johnson and Fulbright 2008). Wet winters can destroy seed released during the growing season, and hard freezes can damage established plants (Cox et al. 1988a). *Pennisetum ciliare*, especially the cultivar 'T-446', most commonly grown in North America, persists where precipitation ranges from 330 to 550 mm but dies when precipitation reaches >600 mm (Ibarra-F et al. 1995). Despite these limitations, cultivars have been produced that better tolerate unfavorable conditions by breeding an apomict with desirable traits with a sexual reproductive plant (Burson et al. 2012; Cox et al. 1988a; Marshall et al. 2012).

When mature plants are removed from a site, seedlings can quickly reestablish themselves if seed vigor is high (Tjelmeland et al. 2008). Lyons et al. (2013) demonstrated that removal of *P. ciliare* increased cover of native herbaceous species in the Sonoran Desert in northern Mexico. The species is fire adapted, with a combination of a deep root system, the capacity for rapid regrowth after defoliation, and responsiveness to nitrogen addition in the soil (Lyons et al. 2013, Marshall et al. 2012). Unlike most native grass species, following defoliation, *P. ciliare* regrows from nodes along lower stems rather than from the crown (Van Devender et al. 1997). *Pennisetum ciliare* has been shown to alter soil carbon and nitrogen across multiple climate regions across Mexico and has been demonstrated to significantly contribute to aboveground carbon losses in the Sonoran Desert (Abella et al. 2012; Williams and Baruch 2000). However, Lyons et al. (2013) found that replacing nitrogen through fertilizer supplementation improved the response of *P. ciliare* over native vegetation cover in test plots.

Pennisetum ciliare responds better to grazing pressure than most native grass species, a factor that is likely due to lateral growth of tillers (Fensham et al. 2013). Its drought tolerance and response to grazing has made it an attractive livestock forage (Marshall et al. 2012). Within Tamaulipan brushland, aboveground primary production was reported to be 7,025 kg ha^{-1} (Martin-R et al. 1995). *Pennisetum ciliare* is a preferred grass species for both cattle and domesticated sheep (Everitt et al. 1981; Ramírez et al. 1995). Nutritional values of *P. ciliare* often outperform those of native grasses (Hanselka 1989). Temporary increases in crude protein and phosphorus were noted after prescribed burning of *P. ciliare*, and burned patches were grazed more heavily due to improvements in palatability and forage quality (Hanselka 1989). Cattle-stocking rates increased in South Texas from approximately 12 ha AU^{-1} (animal unit) on native range to 4 ha AU^{-1} on *P. ciliare* pasture (Hanselka 1988). Similarly, Sonoran Desert stocking rates increased from 27 to 40 ha AUY^{-1} (animal unit year) on native range to 9 to 15 ha per AUY^{-1} on *P. ciliare* pasture (Martin-R et al. 1995). However, high stocking rates may weaken stands of *P. ciliare* and decrease its spread (Ortega-S et al. 2013).

Pennisetum ciliare has been studied as a forage component of *O. virginianus* and mule deer (*Odocoileus hemionus* Rafinesque) diets. Both deer species were shown to use the grass, mostly fresh green growth, as forage in Sonora (Ortega-S et al. 2013). Additionally, *O. hemionus* used *P. ciliare* sites in a manner similar to native range as long as water and thermal cover were provided (Ortega-S et al. 2013). Levels of crude protein were below winter requirements of *O. virginianus* in South Texas, but the grass contributed significantly to winter diets (Everitt and Gonzalez 1979).

Figure 4. Early spring growth of *Pennisetum ciliare* on a pipeline right-of-way in Jim Hogg County, TX.

Lagomorphs in Sonora showed between 70% and 80% use of *P. ciliare* in areas where native grasses were available (Ortega-S et al. 2013).

The presence of stands of *P. ciliare* (Figure 4) appears to decrease the usable space of habitat for several species of birds (Grahmann et al. 2018). Food production is lower on these sites, with a decrease in the cover, density, and diversity of forbs and decreased abundance and diversity of arthropods (Flanders et al. 2006; Sands et al. 2009). Specifically, arthropods from the orders Hymenoptera, Coleoptera, and Araneae, all important protein components of brooding birds, were less abundant (Flanders et al. 2006). The trophic structure appears to be simplified through simplified vegetation communities (Sands et al. 2009). Flanders et al. (2006) discovered that the abundance of lark sparrows (*Chondestes grammacus* Say), black-throated sparrows (*Amphispiza bilineata* Cassin), northern mockingbirds (*Mimus polyglottos* Linnaeus), *C. virginianus*, and *P. cassinii* were all greater on sites with native vegetation. Species that form resident breeding populations preferred native vegetation to *P. ciliare*–dominated sites (Flanders et al. 2006). In South Texas, *C. virginianus* abundance decreases with increases in the percentage of *P. ciliare*, and quail use declines where the grass composes >20% of cover (Hernández and Guthery 2012). *Colinus virginianus* do use the grass as screening cover and nesting sites, but this may be an artifact of lack of preferred vegetation; however, the lack of bare ground produces a barrier to brood use (Hernández and Guthery 2012). Grahmann et al. (2018) found that cool-season prescribed burns combined with continuous grazing improved usable space for *C. virginianus*. Masked quail (*Colinus virginianus ridgwayi* Brewster) in Sonora, Mexico, used *P. ciliare* as cover during a drought, but their use of these sites declined once native herbaceous vegetation recovered (Kuvlesky et al. 2002). Overall, Flanders et al. (2006) found that pastures dominated by *P. ciliare* supported only about half of the biomass of arthropods and half the density of *C. virginianus* compared with pastures dominated by native grasses. Thus, *P. ciliare* has the potential to reduce carrying capacity for *C. virginianus* by about 50%.

The frequent management practices of cool-season prescribed burns and disking to increase forb production for quail may increase the density of a stand of *P. ciliare* (Kuvlesky et al. 2002; Tjelmeland et al. 2008). The species is a noted colonizer of disturbed areas, and these disturbances increase the recruitment of seedlings whose success is contingent on bare ground (McIvor 2003; Sands et al. 2009). Disking may be a method of spreading *P. ciliare* into areas with loamy soils, and root-plowing brush in southern Texas increased the frequency of *P. ciliare* compared with control sites (Johnson and Fulbright 2008; Ruthven et al. 1993). On infertile, arid sites, fire itself may not expand *P. ciliare* so much as the lack of native vegetation (Fensham et al. 2013). The intensity at which the species burns is high (Cohn 2005). Fires do not occur frequently on the Hawaiʻian Islands or in the Sonoran Desert, and as a result, the native vegetation lacks adaptations to fire (McDonald and McPherson 2011; Simonson et al. 2004). *Pennisetum ciliare* creates a landscape more akin to subtropical grasslands than a desert, and the fuel load induces fires in the Sonoran Desert that are more severe; this places species such as saguaro [*Carnegiea gigantea* (Engelm.) Britton & Rose] and organpipe cactus [*Stenocereus thurberi* (Engelm.) Buxbaum] at a higher risk of mortality (McDonald and McPherson 2011). Similarly, Hawaiʻian grasslands of *H. contortus* burned more slowly with a small spread compared with areas invaded by *P. ciliare* (Daehler and Carino 1998). The greatest risk to biodiversity in Mexico posed by *P. ciliare* may be anthropogenic; for example, conversion of native rangeland to improved pasture has been implicated in the clearing of >100,000 ha of land (Brenner 2010, 2011).

Urochloa maxima (Guineagrass)

Urochloa maxima is native to tropical and subtropical Africa with a longer history of establishment in the Americas than the other species described here (Akiyama et al. 2008; Parsons 1972). In its native range, it inhabits conditions from grasslands to open woodlands, with tolerance for shady conditions (Duke 1983; Skerman and Riveros 1990). The species was first recorded in the Caribbean Islands in the late 17th century, presumably introduced from ships engaging in the slave trade between western Africa and European colonies (Parsons 1972). It was present in Mississippi by the 1810s and southern Mexico by the 1860s, where it increased the productivity of grazing lands (Parsons 1972). *Urochloa maxima* had become naturalized in Hawaiʻi by 1871 and spread throughout the islands' *H. contortus* grasslands (Ammondt et al. 2013; Daehler and Carino 1998). Production was investigated near Wollangbar, New South Wales, Australia, in the 1890s and spread north along the coast to tropical areas of Queensland (McCosker and Teitzel 1975). The grass was studied at a Soil Conservation Service Plant Materials Center in Wailuku, Hawaiʻi, in 1957, and though a cultivar was not released publicly, it was distributed for field trials across the state (Alderson and Sharp 1994). The arrival of *U. maxima* in southern Texas and northeastern Mexico is relatively recent, with a rapid expansion evident from the 1970s; however, repeated introductions before 1970 did not result in lasting populations (Best 2006; Correll and Johnston 1970). The current range is approximately from the central Gulf Coast near Victoria, TX, to Monterrey, Nuevo León, Mexico (Best 2006). This population is presumed to have escaped from an unauthorized planting of *U. maxima* in the Rio Grande Valley with seeds obtained from the agriculture experiment station in Weslaco, TX (Best 2006). The species has now been identified rapidly expanding along the southern reach of the San Antonio River within the city limits of San Antonio (KG Lyons, personal communication).

Urochloa maxima is a member of the Paniceae tribe that uses the C_4 photosynthetic pathway (Reinheimer et al. 2005; Shaw 2012). The species is a caespitose perennial, generally growing up to 2.5 m with a many-branched panicle inflorescence (Shaw 2012). Two phenotypes appear in southern Texas: one of tropical provenance with an upright growth habit and a second of subtropical provenance with geniculate growth and shade tolerance (Best 2006). Reproduction may occur apomictically or sexually (Akiyama et al. 2008). Sexual reproduction occurs among diploid individuals, with apomixis occurring in polyploid individuals (Savidan 1980). Propagation is primarily through seed dispersal by wind, water, and animal movements (Ansari et al. 2008; Best 2006). Veldman and Putz (2010) demonstrated that motor vehicles carry the seeds, which established on disturbed logging sites in a tropical dry forest in Bolivia. The species tolerates a variety of soil types, though production decreases on less fertile soils (Duke 1983; Skerman and Riveros 1990). Water-logged soils, saline soils, and hard frost damage the plant (Duke 1983; Langeland et al. 2008). A variety of cultivars have been produced with varying growth forms and adaptations to tolerate different environments (McCosker and Teitzel 1975). A deep root system provides resistance to short periods of drought by accessing water down to 1 m in the soil profile (Langeland et al. 2008). The robust root system was shown by Schaller et al. (2003) to restrict the lateral growth of the root system of young rainbow eucalyptus (*Eucalyptus deglupta* Blume) trees in Costa Rica. The species burns readily and is fire tolerant, regenerating following fire disturbance from belowground rhizomes (Ellsworth et al. 2014; Langeland et al. 2008; Skerman and Riveros 1990). *Urochloa maxima* has shown allelopathic qualities in laboratory experiments (Chou and Young 1975).

