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Source: Natural Areas Journal, 37(2) : 254-264

Published By: Natural Areas Association

URL: https://doi.org/10.3375/043.037.0214

CONSERVATION ISSUES

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The Invasive Legacy of Forage Grass Introductions into Florida

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ABSTRACT: Exotic African warm-season forage grasses were first introduced into the Americas in the 16th century, and have become invasive in many areas. In Florida, 16 exotic grasses are considered invasive, with the majority originating in Africa and introduced as forages. The high propensity of Africa warm-season grasses to become invasive may be related to the same characteristics that are associated with their value as forages, including adaptability to a wide range of abiotic conditions, rapid establishment, persistence in the environment with minimal husbandry, high productivity under grazing pressure, and adaptation to disturbance. The majority of African warm-season grasses in Florida reproduce vegetatively, a trait known to be associated with invasiveness, and many have been widely planted leading to high propagule pressure and opportunities to invade a variety of niches. In spite of a long history of introduction and promotion in Florida, few African forage grasses are in use today, while many have become invasive. The benefit/cost ratio appears to be tilted in the direction of environmental and economic costs, with minimal benefits. We support newly enacted restrictions on the importation of potentially invasive plants into the USA, and suggest the establishment of a more comprehensive and transparent system for tracking past and future introductions.

Index terms: African grasses, Florida, forages, invasive grasses

INTRODUCTION

Grasses are arguably the most important family of plants for man's existence on earth. Cereals provide about 49% of the caloric intake of humans, and are staple crops for billions of people (Alexandratos and Bruinsma 2012; FAO 2015). Humans also consume grasses indirectly through the ingestion of grass-fed animals and their products (e.g., milk and eggs), and benefit from animal-derived commodities such as wool and leather. Approximately 36% of the world's cereal production is used for animal feed, and 25% of the earth's land surface is devoted to grazing (Asner et al. 2004). Grasses are also extensively used for the production of biofuels (USDE 2015) and alcoholic drinks (Witherington 2014). In addition to their direct exploitation by humans, grasslands provide critical ecosystem services by functioning as a major sink for atmospheric carbon dioxide, for soil conservation, and as habitat for untold numbers of organisms (Sala and Paruelo 1997).

However, grasses, like plants in other families, can sometimes cause harm to a region's economy or environment, particularly when they are moved from one geographic area to another (Richardson and Ricciardi 2013; Simberloff and Vitule 2014). In Florida, of the 446 grasses growing outside of cultivation, 184 (41%) are exotic (Wunderlin and Hansen 2008), and a few of these exotic grasses have become invasive. An invasive species can be defined as "a species that is nonnative to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (Federal Register 1999). The Florida Exotic Pest Plant Council (FLEPPC) maintains a list of invasive plant species in two categories. Category I plants "alter plant communities by displacing native species, change community structures or ecological functions or hybridize with natives," while Category II plants "have increased in abundance or frequency, but have not yet altered Florida plant communities to the extent shown by category I species" (FLEPPC 2015). There are 164 plants on the FLEPPC 2015 list, with 80 in Category I and 84 in Category II (FLEPPC 2015). According to Bell et al. (2003), the vast majority (83%) of plants on the 2001 FLEPPC list were introduced as ornamentals, although Fox et al. (2003) present a slightly lower proportion with 71% introduced, or suspected to have been introduced, as ornamentals.

Invasive Grasses in Florida

The FLEPPC list includes 16 grasses, but in contrast to other invasive plants, the majority (nine) were introduced as forages (Table 1). Only three were introduced as ornamentals (*Neyraudia reynaudiana* (Kunth) Keng ex A.S. Hitchc., *Pennisetum setaceum* (Forssk.) Chiov., and *Phyllostachys aurea* Carrière ex Rivière and C. Rivière), and the remaining four may have been accidental introductions (*Dactyloctenium aegyptium* (L.) Willd., *Hymenachne amplexicaulis*

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(Rudge) Nees, *Luziola subintegra* Swallen, and *Sporobolus jacquemontii* Kunth). However, *S. jacquemontii* (or possibly *Sporobolus pyramidalis* P. Beauv.—see discussion below) was also introduced purposely (USDA/GRIN 2015) and may be native. Even though *H. amplexicaulis* was not purposely introduced, it was tested as a forage for wet pastures (Hill 1996; Kalmbacher et al. 1998).