Urochloa maxima is a productive livestock forage worldwide, especially for beef and dairy cattle, but also for sheep (Aganga and Tshwenyane 2004; McCosker and Teitzel 1975). The grass is often used for hay and silage production (Skerman and Riveros 1990). It is considered a highly palatable forage (Best 2006). Continuous grazing of *U. maxima* pasture can lead to mortality, but frequent grazing leaving a standing crop of >0.35 m produces continuous fresh growth (Skerman and Riveros 1990). Due to its worldwide use and differing agronomic practices (e.g., fertilizer application), the nutrient content of *U. maxima* varies widely among localities (Skerman and Riveros 1990). However, crude protein is highest and crude fiber lowest in fresh growth (McCosker and Teitzel 1975). Barbosa et al. (2012) recommend grazing management practices that promote a high tiller population renewal to increase the production of younger growth and thereby increase growth rates and nutritional values. Ramirez-Yañez et al. (2007) found that cattle use of *U. maxima* pastures increased following prescribed burning, presumably from the flush of regrowth in South Texas. The seeds of this species show some ability to germinate after passing through the gastrointestinal tract of cattle (Gardener et al. 1993).

The population of subtropical *U. maxima* in southern Texas has become invasive in croplands, rangelands, and urban areas (Best 2006). *Urochloa maxima* and, to an extent, *P. ciliare* comprise the dominant herbaceous layer along many sites on the Rio Grande river corridor, where they have become impossible to remove (Lonard and Judd 2006). A study of seven sites along the Rio Grande found that *U. maxima* was the dominant species in the ground layer, particularly those sites with a dense shrub and tree canopy cover (Lonard and Judd 2002; Figure 5). The two sites where it was absent were dominated by salt-tolerant species (Lonard and Judd 2002). Restoration of Tamaulipan thornscrub in southern Texas has been hampered by invasion of *M. maximus* (Dick 2015; Twedt and Best 2004; Vela 2015). Additionally, it competes with the endangered Tamaulipan kidneypetal (*Ayenia limitaris* Cristóbal) for partial shade under shrubs (USFWS 2014).


Figure 5. *Urochloa maxima* growing under the canopy of *Prosopis glandulosa* and sweet acacia [*Vachellia farnesiana* (L.) Wight & Arn.] in Kleberg County, TX.

The tall and lanky growth and shade tolerance of *U. maxima* has made it a problem species for citrus growers in Florida and Texas (Hall et al. 1998; Sauls 1995). During drought conditions, the presence of dry tillers in shrubs can create ladders that carry fire from the ground to shrub and tree canopies (Best 2006). Changes in fire behavior and return intervals are blamed for ecosystem changes to dry tropical forests in Hawaiʻi by clearing native forest species and allowing trees and shrubs to invade (Ellsworth et al. 2014). Additionally, *U. maxima* invades native Hawaiʻian *H. contortus* grasslands and remnant dry lowland forests, causing a reduction in plant diversity (Ammondt et al. 2013; Daehler and Carino 1998).

There are few studies investigating the effects of *U. maxima* on wildlife. Moore (2010) investigated *C. virginianus* use of *U. maxima* sites and found that nest success decreased by 4% for every 1% increase of *U. maxima* cover, presumably from reductions in diversity and production of forb and grass seeds. Selection of *U. maxima* for loafing cover may be related to the shade tolerance of the grass and its growth within brush (Moore 2010). A study of grass seed selection among pen-raised *C. virginianus* found preferred selection for *U. maxima* and switchgrass (*Panicum virgatum* L.) seeds compared with Texas millet [*Urochloa texana* (Buckley) R. Webster] and plains bristlegrass [*Setaria leucopila* (Scribn. & Merr.) K. Schum.] seeds (Larson et al. 2012). The seeds of *U. maxima* are large relative to their mass and provide 18% protein and 3.58 kcal g^{-1} of energy; however, in wild *C. virginianus* harvested in Kenedy County, TX, only 11 of 260 crops from necropsied quail contained *U. maxima* seeds, comprising <2% of total grass seeds (Larson 2008; Larson et al. 2012). Displacement of native grasses by *U. maxima* is causing declines in grass skipper butterflies (subfamily Hesperiinae), whose caterpillars feed on native grasses (USFWS 2008).

Eragrostis lehmanniana (Lehmann Lovegrass)

Eragrostis lehmanniana is native to the southern Kalahari Desert and the Karoo of South Africa, where it is considered an early successional species (Cox et al. 1988b; Humphrey 1994). In 1932, seed was imported from the Griqualand West region by Franklin Crider

Figure 6. Dense stand of *Eragrostis lehmanniana* growing alongside a ranch road in southwestern Texas.

and planted near Superior, AZ, at the Boyce Thompson Arboretum (Cox et al. 1988a). Testing of the grass was conducted at the Soil Conservation Service nursery in Tucson, AZ, beginning in 1935, and a refined accession, 'A-68', was selected for seed production in 1937 (Alderson and Sharp 1994; Cox et al. 1988b). Approximately 135 kg of seed produced at the Tucson nursery was planted on Soil Conservation Service plots from Arizona to west Texas, and in 1950, the Arizona Agriculture Experiment Station and Soil Conservation Service released seed for commercial production (Alderson and Sharp 1994; Cox et al. 1988b). Approximately 70% of commercially produced seed was sown on rangelands and along highway rights-of-way in Arizona, New Mexico, and Texas, with the remaining seed planted in the northern Mexican states of Chihuahua, Coahuila, and Sonora (Cox et al. 1988a, 1988b). Seeds from diploid individuals were imported from Northern Cape, South Africa, to allow genetic insertion of preferred traits, and a second variety labeled 'TEM-SD' was commercially released as germplasm by the Texas Agriculture Experiment Station and USDA Agriculture Research Service in 1991 (Alderson and Sharp 1994).

Eragrostis lehmanniana is a caespitose perennial (Figure 6) within the Eragrostideae tribe that utilizes C_4 carbon fixation (Shaw 2012; Soreng et al. 2015). Culms grow to 80-cm tall with a profusion of 7- to 15-cm-long layered leaves that create a clump up to 92 cm across (Crider 1945; Shaw 2012). Plants are weakly stoloniferous with many culms decumbent or geniculate along lower nodes (Burson and Voigt 1996; Zeid et al. 2011). Roots are fine textured and only reach shallowly into soil, with 80% occurring in the top 30 cm of the soil profile (Cox et al. 1992). Asexual reproduction via apomixis occurs in polyploidy individuals, though diploid individuals ($2n = 2x = 20$) produce seed sexually (Alderson and Sharp 1994; Burson and Voigt 1996). Apomictic individuals predominate in its native African range and in the southwestern United States (Burson and Voigt 1996; Schussman et al. 2006; Zeid et al. 2011). Despite lower genetic variability from nonsexual reproduction, *E. lehmanniana* exhibits a high phenotypic plasticity that allows it to survive multiple ecological sites (Schussman et al. 2006). Established stands of *E. lehmanniana* can produce two seed crops each year, a heavy yield in early summer and a lighter yield in late summer to early autumn (Crider 1945). Seedling emergence appears to decrease in soil textures with higher fractions of clay, and germination is inhibited when seeds are below 5 mm in the soil profile (Cox and Martin 1984; Cox et al. 1988b).

Eragrostis lehmanniana is adapted to climates with temperature ranges between 0 and 38 C and requires 130 to 160 mm of precipitation during active growth (Cox et al. 1988a). The species persists but seldom spreads with summer precipitation between 100 and 160 mm and persists and spreads with precipitation between 160 and 220 mm. Stands may produce as much as 2,695 kg ha^{-1} of dry matter during favorable conditions (Anderson et al. 1953). Where it is the dominant species, net aboveground production increases, with pure stands having up to four times that amount (McGlone and Huenneke 2004). Cox et al. (1990) reported that *E. lehmanniana* annually produced three to four times more green forage than native grasses in southeastern Arizona. Palatability of *E. lehmanniana* is low, and cattle prefer native perennial grasses during summer (Cable 1971). During other seasons, utilization increases in relation to native grasses due to *E. lehmanniana*'s prolonged green forage (Cox et al. 1988b). Crude fiber constitutes 35% of fresh forage and provides 3.6% and 3.2% digestible protein for cattle and sheep, respectively (National Research Council 1971). The protein content of *E. lehmanniana* is higher in winter compared with native forages such as Arizona cottontop [*Digitaria californica* (Benth.) Henr.] (Cable 1976). *Eragrostis lehmanniana* is considered resistant to defoliation, as it evolved to withstand high grazing pressures (Anable et al. 1992; Bock et al. 2007). Disturbance, especially grazing, does not appear to be necessary for the spread of *E. lehmanniana* as much as proximity to seed sources (Bock et al. 2007; Geiger and McPherson 2005; McClaran and Anable 1992).

Eragrostis lehmanniana is considered a fire-tolerant species and recovers more quickly than native species (McGlone and Huenneke 2004). This has a 2-fold effect on enhanced propagation of the species. The earlier recovery over native grasses allows for higher seed production within a year after a fire event, and removal of litter, whether by fire or mechanical means, enhances seedling emergence by increasing red light penetration and temperature fluctuations at the ground level (McGlone and Huenneke 2004; Roundy et al. 1992; Ruyle et al. 1988). McGlone and Huenneke (2004) described a higher quantity of litter accumulation in *E. lehmanniana* stands, which may alter fire intensity and encourage further establishment of the species.

Little research has been conducted on the effects of *E. lehmanniana* on wildlife. Several studies of grassland birds indicate that *E. lehmanniana* decreases food and shelter resources (Bock and Bock 1992; Flanders et al. 2006; Whitford 1997). At the Santa Rita Experimental Range, Gambel's quail (*Callipepla gambelii* Gambel) and *C. squamata* both avoided *E. lehmanniana* sites in favor of mesquite grasslands and less dense perennial grass cover with high forb diversity, respectively (Medina 2003). In South Texas, *E. lehmanniana* was used by *C. virginianus* for nesting but generally avoided for forage areas (Sands et al. 2012). *Eragrostis lehmanniana* decreases abundance of Palmer's century plant (*Agave palmeri* Engelm.), which is an important nectar source for Mexican long-tongued bats (*Choeronycteris*

Figure 7. Monoculture sod of *Cynodon dactylon* during anthesis in coastal South Texas.

mexicana Tschundi) and lesser long-nosed bats (*Leptonycteris yerbauenae* Martínez and Villa-R.; Lindsay et al. 2011).

Cynodon dactylon (Bermudagrass)

Cynodon dactylon has a cosmopolitan distribution with likely origins in southeastern Africa and south Asia, though it has been culturally significant in India since at least 1500 BCE due to its ability to provide productive forage for livestock (Kneebone 1966; Way 2014). It is one of the most widely distributed plants in the world (Harlan et al. 1970). *Cynodon dactylon* first arrived in the Western Hemisphere on one of the voyages of Christopher Columbus to the Caribbean Islands (Way 2014). The first likely introduction to North America occurred between 1733 to 1738, when botanist Robert Miller brought material to Savannah, GA, and within 50 yr, it was recorded in South Carolina as well (Kneebone 1966). Intentional plantings were used for pasture, but spread is also attributed to movement of livestock and the use of hay as packing material (Kneebone 1966). The first cultivar, 'Coastal', was released in 1943 as a cross between a productive strain discovered near Tifton, GA, and two tall strains of southern African provenance (Burton 1948; Kneebone 1966; Way 2014). Many seeded cultivars have since been developed, as well as hybrids that are essentially sterile and require propagation by sprigging (Corriher and Redmon 2009).

Cynodon dactylon is a rhizomatous and stoloniferous sod-forming grass (Figure 7) of the Cynodonteae tribe that utilizes C_4 photosynthesis (Shaw 2012; Soreng et al. 2015). Besides being used for pasture and hay production, it is a common lawn grass in the southern United States (Way 2014). The most frequently encountered varieties outside cultivation are the diploid ($2n = 2x = 36$) 'common' and the tetraploid 'Coastal', which is larger and more resistant to foliage removal, drought, frost, and disease (Alderson and Sharp 1994; Harlan et al. 1970; Rouquette et al. 2011). Both varieties are adaptable to many soil textures and pH ranges, but heavy clays and sands reduce production without fertilizer application (Burton 1948; Corriher and Redmon 2009; Marsalis 2004). *Cynodon dactylon* has little freeze tolerance, which limits its distribution (Anderson et al. 2002). The species exhibits a high degree of phenotypic plasticity, with many naturally occurring ecotypes (Harlan et al. 1970; Hoveland 1960; Rouquette et al. 2011). It is considered drought resistant, though the degree varies depending on ecotype or cultivar, and it is able to withstand submergence, both at depth and of long duration (Tan et al. 2010; Zhou et al. 2013).

Cynodon dactylon has a history of use for livestock production in the southern United States since the late 19th century (Way 2014). It withstands defoliation well (Grace et al. 2001). Fresh, mature *C. dactylon* forage provides 28.5% crude fiber, 5.8% protein, and energy levels of 2.72 Mcal kg^{-1} for cattle, while its hay provides 29.4% crude fiber, 7.9% protein, and energy of 2.20 Mcal kg^{-1} for cattle (National Research Council 1971). Average annual crude protein from South Texas samples was 11.4%, which meet the needs for dry cows across all seasons and for lactating cows all seasons but winter (Gonzalez and Everitt 1982).

Dense growth of *C. dactylon* has been shown to be highly utilized forage of black-bellied whistling ducks (*Dendrocygna autumnalis* Linnaeus) and Canada geese (*Branta canadensis* Linnaeus) in South Texas (Bolen and Forsyth 1967; Glazener 1946). However, this growth decreases survivability of *C. virginianus* chicks by impeding movement and increasing temperatures up to 4 C compared with forb-dominated sites (Martin et al. 2015). Furthermore, *C. dactylon* provides poor nesting cover, and it outcompetes other plants, subsequently decreasing seed and arthropod availability to *C. virginianus* (Bond et al. 2005; Crouch 2017). Gust and Schmidly (1986) observed a change in rodent diversity and hypothesized that the monoculture habit of *C. dactylon* decreases food availability of small mammals.

Cynodon dactylon is considered an early successional species and is closely associated with disturbed rangelands (Barnes et al. 2013; Grace et al. 2001). Way (2014) suggests it seldom exists naturally as a component of climax vegetation. It has been found to be an early colonizer of formerly submerged land in the Texas Gulf prairies (Scifres and Mutz 1975). The affinity for disturbance by *C. dactylon* could prove problematic for habitat restoration projects; however, drought has been shown to be a factor aiding in removal of *C. dactylon* during a restoration in South Texas (Crouch 2017). This suggests that the spread of this species in South Texas may be restricted to the more mesic coastal prairies and riparian zones farther inland.

Monitoring Invasive Species: Remote Sensing Approaches

Understanding the spatial and temporal dynamics of invasive grasses is critical to the effective monitoring and management of rangelands (Villarreal et al. 2019). Monitoring of rangeland conditions was first systematically established under a range succession model based on Clementsian succession theory (Westoby et al. 1989). This model allowed changes in vegetation along a single axis and did not account for encroachment of shrubs and trees or the introduction of exotic species (Briske et al. 2005). State and transition models were developed wherein the ecosystem may occupy one of multiple potential stable states (Briske et al. 2005; Westoby et al. 1989). Autogenic or allogenic triggers may modify ecological structure and function during transitions between states creating a threshold, with return to a previous state requiring intervention (Young et al. 2014). This model has since become useful for describing many types of terrestrial ecosystems (Bestlemeyer et al. 2011). It is under this framework that we hypothesize that invasive grass species have transitioned rangelands in South Texas into a new stable state.

Past monitoring in rangelands relied on subjective measurements of ground observations (Booth and Tueller 2003). Remote sensing technologies have played an increasing role in the estimation of standing yields and canopy heights, mapping

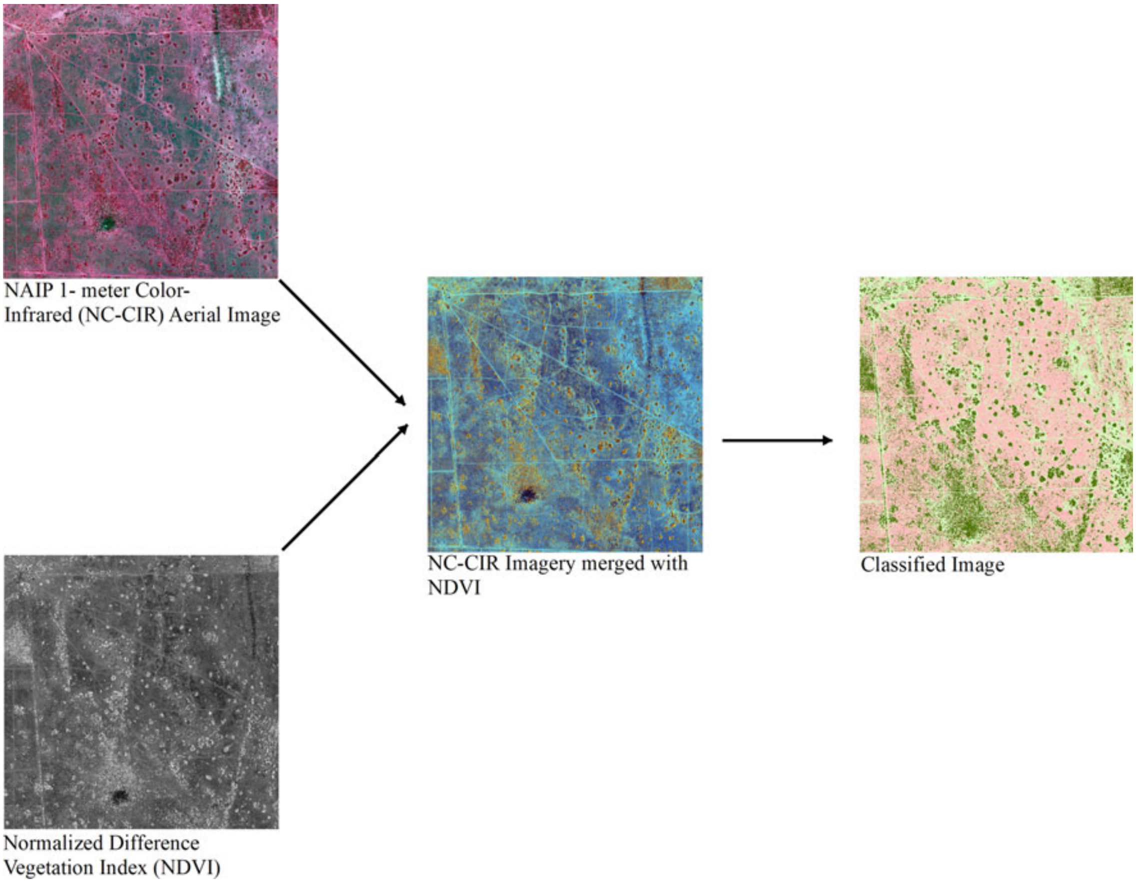

Figure 8. Workflow of unsupervised classification of 2014 National Agriculture Imagery Program aerial photography with normalized difference vegetation index layer stack (adapted from Mata et al. 2018).

of vegetation distributions, and detection of invasive plant species (Bradley and Mustard 2006; Everitt and Deloach 1990; Everitt et al. 1995, 1996; Franklin et al. 2006; Hestir et al. 2008; Hunt et al. 2003; Piñeiro et al. 2006). Since 1972, Landsat satellites have provided the longest record of Earth observation and have been used to classify invasive grasses (Roy et al. 2014). Knight (2004) successfully classified Landsat imagery to distinguish *B. ischaemum* and *B. bladhii* from native grasslands and croplands in Oklahoma. Image classification, combined with habitat models, has been applied to quantify *P. ciliare* environments where invasion is likely (Brenner et al. 2012; Young et al. 2013). Coarser spatial and high-spectral resolution satellites, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), have been used to map the distribution and phenological status of *P. ciliare* in the Sonoran Desert of Arizona (Wallace et al. 2016). Using higher spatial resolutions (<5-m pixel size) than MODIS and Landsat, aerial photography has also been used to detect the phenological responses of *P. ciliare* to water stress in South Texas (Everitt et al. 1987). More recently, Mata et al. (2018) classified National Agriculture Imagery Program images to assess the spatial and temporal distribution of *H. contortus* (Figure 8) between 2008 and 2014 and observed an increase from 4% to 20% in *H. contortus* cover. Although aerial photography provides higher spatial resolution for lower cost, it lacks the spectral resolution of satellite imagery, usually providing only bands in the visible and near-infrared spectra (Huang and Asner 2009; Underwood et al. 2003). Additionally, imagery lacks consistent data acquisition, with very low temporal revisit times that can limit its usefulness for monitoring studies (Underwood et al. 2003).