In spite of the recognition of invasiveness of some exotic forage grasses in Florida, in most cases their impacts have not been well documented. *Imperata cylindrica* (L.) P. Beauv. (cogongrass) alters fire regimes resulting in increased mortality of longleaf pine and other sandhill flora (Lippincott 2000), and displaces native species such as wiregrass (Jose et al. 2002). *Panicum repens* L. (torpedo grass) displaces native species, particularly in shallow water (Shilling and Haller 1989), and displaced >5600 ha of native marsh in Lake Okeechobee, Florida, in 1992 (Schardt 1994). *Urochloa mutica* (Forsk.) Nguyen (paragrass) displaces native vegetation along freshwater shorelines, marshes, and swamps (Schardt and Schmitz 1991).

The geographic origin of Florida's invasive grasses is highly skewed towards Africa, with seven species native to Africa, and four others—cogongrass, torpedo grass, limpograss (*Hemarthria altissima* (Poir.) Stapf and C.E. Hubb), and green fountain grass (*Pennisetum setaceum* (Forssk.) Chiov.—with Old World distributions that include Africa. According to at least one author, the center of origin of cogongrass is East Africa (Evans 1991). Thus, 11 of 16 invasive grasses in Florida are considered native in Africa (Table 1).

In addition, the origin of some *Sporobolus* spp. populations in Florida is uncertain. Peterson et al. (2003) indicate that both *Sporobolus indicus* (L.) R.Br. and *S. jacquemontii* are native to North America, with *S. indicus* widely distributed in the southeastern USA and southern California, and *S. jacquemontii* known only from coastal and low-elevation sites in Florida. *Sporobolus jacquemontii* is regarded as distinct from the African species, *S. pyramidalis*, by some (Clayton et al. 1974; Simon and Jacobs 1999; Peterson et al. 2003), with *S. jacquemontii* characterized as having a shorter habit (to 75 cm vs. 170 cm in *S. pyramidalis*), shorter and narrower leaves (to 40 × 0.10–0.35 cm vs. 70 × 0.3–1.0 cm), and a narrowly lanceolate inflorescence with loosely appressed branches (vs. pyramidal). Others have regarded these two as morphologically indistinguishable, synonymous, and nonnative to Florida (Baaijens and Veldkamp 1991; Wunderlin and Hansen 2008; USDA/NRCS 2016, all as *S. indicus* (L.) R. Br. var. *pyramidalis* (P. Beauv.) Veldkamp). A recent molecular phylogenetic study suggests that *S. jacquemontii*, *S. indicus*, and *S. pyramidalis* are all part of *S.* sect. *Sporobolus*, but that samples of *S. pyramidalis* (from Tanzania and Australia) are far removed from the very closely related samples of *S. indicus* (from Mexico and Panama) and *S. jacquemontii* (from Mexico) (Peterson et al. 2014). Fifteen accessions listed as *S. indicus* var. *pyramidalis* (= *S. pyramidalis*) were introduced into the USDA National Genetic Resources Program between 1920 and 1981, with 11 collected from various locations in Africa, two from St. Helena Island off the west coast of Africa, and two from Brazil. Thus, it seems likely that the introductions from Africa were indeed not *S. indicus* or *S. jacquemontii* and the two from Brazil could perhaps be *S. jacquemontii*. It is unknown whether the African accessions were ever planted in Florida, but a molecular genetics study of the *Sporobolus* spp. populations in Florida appears to be warranted.

Native grasses were relied upon as livestock forage in the early years of colonization of the tropical New World (Leithead et al. 1971), but according to Baruch (1994), suffered from seasonal water stress, performed poorly in low-fertility soils, and generally had low nutritional value. Today, very few native grasses are used in improved pastures in the USA (Vogel and Moore 1993; Newman et al. 2014), and in Florida, the only native species promoted to any degree is St. Augustine grass (*Stenotaphrum secundatum* (Walt.) Kuntze), which is adapted to moist organic soils (Ezenwa et al. 2011). However, unimproved rangelands are composed of a high diversity of native forages (Kalmbacher et al. 1984; Swain et al. 2013).