Recently launched satellites have included hyperspectral sensors that detect a continuous spectrum of visible and shortwave electromagnetic radiation divided into hundreds of small bands (Huang and Asner 2009; Toth and Jóźków 2016). Production of microsatellites has allowed for constellations producing <10-m resolution multispectral data at weekly or shorter time intervals (Toth and Jóźków 2016). These microsatellites lack the spectral resolution of the larger satellites, but some platforms, such as RapidEye, include a red edge band, which has improved vegetation mapping accuracies and allowed for detection of foliar nitrogen estimation (Ramoelo et al. 2012; Schuster et al. 2012). Operating a constellation of small satellites allows reductions in revisit times to days compared with the large Earth-observing satellites (Butler 2014). Deployment of unmanned aerial vehicles (Figure 9) has allowed production of low-cost on-demand imagery with spatial scales <2 cm (Anderson and Gaston 2013; Rango et al. 2006). These high spatial resolutions allow the identification of individual patches using mounted digital cameras and ground control points to create mosaicked, georeferenced imagery (Hill et al. 2017; Lu and He 2017). This data-acquisition process can also be used to construct digital elevation models and digital surface models to quantify canopy height comparable with more expensive Lidar data (Ni et al. 2015).

While remote sensing has advanced significantly in terms of platforms, classification algorithms, and access to data and

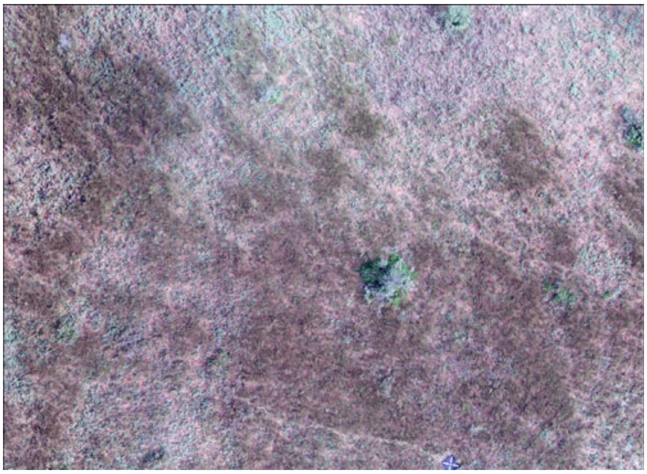

Figure 9. Natural color orthoimagery acquired by an unmanned aerial vehicle of a pasture containing *Heteropogon contortus* in South Texas. Dark areas in the image correspond to patches of *H. contortus*. Pixel resolution is 1.4 cm.

classification approaches through the cloud, there is a need to improve accuracy and the delivery of information to end users (e.g., ranchers, land managers). Traditional image classifications have allowed the classification of invasive monocultures of *H. contortus* in South Texas with accuracies greater than 85% (Mata et al. 2018). However, there is a need to develop classification approaches for the other species in South Texas. This may require the combination of unmanned aerial vehicle platforms combined with satellite platforms to improve both temporal and spatial resolution (Rango et al. 2006). Development of classification approaches and very-high-resolution multispectral imagery in different seasons may also prove useful to improve identification of invasive grasses in South Texas. New approaches such as deep learning and artificial intelligence can potentially improve accuracies to greater than 95% (Zeng et al. 2019). The use of multiple periods and time-series analyses can be used to inform the temporal dynamics of invasive grasses at local and regional scales (Mata et al. 2018; Villarreal et al. 2019). The use of landscape metrics to assess patch dynamics can be used to evaluate the spread of invasive grasses across the landscape (Mata et al. 2018). Young et al. (2014) used remote sensing information and combined it with landscape metrics to quantify thresholds among states in UK peatlands. Image classification, combined with wildlife observation data, can provide a useful framework to develop spatially explicit habitat suitability models to prioritize management and restoration of wildlife habitat. Hence, developing approaches that integrate image classification, soil information, wildlife data, and other environmental variables can help translate remote sensing products from image classifications to management tools for land managers in rangelands as part of their geospatial technology tools.

Future Directions

Land use in South Texas has changed in the last 100 yr from dedicated livestock operations to a combination of livestock and wildlife conservation. The introduction of grasses, once very beneficial to livestock operations, may now have become problematic for wildlife conservation and habitat management. The spread of invasive grasses as a result of changes in land-use practices, such as reduced grazing and oil and energy development, may pose new challenges in South Texas landscapes (Smith 2010; Wester et al. 2018). The extent that invasive species have spread precludes complete eradication as a practical conservation option. Some exotics like *P. ciliare* and *C. dactylon* are still planted and actively managed by some landowners. Approaches to manage invaded areas may include the introduction of pyric herbivory (Grahmann et al. 2018; Walther 2019). Depending on management objectives, reintroducing native species through fire or native reseeding may improve habitat for wildlife and provide a more sustainable livestock production, with potentially more resilient and profitable ecosystems in the long term. There is a need to develop state and transition models for South Texas rangelands and determine whether these rangelands have transitioned beyond a threshold to a new potentially stable state. Quantifying the spatial and temporal distribution and monitoring the spread of these species will best inform management practices moving into the future. We have already been able to quantify the spatial and temporal dynamics of *H. contortus* (Mata et al. 2018), but it is important to develop regional models to assess potential areas of *H. contortus* invasions. Research into creating methods to quantify the distribution of *B. ischaemum* and *D. annulatum* with daily, high spatial resolution satellite imagery may provide the framework for local and regional image classifications. Similar studies need to be conducted for *D. aristatum*, *P. ciliare*, *M. maximus*, *E. lehmanniana*, and *C. dactylon*. These approaches, combined with fieldwork, would provide a road map to understanding the biology and ecology of invasive grasses in South Texas. The results of these studies will provide conservationists and landowners the tools to preserve and maintain the Last Great Habitat.

Acknowledgments. Funding for this project was provided by the South Texas chapter of the Quail Coalition. An additional grant was awarded from NASA and the Center for Systems Integration and Sustainability at Michigan State University to JPW. LAB was supported by the C.C. “Charlie” Winn Endowed Chair in the Richard M. Kleberg, Jr. Center for Quail Research. We are grateful to F. S. Smith, A. D. Falk, K. G. Lyons, and the two anonymous reviewers who helped us improve this article. Figures 6 and 7 were provided by F. S. Smith. No conflicts of interest have been declared. This is manuscript number 19-118 from the Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, Kingsville, TX.

References

Abella SR, Chiquoine LP, Backer DM (2012) Ecological characteristics of sites invaded by buffelgrass (*Pennisetum ciliare*). Invasive Plant Sci Manag 5: 443–453

Aganga AA, Tshwenyane S (2004) Potentials of Guinea grass (*Panicum maximum*) as forage crop in livestock production. Pak J Nutr 3:1–4

Ahring RM, Taliaferro CM, Russell CC (1978) Establishment and Management of Old World Bluestem Grasses for Seed. Stillwater: Oklahoma State University Agriculture Experiment Station Technical Bulletin T-149. 28 p

Akiyama Y, Hanna WW, Ozias-Akins P (2005) High-resolution physical mapping reveals that the apospory-specific genomic region (ASGR) in *Cenchrus ciliaris* is located on a heterochromatic and hemizygous region of a single chromosome. Theor Appl Genet 111:1042–1051

Akiyama Y, Yamada-Akiyama H, Yamanouchi H, Takahara M, Ebina M, Takamizo T, Sugita S, Nakagawa H (2008) Estimation of genome size and physical mapping of ribosomal DNA in diploid and tetraploid guineagrass (*Panicum maximum* Jacq.). Grassl Sci 54:89–97

Alderson J, Sharp WC (1994) Grass Varieties in the United States. 2nd ed. Washington, DC: U.S. Department of Agriculture Handbook 170. 296 p

Allred BW, Nixon WM (1955) Grass for Conservation in the Southern Great Plains. Washington, DC: U.S. Department of Agriculture Farmers' Bulletin No. 2093. 30 p

Alofs KM, Fowler NL (2013) Loss of native herbaceous species due to woody plant encroachment facilitates the establishment of an invasive grass. Ecology 94:751–760

Ammondt SA, Litton CM, Ellsworth LM, Leary JK (2013) Restoration of native plant communities in a Hawaiian dry lowland ecosystem dominated by the invasive grass *Megathyrsus maximus*. Appl Veg Sci 16:29–39

Anable ME, McClaran MP, Ruyle GP (1992) Spread of introduced Lehmann lovegrass *Eragrostis lehmanniana* Nees. in southern Arizona, USA. Biol Conserv 61:181–188

Anderson D, Hamilton LP, Reynolds HG, Humphrey RR (1953) Reseeding desert grassland ranges in southern Arizona. Tucson: Arizona Agricultural Experiment Station Bulletin 249. 32 p

Anderson JA, Taliaferro CM, Martin D (2002) Freeze tolerance of bermudagrasses. Crop Sci 42:975–977

Anderson K, Gaston KJ (2013) Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Front Ecol Environ 11:138–146

Ansari S, Hirsh H, Thair T (2008) Removal of Invasive Fire-Prone Grasses to Increase Training Lands in the Pacific. Department of Defense Legacy Resources Management Program Report. Honolulu, HI: SWCA Environmental Consultants. 42 p

Arnold LA, Drawe DL (1979) Food habits of white-tailed deer in the South Texas Plains. J Range Manage 32:175–178

Arredondo JA, Hernández F, Bryant FC, Bingham RL, Howard R (2007) Habitat-suitability bounds for nesting cover of northern bobwhites on semiarid rangelands. J Wildl Manag 71:2592–2599

Arriaga L, Castellanos-V. AE, Moreno E, Alarcón J (2004) Potential ecological distribution of alien invasive species and risk assessment: a case study of buffel grass in arid regions of Mexico. Conserv Biol 18:1504–1514

Arthan A, McKain MR, Traiperm P, Welker CAD, Teisher JK, Kellogg EA (2017) Phylogenomics of Andrpogoneae (Panicoideae: Poaceae) of mainland Southeast Asia. Syst Bot 42:418–431

Barbosa RA, do Nascimento Júnior D, Vilela HH, de Lana Sousa BM, da Silva SC, Batista Euclides VP, Teixeira da Silveira MC (2012) Morphogenetic and structural characteristics of guinea grass tillers at different ages under intermittent stocking. R Bras Zootec 41:1583–1588

Barnes TG, DeMaso SJ, Bahm MA (2013) The impact of 3 exotic, invasive grasses in the southeastern United States on wildlife. Wildlife Soc B 37:497–502

Bhat V, Mahalakshmi C, Saran S, Raina SN (2011) *Dichanthium*. Pages 89–112 *in* Kole C, ed. Wild crop relatives: genomic and breeding resources–millets and grasses. Berlin: Springer

Best C (2006) Fighting weeds with weeds: battling invasive grasses in the Rio Grande delta of Texas. Pages 307–318 *in* Proceedings of the Weeds across Borders Conference. Tucson: Arizona-Sonora Desert Museum

Bestlemeyer BT, Goolsby DP, Archer SR (2011) Spatial perspectives in state-and-transition models: a missing link to land management? J Appl Ecol 48:746–757

Bielfelt BJ (2013) Invasion by a Native Grass: Implications of Increased Dominance of *Heteropogon contortus* (Tanglehead) for Grassland Birds. MS thesis. Kingsville: Texas A&M University–Kingsville. 117 p

Bielfelt BJ, Litt AR (2016) Effects of increased *Heteropogon contortus* (tanglehead) on rangelands: the tangled issue of native invasive species. Rangeland Ecol Manag 69:508–512

Bock CE, Bock JH (1992) Response of birds to wildfire in native versus exotic Arizona grassland. Southwest Nat 37:73–81

Bock CE, Bock JH, Kennedy L, Jones ZF (2007) Spread of non-native grasses into grazed versus ungrazed desert grasslands. J Arid Environ 71:229–235

Bolen EG, Forsyth BJ (1967) Foods of the black-bellied tree duck in South Texas. Wilson Bull 79:43–49

Bond BT, Baumann CD, Lane MW II, Thackston RE, Bowman JL (2005) Efficacy of herbicides to control bermudagrass for enhancement of northern bobwhite habitat. Proc Annu Conf SEAFWA 59:191–199

Booth DT, Tueller PT (2003) Rangeland monitoring using remote sensing. Arid Land Res Manage 17:455–467

Bradley BA, Mustard JF (2006) Characterizing the landscape dynamics of an invasive plant and risk of invasion using remote sensing. Ecol Appl 16:1132–1147

Brennan LA, Hernández F, Bryan FC (2007) Introduction. Pages 3–5 *in* Brennan LA, ed. Texas Quails: Ecology and Management. 1st ed. College Station: Texas A&M University Press

Brenner JC (2010) What drives the conversion of native rangeland to buffelgrass (*Pennisetum ciliare*) pasture in Mexico's Sonoran Desert? The social dimensions of a biological invasion. Hum Ecol 38:495–505

Brenner JC (2011) Pasture conversion, private ranchers, and the invasive exotic buffelgrass (*Pennisetum ciliare*) in Mexico's Sonoran Desert. Ann Assoc Am Geogr 101:84–106

Brenner JC, Christman Z, Rogan J (2012) Segmentation of Landsat Thematic Mapper imagery improves bufelgrass (*Pennisetum ciliare*) pasture mapping in the Sonoran Desert of Mexico. Appl Geogr 34:569–575

Briske DD, Fuhlendorf SD, Smeins FE (2005) State-and-transition models, thresholds, and rangeland health: a synthesis of ecological concepts and perspectives. Rangeland Ecol Manage 58:1–10

Bryant FC, Kothmann MM, Merrill LB (1979) Diets of sheep, Angora goats, Spanish goats and white-tailed deer under excellent range conditions. J Range Manage 32:412–417

Bryant FC, Taylor CA, Merrill LB (1981) White-tailed deer diets from pastures in excellent and poor range condition. J Range Manage 34:193–200

Buelow MC, Brennan LA, Hernández F, Fulbright TE (2011) Influence of invasive tanglehead grass on northern bobwhite nesting and habitat use in South Texas. Bull Tex Ornithol Soc 44:15–27

Burson BL, Actkinson JM, Hussey MA, Jessup RW (2012) Ploidy determination of buffel grass accessions in the USDA National Plant Germplasm System collection byflow cytometry. S Afr J Bot 79:91–95

Burson BL, Voigt PW (1996) Cytogenetic relationships between the *Eragrostis curvula* and *E. lehmanniana* complexes. Int J Plant Sci 157:632–637

Burton GW (1948) Coastal Bermuda grass. Tifton, GA: -+Coastal Plain Experiment Station Circular 10. 21 p

Butler D (2014) Many eyes on Earth. Nature 505:143–144

Cable DR (1971) Lehmann lovegrass on the Santa Rita Experimental Range, 1937–1968. Rangeland Ecol Manag 24:17–21

Cable DR (1976) Twenty years of changes in grass production following mesquite control and reseeding. J Range Manage 29:286–289

Canfield RH (1948) Perennial grass composition as an indicator of condition in southwestern mixed grass ranges. Ecology 29:190–204

Carter MG (1958) Reclaiming Texas brushland range. J Range Manage 11:1–5

Celarier RP, Harlan JR (1955) Studies on Old World bluestems. Stillwater: Oklahoma Agricultural Experiment Station Bulletin T-58. 31 p

Celarier RP, Harlan JR (1956) An Andropogoneae garden in Oklahoma. Taxon 5:183–186

Chamrad AD, Box TW (1968) Food habits of white-tailed deer in South Texas. J Range Manage 21:158–164

Chapman RN, Engle DM, Masters RE, Leslie DM Jr (2004) Grassland vegetation and bird communities in the southern Great Plains of North America. Agric Ecosyst Environ 104:577–585

Chou C, Young C (1975) Phytotoxic substances in twelve subtropical grasses. J Chem Ecol 1:183–193

Cobb F, Smith FS, Stuver S (2016) Invasive Grass Species Distributions at Well Pad Sites in South Texas. College Station: Texas A&M Institute of Renewable Natural Resources Final Report to Texas General Land Office and Houston Advanced Research Council. 23 p

Cohn JP (2005) Tiff over tamarisk: can a nuisance be nice, too? BioScience 55:648–654

Coleman SW, Forbes TDA (1998) Herbage characteristics and performance of steers grazing Old World bluestems. J Range Manage 51:399–407

Cord EE (2011) Changes in Arthropod Abundance and Diversity with Invasive Grasses. MS thesis. Kingsville: Texas A&M University–Kingsville. 99 p

Correll DS, Johnston MC (1970) Manual of the Vascular Plants of Texas. Renner: Texas Research Foundation

Corriher VA, Redmon LA (2009) Bermudagrass varieties, hybrids and blends for Texas. College Station: Texas AgriLife Extension Publication E-320. 8 p

Cortez JD, Henke SE, Wiemers DW, Fulbright TE, Wester DB, Riddle R (2015) Distribution and habitat selection by the maritime pocket gopher. Southeast Nat 14:41–56

Cox JR, Giner-Mendoza M, Dobrenz AK, Smith MF (1992) Defoliation effects on resource allocation in Arizona cottontop (*Digitaria californica*) and Lehmann lovegrass (*Eragrostis lehmanniana*). J Grassl Soc South Afr 9:53–59

Cox JR, Martin MH (1984) Effects of planting depth and soil texture on the emergence of four lovegrasses. J Range Manage 37:204–205

Cox JR, Martin-R MH, Ibarra-F FA, Fourie JH, Rethman JFG, Wilcox DG (1988a) The influence of climate and soils on the distribution of four African grasses. J Range Manage 41:127–139

Cox JR, Ruyle GB, Fourie JH, Donaldson C (1988b) Lehmann lovegrass—central South Africa and Arizona, USA. Rangelands 10:53–55

Cox JR, Ruyle GB, Roundy BA (1990) Lehmann lovegrass in southeastern Arizona: biomass production and disappearance. J Range Manage 43:367–372

Crider FJ (1945) Three Introduced Lovegrasses for Soil Conservation. Washington, DC: Soil Conservation Service Circular No. 730. 90 p

Crouch CG (2017) Ecology and Habitat of Grassland Birds in South Texas. Ph.D dissertation. Kingsville: Texas A&M University–Kingsville. 123 p

Daehler CC, Carino DA (1998) Recent replacement of native pili grass (*Heteropogon contortus*) by invasive African grasses in the Hawaiian Islands. Pac Sci 52:220–227

D'Antonio CM, Vitousek PM (1992) Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu Rev Ecol Syst 23:63–87

Davis FH (2011) Effects of Prescribed Burning on King Ranch Bluestem at Vegetative Regrowth and Flowering Stages. MS thesis. San Marcos: Texas State University–San Marcos. 43 p

Dick KN (2015) Restoring Semi-arid Thornscrub Forests: Seedling Growth and Survival in Response to Shelter Tubes, Grass-Specific Herbicide, and Herbivore Exclosures. MS thesis. Brownsville: University of Texas at Brownsville. 83 p

Duke JA (1983) Handbook of Energy Crops. West Lafayette, IN: Purdue University Center for New Crops & Plants Products Publication. http://hort.purdue.edu/newcrop/duke_energy/dukeindex.html. Accessed: March 26, 2019

Edwards JT, Hernández F, Wester DB, Brennan LA, Parent CJ, Bryant FC (2017) Effects of tanglehead expansion on bobwhite habitat use in South Texas. Page 132 *in* Proceedings of the 8th National Quail Symposium. Knoxville: University of Tennessee

Ellsworth LM, Litton CM, Dale AP, Miura T (2014) Invasive grasses change landscape structure and fire behavior in Hawaii. Appl Veg Sci 17:680–689

Everitt JH, Anderson GL, Escobar DE, Davis MR, Spencer NR, Andrascik RJ (1995) Use of remote sensing for detecting and mapping leafy spurge (*Euphorbia esula*). Weed Technol 9:599–609

Everitt JH, Deloach CJ (1990) Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. Weed Sci 38:273–278

Everitt JH, Drawe DL (1974) Spring food habits of white-tailed deer in the South Texas plains. J Range Manage 27:15–20

Everitt JH, Drawe DL, Little CR, Londard RI (2011) Grasses of South Texas: a guide to their identification and value. Lubbock: Texas Tech University Press. 336 p

Everitt JH, Escobar DE, Alaniz MA, Hussey MA (1987) Drought-stress detection of buffelgrass with color-infrared aerial photography and computer-aided image processing. Photogramm Eng Rem S 53:1255–1258

Everitt JH, Gonzalez CL (1979) Botanical composition and nutrient content of fall and early winter diets of white-tailed deer in South Texas. Southwest Nat 24:297–310

Everitt JH, Gonzalez CL, Scott G, Dahl BE (1981) Seasonal food preferences of cattle on native range in the South Texas plains. J Range Manage 34:384–388

Everitt JH, Judd FW, Escobar DE, Davis MR (1996) Integration of remote sensing and spatial information technologies for mapping black mangrove on the Texas Gulf Coast. J Coastal Res 12:64–69

Falk AD, Fulbright TE, Smith FS, Brennan LA, Ortega-Santos AJ, Benn S (2013) Does seeding a locally adapted native mixture inhibit ingress by exotic plants? Restor Ecol 21:474–480