Nonnative African warm-season (C_4) perennial grasses were likely first introduced to the New World tropics during the early period of European colonization in the 16th and 17th centuries, and based on Parsons (1972), several arrived inadvertently. However, once in the New World, their value as livestock fodder quickly became apparent, and they were spread by humans in the ensuing years throughout Central and South America and the West Indies, with several arriving in the southern USA in the 19th century (Weintraub 1953; Parsons 1972; Baruch 1994).

African grasses evolved under pressure of herbivory from large mammals (Stuart-Hill and Mentis 1982; Coughenour 1985; Cerling et al. 2015) and there is evidence of enhanced productivity when subjected to repetitive grazing (McNaughton 1979; Wallace et al. 1985; Simoes and Baruch 1991). In addition, they are adapted to a wide range of abiotic conditions (Baruch 1994), and considered to be more palatable and nutritious than native North American grasses (Parsons 1972; Baruch 1994; Brown and Kalmbacher 1998). Moreover, African grasses, *Homo* spp., and *Homo sapiens* have coexisted in Africa much longer than on any other continent (Marean 2015; Faith et al. 2016). Native Florida grasses likely once experienced herbivory from C_4-feeding large mammals such as *Equus*, *Mammuthus*, and *Bison antiquus* (Webb et al. 1984; Feranec and MacFadden 2000; Feranec 2004; Feranec and DeSantis 2014), but those mammals have been extinct for at least 10,000 years, likely partly due to the arrival of humans (Haynes 2013; Purdy et al. 2015), while *Bison bison* may have only recently colonized Florida during the 1600s to 1800s (Rostlund 1960). It is unclear if the loss of these selection pressures on Florida grasses in the early Holocene has impacted their suitability for modern grazing and ability to colonize disturbed habitats apparent in some invasive African grasses.

African Forage Grasses in Florida

Many of the African grasses that were test-

Table 1. Invasive grasses in Florida, their origins, introduction history, and ecological impacts.

FLEPPC Category						
I	Species (common name)	Native region	Reason introduced	Year of introduction	Ecological impacts	References
	Hymenachne amplexicaulis (Rudge) Nees (West Indian marsh grass)	South and Central America	Probably accidental, but tested as a forage	Unknown, first herbarium sample in Florida 1957 (FLAS 73289)	Displacement of native species, blocks light	Kalmbacher et al. 1998 (forage testing) Diaz et al. 2013 (ecological impacts)
	Imperata cylindrica (L.) P.Beauv. (cogongrass)	Asia, Africa	Packing material, and later as a potential forage	Accidental in 1911 to Alabama, as forage in 1921 to Mississippi; sent to Florida from Mississippi for testing as forage	Displacement of native species, alteration of fire regimes	MacDonald 2009 (introduction) Jose et al. 2002 (displacement) Lippincott 2000 (fire impacts)
	Luziola subintegra Swallen	South and Central America	Accidental introduction	First observed in Lake Okeechobee in 2008	Creates dense mats on the water surface that change habitat structure and crowd out native species	Kunzer and Bodle 2008
	Melinis repens (Willd.) Zizka) (Natal grass)	Southern Africa	Forage	Around 1875	Displaces native vegetation	Austin 1978 (introduction) Langeland et al. 2008 (ecological impacts)
	Neyraudina reynaudiana (Kunth) Keng ex A.S. Hitchc. (silk reed)	Asia	Ornamental	1916	Forms dense stands in pine rocklands and outcompetes native species. Alters fire behavior, increases organic litter accumulation and alters succession patterns. Displaces endangered and rare species	Gordon 1998 (introduction) Schmitz et al. 1997 (ecological impacts)
	Panicum repens L. (torpedo grass)	Old World	Unknown for first introduction, later from Java for testing as a forage	Prior to 1876 but seeds introduced for testing as forage in 1926	Displaces native vegetation in or near shallow waters	Tarver 1979 (introduction) Shilling and Haller 1989 (ecological impacts)

Continued

Table 1. Invasive grasses in Florida, their origins, introduction history, and ecological impacts.