Fensham RJ, Donald S, Dwyer JM (2013) Propagule pressure, not fire or cattle grazing, promotes invasion of buffel grass *Cenchrus ciliare*. J Appl Ecol 50:138–146

Flanders AA, Kuvlesky WP Jr, Ruthven DC III, Zaiglin RE, Bingham RL, Fulbright TE, Hernández F, Brennan LA (2006) Effects of invasive exotic grasses on South Texas rangeland breeding birds. Auk 123:171–182

Franklin KA, Lyons K, Nagler PL, Lampkin D, Glenn EP, Molina-Fraener F, Markow T, Huete AR (2006) Buffelgrass (*Pennisetum ciliare*) land conversion and productivity in the plains of Sonora, Mexico. Biol Conserv 127:62–71

Franks AJ (2002) The ecological consequences of buffel grass *Cenchrus ciliaris* establishment within remnant vegetation of Queensland. Pac Conserv Biol 8:99–107

Fulbright TE (2001) Human-induced vegetation changes in the Tamaulipan scrub of *La Frontera*. Pages 166–175 *in* Webster GL, Bahre CJ, eds. Changing Plant Life of *La Frontera*. Albuquerque: University of New Mexico Press

Fulbright TE, Bryant FC (2002) The last great habitat. Kingsville, TX: Caesar Kleberg Wildlife Research Institute Special Publication 1. 32 p

Fulbright, N, Fulbright, TE (1990) Germination of 2 legumes in leachate from introduced grasses. J Range Manage 43:466–467

Fulbright TE, Hickman KR, Hewitt DG (2013) Exotic grass invasion and wildlife abundance and diversity, south-central United States. Wildlife Soc B 37:503–509

Gabbard BL, Fowler NL (2007) Wide ecological amplitude of a diversity-reducing invasive grass. Biol Invasions 9:149–160

Gardener CJ, McIvor JG, Jansen A (1993) Passage of legume and grass seeds through the digestive tract of cattle and their survival in faeces. J Appl Ecol 30:63–74

Geiger EL, McPherson GR (2005) Response of semi-desert grasslands invaded by non-native grasses to altered disturbance regimes. J Biogeogr 32: 895–902

George AD, O'Connell TJ, Hickman KR, Leslie DM Jr (2009) Influence of old world bluestem (*Bothriochloa ischaemum*) monocultures on breeding density of three grassland songbirds in Oklahoma. Pages 691–697 *in* Proceedings of the 4th International Partners in Flight Conference. McAllen, TX: Partners in Flight

George AD, O'Connell TJ, Hickman KR, Leslie DM Jr (2013a) Food availability in exotic grasslands: a potential mechanism for depauperate breeding assemblages. Wilson J Ornithol 125:526–533

George AD, O'Connell TJ, Hickman KR, Leslie DM Jr (2013b) Use of seeded exotic grasslands by wintering birds. Prairie Nat 45:77–83

Glazener WC (1946) Food habits of wild geese on the Gulf Coast of Texas. J Wildl Manag 10:322–329

Goergen E, Daehler CC (2001) Reproductive ecology of a native Hawaiian grass (*Heteropogon contortus*; Poaceae) versus its invasive alien competitor (*Pennisetum setaceum*; Poaceae). Int J Plant Sci 162:317–326

Goertz S (2013) Patterns of Old World Bluestem Invasion during 37 Years in Southern Texas. MS thesis. Kingsville: Texas A&M University–Kingsville. 50 p

Gonzalez CL, Everitt JH (1982) Nutrient contents of major food plants eaten by cattle in the South Texas plains. J Range Manage 35:733–736

Gould FW, Shaw RB (1983) Grass Systematics. College Station: Texas A&M University Press. 397 p

Grace JB, Smith MD, Grace SL, Collins SL, Stohlgren TJ (2001) Interactions between fire and invasive plants in temperate grasslands of North America. Pages 40–65 *in* Proceedings of the Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Tallahassee, FL: Tall Timbers Research Station Misc. Pub. 11

Grace JL, Tjelmeland AD, Smith FS, Mitchell SL, Rideout-Hanzak S, Lloyd-Reilley J, Maher SD, Wester DB (2016) Effects of depth and duration of burial on tanglehead (*Heteropogon contortus*) seed viability and germination in southern Texas. Ecol Restor 34:7–10

Grahmann ED, Fulbright TE, Hernández F, Hehman MW, Wester DB, Ortega-Santos A, Martin BA (2018) Demographic and density response of northern bobwhites to pyric herbivory of non-native grasslands. Rangeland Ecol Manag 71:458–469

Greer M, Noland MA, Hickman KR, Wilson GWT (2014) Old World bluestem and its effects on the small mammal communities of North Central Oklahoma, USA: an ecological game changer. Pages 109–110 *in* Proceedings of the 2nd Biennial Conference on the Conservation of America's Grasslands. Manhattan; Kansas State University

Griffith G, Bryce S, Omernik J, Rogers A (2007) Ecoregions of Texas. Austin: Texas Commission on Environmental Quality Report. 125 p

Gust DA, Schmidly DJ (1986) Small mammal populations on reclaimed strip-mined areas in Freestone County, Texas. J Mammal 67:214–217

Hacker JB, Ratcliff D (1989) Seed dormancy and factors controlling dormancy breakdown in buffel grass accessions from contrasting provenances. J Appl Ecol 26:201–212

Hafner VE (1926) Angleton Grass. College Station: Texas Agriculture Extension Service Bulletin No. 342. 11 p

Hall DW, Currey WL, Orsenigo JR (1998) Weeds from other places: the Florida beachhead is established. Weed Technol 12:720–725

Hanselka CW (1988) Buffelgrass: South Texas wonder grass. Rangelands 10:279–281

Hanselka CW (1989) Forage quality of common buffelgrass as influenced by prescribed fire. Tex J Agric Nat Res 3:15–18

Harlan JR (1951) New grasses for old ranges. J Range Manage 4:16–18

Harlan JR, Brooks MH, Borgaonkar DS, de Wet JMJ (1964) Nature and inheritance of apomixis in *Bothriochloa* and *Dichanthium*. Bot Gaz 125:41–46

Harlan JR, Celarier RP, Richardson WL, Brooks MH, Mehra KL (1958) Studies on Old World Bluestems II. Stillwater: Oklahoma Agricultural Experiment Station Bulletin T-72. 23 p

Harlan JR, de Wet JMJ (1963) The compilospecies concept. Evolution 17: 497–501

Harlan JR, de Wet JMJ, Huffine WW, Deakin JR (1970) A guide to the species of *Cynodon* (Graminae). Stillwater: Oklahoma Agricultural Experiment Station Bulletin B-673. 37 p

Hatch SL, Schuster JL, Drawe DL (1999) Grasses of the Texas Gulf prairies and marshes. College Station: Texas A&M University Press. 355 p

Hernández F, Guthery FS (2012) Beef, Brush, and Bobwhites: Quail Management in Cattle Country. 1st ed. College Station: Texas A&M University Press. 244 p

Hestir EL, Khanna S, Andrew ME, Santos MJ, Viers JH, Greenberg JA, Rajapakse SS, Ustin SL (2008) Identification of invasive vegetation using hyperspectral remote sensing in the California Delta ecosystem. Remote Sens Environ 112:4034–4047

Hickman KR, Farley GH, Channell R, Steier JE (2006) Effects of Old World bluestem (*Bothriochloa ischaemum*) on food availability and avian community composition within the mixed-grass prairie. Southwest Nat 51:524–530

Hill DJ, Tarasoff C, Whitworth GE, Baron J, Bradshaw JL, Church JS (2017) Utility of unmanned aerial vehicles for mapping invasive plant species: a case study on yellow flag iris (*Iris pseudacorus* L.). Int J Remote Sens 38:2083–2105

Holt EA, Allen KE, Parker NC, Baker RJ (2000) Ecotourism and conservation: richness of terrestrial vertebrates across Texas. Lubbock: Museum of Texas Tech University Occasional Paper OP-201. 16 p

Hoveland CS (1960) Bermudagrass for Forage in Alabama. Auburn: Alabama Agricultural Experiment Station Bulletin 328. 22 p

Huang C, Asner GP (2009) Applications of remote sensing to alien invasive plant studies. Sensors 9:4869–4889

Humphrey N (1994) History, status and management of Lehmann lovegrass. Rangelands 16:205–206

Hunt ER Jr, Everitt JH, Ritchie JC, Moran MS, Booth DT, Anderson GL, Clark PE, Seyfried MS (2003) Applications and research using remote sensing for rangeland management. Photogramm Eng Rem S 69:675–693

Ibarra-F FA, Cox JR, Martin-R MH, Crowl TA, Call CA (1995) Predicting buffelgrass survival across a geographical and environmental gradient. J Range Manage 48:53–59

Jahrsdoerfer SE, Leslie DM Jr (1988) Tamaulipan Brushland of the Lower Rio Grande Valley of South Texas: Description, Human Impacts, and Management Options. Washington, DC: U.S. Fish and Wildlife Service Biological Report 88(36). 63 p

Johnson MVV, Fulbright TE (2008) Is exotic plant invasion enhanced by a traditional wildlife habitat management technique? J Arid Environ 72:1911–1917

Johnston MC (1963) Past and present grasslands of southern Texas and northeastern Mexico. Ecology 44:456–466

Kamler JF, Ballard WB, Fish EB, Lemons PR, Mote K, Perchellet CC (2003) Habitat use, home ranges, and survival of swift foxes in a fragmented landscape: conservation implications. J Mammal 84:989–995

Kneebone WR (1966) Bermuda grass: worldly, wily, wonderful weed. Econ Bot 20:94–97

Knight RA (2004) Assessment of the spread and distribution of Old World bluestems (*Bothriochloa* spp.) at local and landscape scales. MS thesis. Hays, KS: Fort Hays State University. 71 p

Kuvlesky WP Jr, Brennan LA, Fulbright TE, Hernández F, DeMaso SJ, Sands JP, Perez RM, Hardin JB (2012) Impacts of invasive, exotic grasses on quail of southwestern rangelands: a decade of progress? Pages 25–33 *in* Proceedings of the 7th National Quail Symposium. Knoxville: University of Tennessee

Kuvlesky WP Jr, Fulbright TE, Engel-Wilson R (2002) The impact of invasive exotic grasses on quail in the southwestern United States. Pages 118–128 *in* Proceedings of the 5th National Quail Symposium. Knoxville: University of Tennessee

Langeland KA, Cherry HM, McCormick CM, Craddock Burks KA (2008). Identification and biology of nonnative plants in Florida's natural areas. Gainesville: University of Florida Press. 210 p

Larson JA (2008) Preference and Nutrition of Grass Seeds and Common Supplemental Feeds Eaten by Northern Bobwhites. MS thesis. Kingsville: Texas A&M University–Kingsville. 56 p

Larson JA, Fulbright TE, Brennan LA, Hernández F, Bryant FC (2012) Selection of seeds of an exotic and three native grasses by northern bobwhites (*Colinus virginianus*). Southwest Nat 57:319–322

Lea T (1957) The King Ranch. 1st ed. Boston: Little, Brown. 838 p

Lehmann VW (1969) Forgotten Legions: Sheep in the Rio Grande Plain of Texas. El Paso: Texas Western Press. 226 p

Leslie DM Jr (2016) An International Borderland of Concern: Conservation of the Biodiversity in the Lower Rio Grande Valley. Reston, VA: US Geological Survey Scientific Investigations Report 2016-5078. 120 p

Lindsay DL, Bailey P, Lance RF, Clifford MJ, Delph R, Cobb NS (2011) Effects of a nonnative, invasive lovegrass on *Agave palmeri* distribution, abundance, and insect pollinator communities. Biodivers Conserv 20:3251–3266

Litt AR, Steidl RJ (2010) Insect assemblages change along a gradient of invasion by a nonnative grass. Biol Invasions 12:3449–3463

Lonard RI, Judd FW (2002) Riparian vegetation of the Lower Rio Grande. Southwest Nat 47:420–432

Lonard RI, Judd FW (2006) Notes on invasive plants in the Rio Grande delta of Cameron County, Texas. Tex J Sci 58:271–277

Lu B, He Y (2017) Species classification using unmanned aerial vehicle (UAV)-acquired high spatial resolution imagery in a heterogeneous grassland. ISPRS J Photogramm 128:73–85

Lyons KG, Maldonado-Leal BG, Owen G (2013) Community and ecosystem effects of buffelgrass (*Pennisetum ciliare*) and nitrogen deposition in the Sonoran Desert. Invasive Plant Sci Manag 6:65–78

Marsalis MA (2004) Adaptation of Forage Bermudagrasses [*Cynodon dactylon* (L.) Pers.] to the Texas High Plains Grown under Saline and Limited Irrigation Conditions. Ph.D dissertation. Lubbock: Texas Tech University. 207 p

Marshall VM, Lewis MM, Ostendorf B (2012) Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments: a review. J Arid Environ 78:1–12

Martin JA, Burkhart JK, Thackston RE, Carroll JP (2015) Exotic grass alters micro-climate and mobility for northern bobwhite chicks. Wildlife Soc B 39:834–839

Martin-R MH, Cox JR, Ibarra-F F (1995) Climatic effects on buffelgrass productivity in the Sonoran Desert. J Range Manage 48:60–63

Mata JM, Perotto-Baldivieso HL, Hernández F, Grahmann ED, Rideout-Hanzak S, Edwards JT, Page MT, Shedd TM (2018) Quantifying the spatial and temporal distribution of tanglehead (*Heteropogon contortus*) on South Texas rangelands. Ecol Process 7:2

Mathews S, Sprangler RE, Mason-Gamer RJ, Kellogg EA (2002) Phylogeny of Andropogoneae inferred from phytochrome B, GBSSI, and *NDHF*. Int J Plant Sci 163:441–450

Mayeux HS Jr, Hamilton WT (1983) Response of common goldenweed (*Isocoma coronopifolia*) and buffelgrass (*Cenchrus ciliaris*) to fire and soil-applied herbicides. Weed Sci 31:355–360

McClaran MP, Anable ME (1992) Spread of introduced Lehmann lovegrass along a grazing intensity gradient. J Appl Ecol 29:92–98

McCollum FT III (2000) Old World bluestem pasture management strategies for Panhandle and South Plains. Pages 11–17 *in* Proceedings of the Plains Nutrition Council 2000 Fall Grazing Conference. Amarillo: Texas A&M AgriLife Research and Extension Center

McCosker TH, Teitzel JK (1975) A review of Guinea grass (*Panicum maximum*) for the wet tropics of Australia. Trop Grasslands 9:177–190

McCully WG, Bowmer WJ, Stubbendieck JL (1970) Problems in Establishing or Maintaining Vegetation on Roadsides. College Station: Texas Transportation Institute Research Report 142–1. 26 p

McDonald CJ, McPherson GR (2011) Fire behavior characteristics of buffelgrass-fueled fires and native plant community composition in invaded patches. J Arid Env 75:1147–1154

McFarland ML, Ueckert DN, Hartmann S (1987) Revegetation of oil well reserve pits in West Texas. J Range Manage 40:122–127

McGlone CM, Huenneke LF (2004) The impact of a prescribed burn on introduced Lehmann lovegrass versus native vegetation in the northern Chihuahuan Desert. J Arid Environ 57:297–310

McIntyre NE (2003) Effects of Conservation Reserve Program seeding regime on harvester ants (*Pogonomyrmex*), with implications for the threatened Texas horned lizard (*Phrynosoma cornutum*). Southwest Nat 48:274–277

McIntyre NE, Thompson TR (2003) A comparison of Conservation Reserve Program habitat plantings with respect to arthropod prey for grassland birds. Am Midl Nat 150:291–301

McIvor JG (2003) Competition affects survival and growth of buffel grass seedlings—is buffel grass a coloniser or an invader? Trop Grasslands 37:176–181

Medina AL (2003) Gabel and scaled quail diets on the Santa Rita Experimental Range. Pages 133–140 *in* Santa Rita Experimental Range: 100 Years (1903–2003) of Accomplishments and Contributions. Ogden, UT: U.S. Forest Service Proceedings RMRS-P-30

Meyer MW, Brown RD (1985) Seasonal trends in the chemical composition of ten range plants in South Texas. J Range Manage 38:154–157

Meyer MW, Brown RD, Graham MW (1984) Protein and energy content of white-tailed deer diets in the Texas Coastal Bend. J Wildl Manag 48:527–534

Mitchell AB, Litt AR (2016) Nonnative plant shifts functional groups of arthropods following drought. Biol Invasions 18:1351–1361

Moore SF (2010) Effects of Guineagrass on Northern Bobwhite Habitat Use. MS thesis. Kingsville: Texas A&M University–Kingsville. 89 p

National Research Council (1971) Atlas of Nutritional Data on United States and Canadian Feeds. Washington, DC: National Academy of Sciences. 772 p

[NRCS] Natural Resource Conservation Service (2019) Plants Database. http://plants.usda.gov. Accessed: March 4, 2019

Ni W, Liu J, Zhang Z, Sun G, Yang A (2015) Evaluation of UAV-based forest inventory system compared with LiDAR data. Pages 3874–3877 *in* Proceedings of the 2015 IEEE International Geoscience and Remote Sensing Symposium. Milan, Italy: Institute of Electrical and Electronics Engineers

Nixon WM (1949) Range reseeding in Texas and Oklahoma. J Range Manage 2:213–217

Novosad AC, Pratt JN (1959) Introduced bluestem grasses for cultivated pastures. College Station: Texas Agriculture Extension Service Publication MP-340. 12 p

Ortega-S JA, Avila-C JM, Gonzalez-V EA, Gonzalez-P MA (2007) Grazing intensity and nitrogen fertilization to manage invasive Kleberg bluestem on pangolagrass pastures in Northern Mexico. Tex J Agric Nat Res 20:109–115

Ortega-S JA, Ibarra-Flores FA, Gonzalez-Valenzuela EA, Martin-Rivera MH, Ávila-Curiel JM, Ayala-Alvares F, Pinedo C, Rivero O (2013) Exotic grasses and wildlife in northern Mexico. Wildlife Soc B 37:537–545

Ozias-Akins P, Van Dijk P (2007) Mendelian genetics of apomixis in plants. Annu Rev Genet 41:509–537

Pacheco ME, Brown RD, Bingham RL (1983) Nutritive value and intake of Kleberg bluestem by beef cattle. J Range Manage 36:222–224

Parsons JJ (1972) Spread of African pasture grasses to the American tropics. J Range Manage 25:12–17

Pavur GC (2016) Status of Mesocarnivores in the Last Area Known to be Occupied by Swift Foxes, *Vulpes velox*, in Texas. MS thesis. Lubbock: Texas Tech University. 73 p

Piñeiro G, Oesterheld M, Paruelo JM (2006) Seasonal variation in aboveground production and radiation-use efficiency of temperate rangelands estimated through remote sensing. Ecosystems 9:357–373

Pinkerton B, Hussey M (1985) Buffelgrass. College Station: Texas Agriculture Extension Service Leaflet L-2136. 4 p

Powell AM (1994) Grasses of the Trans-Pecos and Adjacent Areas. Austin: University of Texas Press. 377 p

Ramírez RG, Mireles E, Huerta JM, Aranda J (1995) Forage selection by range sheep on a buffelgrass (*Cenchrus ciliaris*) pasture. Small Ruminant Res 17:129–135

Ramirez-Yañez LE, Ortega-S JA, Brennan LA, Rasmussen GA (2007) Use of prescribed fire and cattle grazing to control guineagrass. Pages 240–245 *in* Proceedings of the 23rd Tall Timbers Fire Ecology Conference: Fire in Grassland and Shrubland Ecosystems. Tallahassee, FL: Tall Timbers Research Station

Ramoelo A, Skidmore AK, Cho MA, Schlerf M, Mathieu R, Heitkönig IMA (2012) Regional estimation of savanna grass nitrogen using the red-edge band of the spaceborne RapidEye sensor. Int J Appl Earth Obs 19:151–162

Rango A, Laliberte A, Steele C, Herrick JE, Bestelmeyer B, Schmugge T, Roanhorse A, Jenkins V (2006) Using unmanned aerial vehicles for rangelands: current applications and future potentials. Environ Pract 8:159–168

Reilly J, Maher SD, Duvauchelle D (2002) Plant Fact Sheet: Tanglehead. Washington, DC: Natural Resources Conservation Service Publication. 2 p

Reinheimer R, Pozner R, Vegetti AC (2005) Inflorescence, spikelet, and floral development in *Panicum maximum* and *Urochloa plantaginea* (Poaceae). Am J Bot 92:565–575

Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. Divers Distrib 6:93–107

Ripper D, McLachlan M, Toombs T, VerCauteren T (2008) Assessment of Conservation Reserve Program fields within the current distribution of lesser prairie-chicken. Gt Plains Res 18:205–218

Roundy BA, Taylorson RB, Sumrall LB (1992) Germination responses of Lehmann lovegrass to light. J Range Manage 45:81–84

Rouquette FM Jr, Anderson WF, Harris-Schultz KR, Smith GR (2011) Stand maintenance and genetic diversity of bermudagrass pastures under different grazing management strategies during a 38-year period. Crop Sci 51: 2886–2894