FLEPPC Category (*Cont'd*)						
I	Species (common name)	Native region	Reason introduced	Year of introduction	Ecological impacts	References
	Pennisetum purpureum Schumach. (napier grass)	Africa	Forage	1913	Alters fire regimes, hydrology cycles, biophysical dynamics, nutrient cycles, and community composition	Hoover et al. 1948 (introduction) D'Antonio and Vitousek 1992 (ecological impacts)
	Sporobolus jacquemontii Kunth (smutgrass)	tropical America	Unknown	12 accessions introduced from 1951 to 1981, almost all from various locations in Africa	Weed in pastures where it outcompetes desirable grasses, recently began invading natural areas	FLEPPC 2015 USDA/GRIN 2015
II	*Urochloa mutica* (Forssk.) T.Q. Nguyen (paragrass)	Africa	Forage	1870, recommended for pastures in 1919	Competes aggressively with other plants, with fast growth, high productivity, and allelopathic abilities that allow it to form dense stands	Austin 1978 (introduction) Thompson 1919 (forage value) Handley et al. 1989 (ecological impacts)
	Dactyloctenium aegyptium (L.) Willd.) (Durban crowfoot grass)	Africa	Unknown	Rugel collected a specimen in 1842 in Florida	Pioneer species that quickly colonizes disturbed areas with light sandy soils	Smith 2016 (origin) USF herbarium specimen 76511 (Rugel specimen) CABI 2016 (ecological impacts)
	Hemarthria altissima (Poir.) Stapf and C.E. Hubb (limpograss)	Old World, but introduced from southern Africa	Forage	1964–1971	Competes with native plant communities	Oakes 1973 (origin) Sellers et al. 2007 (ecological impacts)

Continued

Table 1. Invasive grasses in Florida, their origins, introduction history, and ecological impacts.

FLEPPC Category (*Cont'* d)						
II	Species (common name)	Native region	Reason introduced	Year of introduction	Ecological impacts	References
	Hyparrhenia rufa (Nees) (Stapf) (jaragua)	Africa	Forage	Introduced into South America in late 19th, early 20th centuries; two accessions introduced by USDA: 1952 and 1957 from Madagascar and Panama, respectively	Displaces native pasture grasses in South America	Williams and Baruch 2000 (introduction) D'Antonio and Vitousek 1992 (ecological impacts)
	Melinis minutiflora P. Beauv. (molasses grass)	Africa	Forage	Around 1914	Forms dense mats that exclude native species, alter successional processes, reduce native tree and grass regeneration, and increase intensity and frequency of fires	Gordon and Thomas 1997 (introduction) Hoffman et al. 2004 (ecological impacts)
	Pennisetum setaceum (Forssk.) Chiov. (green fountain grass)	Africa, Middle East	Ornamental	Available in a New York seed catalog in 1883 First Florida herbarium record in 1920	Replaces native grass communities and alters fire regimes in Hawaii	Mack 1991 (seed catalog) Daehler and Carino 1998 (ecological impacts) Smith and Tunison 1992 (ecological impacts) FLAS 3699 (earliest herbarium specimen)
	Phyllostachys aurea ex Rivière and C. Rivière (golden bamboo)	Southern China	Ornamental and erosion control	Before 1870 into southern USA	Forms dense stands and excludes other species in Texas	Borowski et al. 1996 (introduction and ecological impacts)

Continued

Table 1. Invasive grasses in Florida, their origins, introduction history, and ecological impacts.