Roy DP, Wulder MA, Loveland TR, Woodcock CE, Allen RG, Anderson MC, Helder D, Irons JR, Johnson DM, Kennedy R, Scambos TA, Schaaf CB, Schott JR, Sheng Y, Vermote EF, *et al.* (2014) Landsat-8: Science and product vision for terrestrial global change research. Remote Sens Environ 145: 154–172

Ruckman EM, Schwinning S, Lyons KG (2012) Effects of phenology at burn time on post-fire recovery in an invasive C_4 grass. Restor Ecol 20:756–763

Ruffner ME, Barnes TG (2012) Evaluation of herbicide and disking to control invasive bluestems in a South Texas coastal prairie. Range Ecol Manag 65:277–285

Ruthven DC III, Fulbright TE, Beasom SL, Hellgren EC (1993) Long-term effects of root-plowing on vegetation in the eastern south Texas plains. J Range Manage 46:351–354

Ruyle GB, Roundy BA, Cox JR (1988) Effects of burning on germinability of Lehmann lovegrass. J Range Manage 41:404–406

Sammon JG, Wilkins KT (2005) Effects of an invasive grass (*Bothriochloa ischaemum*) on a grassland rodent community. Tex J Sci 57:371–382

Sands JP, Brennan LA, Hernández F, Kuvlesky WP Jr, Gallagher JF, Ruthven DC III (2012) Impacts of introduced grasses on breeding season habitat use by northern bobwhite in the South Texas plains. J Wildl Manag 76:608–618

Sands JP, Brennan LA, Hernández F, Kuvlesky WP Jr, Gallagher JF, Ruthven DC III, Pittman JE III (2009) Impacts of buffelgrass (*Pennisetum ciliare*) on a forb community in South Texas. Invasive Plant Sci Manag 2:130–140

Sauls JW (1995) Texas Citrus Weed Control. College Station: Texas Agriculture Extension Service Publication L-2317. 4 p

Savidan Y (1980) Chromosomal and embryological analyses in sexual × apomictic hybrids of *Panicum maximum* Jacq. Theor Appl Genet 57: 153–156

Schaller M, Schroth G, Beer J, Jiménez F (2003) Root interactions between young *Eucalyptus deglupta* trees and competitive grass species in contour strips. For Ecol Manag 179:429–440

Schnupp MJ, DeLaney DS (2012) Funding research as an investment for improving management. Pages 99–116 *in* Sands JP, Brennan LA, DeMaso SJ, Schnupp MJ, eds. Wildlife Science: Connecting Research with Management. Boca Raton, FL: CRC Press

Schussman H, Geiger E, Mau-Crimmins T, Ward J (2006) Spread and current potential distribution of an alien grass, *Eragrostis lehmanniana* Nees, in the southwestern USA: comparing historical data and ecological niche models. Divers Distrib 12:582–592

Schuster C, Förster M, Kleinschmit B (2012) Testing the red edge channel for improving land-use classifications based on high-resolution multi-spectral satellite data. Int J Remote Sens 33:5583–5599

Scifres CJ, Mutz JL (1975) Secondary succession following extended inundation of Texas coastal rangelands. J Range Manage 28:279–282

Shaw RB (2012) Guide to Texas Grasses. 1st ed. College Station: Texas A&M University Press. 1080 p

Simberloff, D, Martin JL, Genovesi P, Maris V, Wardle DA, Aronson J, Courchamp F, Galil B, García-Bertou E, Pascal M, Pyšek P, Sousa R, Tabacchi E, Vilà M (2013) Impacts of biological invasions: what's what and the way forward. Trends Ecol Evol 28:58–66

Simmons MT, Windhager S, Power P, Lott J, Lyons RK, Schwope C (2007) Selective and non-selective control of invasive plants: the short-term effects of growing-season prescribed fire, herbicide, and mowing in two Texas prairies. Restor Ecol 15:662–669

Simonson S, Barnett D, Stohlgren T (2004) The Invasive Species Survey: A Report on the Invasion of the National Wildlife Refuge System. Fort Collins, CO: National Institute of Invasive Species Science Technical Report. 38 p

Singh AP (1965) Intergeneric cross of *Dichanthium annulatum* with *Bothriochloa ischaemum*. Cytologia 30:54–57

Skerman PF, Riveros F (1990) Tropical Grasses. Rome: Food and Agriculture Organization of the United Nations Plant Production and Protection Series No. 23. 832 p

Smith FS (2010) Texas today: a sea of the wrong grasses. Ecol Restor 28: 112–117

Soreng RJ, Peterson PM, Romaschenko K, Davidse G, Zuloaga FO, Judziewicz EJ, Filgueiras TS, Davis JI, Morrne O (2015) A worldwide phylogenetic classification of the Poaceae (Gramineae). J Syst Evol 53:117–137

Tan S, Zhu M, Zhang Q (2010) Physiological responses of bermudagrass (*Cynodon dactylon*) to submergence. Acta Physiol Plant 32:133–140

Tjelmeland AD (2011) Tanglehead Ecology and Management on South Texas Rangelands. Kingsville, TX: Caesar Kleberg Wildlife Research Institute Research Report. 10 p

Tjelmeland AD, Fulbright TE, Lloyd-Reilley J (2008) Evaluation of herbicides for restoring native grasses in buffelgrass-dominated grasslands. Restor Ecol 16:263–269

Todd DA, Ogren J (2016) The Texas Landscape Project: Nature and People. College Station: Texas A&M University Press. 303 p

Toth C, Jóźków G (2016) Remote sensing platforms and sensors: a survey. ISPRS J Photogramm 115:22–36

Tothill JC, Hacker JB (1976) Polyploidy, flowering phenology and climatic adaptation in *Heteropogon contortus* (Graminae). Aust J Ecol 1:213–222

Twedt DJ, Best C (2004) Restoration of floodplain forests for the conservation of migratory landbirds. Ecol Restor 22:194–203

Twidwell D, Rogers WR, McMahon EA, Thomas BR, Kreuter UP, Blankenship TL (2012) Prescribed extreme fire effects on richness and invasion in coastal prairie. Invasive Plant Sci Manag 5:330–340

Underwood E, Ustin S, DiPietro D (2003) Mapping nonnative plants using hyperspectral imagery. Remote Sens Environ 86:150–161

[USFWS] U.S. Fish and Wildlife Service (2008) Butterflies of Santa Ana National Wildlife Refuge. Albuquerque, NM: U.S. Fish and Wildlife Service Southwest Region. 2 p

[USFWS] U.S. Fish and Wildlife Service (2014) Recovery Plan for the Tamaulipan Kidneypetal (Texas ayenia; *Ayenia limitaris*). Albuquerque, NM: U.S. Fish and Wildlife Service Southwest Region. 80 p

Van Devender TR, Felger RS, Búrquez-M. A (1997) Exotic plants in the Sonoran Desert Region, Arizona and Sonora. Pages 1–6 *in* Proceedings of the California Exotic Pest Plant Council. Berkeley: California Exotic Pest Plant Council

Vela JL (2015) Alternative Restoration Treatments to Maximize Growth and Survival of Tamaulipan Thornscrub Species during Seedling Establishment. MS thesis. Brownsville: University of Texas at Brownsville. 61 p

Veldman JW, Putz FE (2010) Long-distance dispersal of invasive grasses by logging vehicles in a tropical dry forest. Biotropica 42:697–703

Villarreal ML, Soulard CE, Waller EK (2019) Landsat time series assessment of invasive annual grasses following energy development. Remote Sens 11:2553

Vitousek PM (1990) Biological invasions and ecosystem processes: towards an integration of population biology and ecosystem studies. Oikos 57:7–13

Wallace CSA, Walker JJ, Skirvin SM, Patrick-Birdwell C, Weltzin JF, Raichle H (2016) Mapping presence and predicting phenological status of invasive buffelgrass in southern Arizona using MODIS, climate and citizen science observation data. Remote Sens 8:524

Walther CH (2019) Response of Tanglehead (*Heteropogon contortus*) to Prescribed Burning and Cattle Grazing. MS thesis. Kingsville: Texas A&M University–Kingsville. 93 p

Way AG (2014) A cosmopolitan weed of the world: following bermudagrass. Agric Hist 88:354–367

Wester DB, Bryant FC, Tjelmeland AD, Grace JL, Mitchell SL, Edwards JT, Hernández F, Lyons RK, Clayton MK, Rideout-Hanzak S, Machen RV, Ortega-S JA, (2018) Tanglehead in southern Texas: a native grass with an invasive behavior. Rangelands 40:37–44

Westoby M, Walker B, Noy-Meir I (1989) Opportunistic management for rangelands not at equilibrium. J Range Manage 42:266–274

Whitford WG (1997) Desertification and animal biodiversity in the desert grasslands of North America. J Arid Environ 37:709–720

Wiens JA (1973) Pattern and process in grassland bird communities. Ecol Monogr 43:237–270

Williams DG, Baruch Z (2000) African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. Biol Invasions 2:123–140

Winkworth RE (1971) Longevity of buffel grass seed sown in an arid Australian range. J Range Manage 24:141–145

Wolfe DH, Larsson LC, Patten MA (2016) The lesser prairie-chicken in the mixed-grass prairie ecoregion of Oklahoma, Kansas, and Texas. Pages 299–314 *in* Haukos DA, Boal CW, eds. Ecology and Conservation of Lesser Prairie-Chickens. Boca Raton, FL: CRC Press

Woodin MC, Skoruppa MK, Pearce BD, Ruddy AJ, Hickman GC (2010) Grassland Birds Wintering at U.S. Navy Facilities in Southern Texas. Corpus Christi, TX: U.S. Geological Survey Report 2010-1115. 62 p

Young D, Perotto-Baldivieso HL, Brewer T, Homer R, Santos SA (2014) Monitoring British upland ecosystems with the use of landscape structure as an indicator for state-and-transition models. Rangeland Ecol Manag 67:380–388

Young KE, Abbot LB, Caldwell CA, Schrader TS (2013) Estimating suitable environments for invasive plant species across large landscapes: a remote sensing strategy using Landsat 7 ETM+. Int J Biodivers Conserv 5:122–134

Zeid M, Echenique V, Díaz M, Pessino S, Sorrels ME (2011) *Eragrostis*. Pages 135–151 *in* Kole C, ed. Wild Crop Relatives: Genomic and Breeding Resources—Millets and Grasses. Berlin: Springer

Zeng F, Cheng L, Li N, Xia N, Ma L, Zhou X, Li M (2019) A hierarchical airport detection method using spatial analysis and deep learning. Remote Sens 11:2204

Zhou Y, Lambrides CJ, Fukai S (2013) Drought resistance of bermudagrass (*Cynodon* spp.) ecotypes collected from different climate zones. Environ Exp Bot 85:22–29