FLEPPC Category (*Cont'd*)					
II Species (common name)	Native region	Reason introduced	Year of introduction	Ecological impacts	References
Urochloa maxima (Jacq.) R.D. Webster (=Megathyrsus max., =Panicum max., Guinea grass)	Africa	Forage	1813 to Louisiana	Displaces native grasses, affects natural succession, increases fuel loads, and promotes fires	Parsons 1972 (introduction) Lonard and Judd 2002 (ecological impacts)

ed and rejected as forages in the southeastern USA became invasive and have resulted in enormous costs to control their spread, particularly in natural areas. This group includes Guinea grass (*Urochloa maxima* (Jacq.) R.D. Webster), jaragua (*Hyparrhenia rufa* (Nees) Stapf), molasses grass (*Melinis minutiflora* P. Beauv.), Napier grass (*Pennisetum purpureum* Schumach.), Natal grass (*Melinis repens* (Willd.) Zizka), paragrass, torpedo grass, and cogongrass, assuming an East African center of origin of the latter species. The reasons for rejection are often missing from the literature, but are known in a few cases. Napier grass was initially not widely exploited because of its large-diameter stems and height, but a dwarf variety, Mott elephant grass, became available in the 1970s. Despite being highly nutritious, Mott has not been widely adopted because propagation is vegetative and expensive (Sollenberger 2011). Natal grass was used for hay in the early 1900s but later replaced by more productive grasses (Piper 1934). Mislevy (1985) listed disadvantages of jaragua as a forage, including poor nutritive value and low tolerance to close grazing. The value of cogongrass as a forage is compromised by its relatively low yield and poor nutritive value (MacDonald 2009), let alone its extreme aggressiveness outside of pastures and tendency for promoting intense fires (Lippincott 2000). *Urochloa humidicola* (Rendle) Morrone and Zuloaga, a relatively recent introduction from South Africa in the 1960s and 1970s, was shown to be as productive and nutritious as bahiagrass (*Paspalum notatum* Flüggé, native to the Neotropics), but was susceptible to freezes and growth was limited before June (Ezenwa et al. 2006). Although not yet on the FLEPPC list, *U. humidicola* has recently exhibited tendencies toward invasiveness (FWC 2015), and the IFAS Assessment of Non-native Plants in Florida's Natural Areas has rated it as having a high risk for invasiveness (UF/IFAS 2016).

A few African grasses, not yet reported as invasive, are still promoted for use in Florida pastures, including African stargrass (*Cynodon nlemfuensis* Vanderyst), pangola grass (*Digitaria eriantha* Steud.), and Rhodesgrass (*Chloris gayana* Kunth) (Vendramini and Mislevy 2006; Vendramini et al. 2013, 2015). Additionally, one African grass on the FLEPPC Category II list, limpograss, is still advocated as a forage (Newman et al. 2014). Limpograss was introduced relatively recently compared to other invasive forage grasses, and was not placed on the FLEPPC list until 2003. New cultivars of limpograss continue to be developed and released to ranchers in Florida (Buck 2014).

Invasiveness of African Forage Grasses Outside of Florida

The invasiveness of African forage grasses in Florida is not unique, as these grasses have exhibited similar tendencies in several other areas of the world. In the southwestern USA and northern Mexico, buffelgrass (*Cenchrus cilaris* L.) has invaded millions of acres where it poses a threat to the unique biodiversity of the Sonoran Desert (Williams and Baruch 2000; Arriaga et al. 2004). In south Texas, buffelgrass was associated with a 32% reduction in bird abundance, attributed to a concurrent 42%–83% decrease in spiders, beetles, and ants (Flanders et al. 2006). A similar decrease in bird abundance was observed in areas invaded by African lovegrasses (*Eragrostis* spp.) in Arizona (Bock et al. 1986). In Puerto Rico, Guinea grass was associated with a decrease in abundance of ground-dwelling arthropods (Moreno et al. 2014). A decrease in the abundance of tree and shrub species and increased fire loads in Brazilian riverine habitats was attributed to invasion by molasses grass (Hoffman et al. 2004). In Australia, gamba grass (*Andropogon gayanus* Kunth) affected fire cycles by a seven-fold increase in fuel loads and an eight-fold increase in fire intensity compared to areas with native grasses (Rossiter et al. 2003). The same grass altered nitrogen cycling in Australia (Rossiter-Rachor et al. 2009) and in Hawaii (Asner and Beatty 1996). Grice et al. (2013) also noted a modified frequency and intensity of fires due to invasive grasses in Australia, as well as negative effects to biodiversity. Thus, African forage grasses present a recurring pattern of invasiveness in many subtropical and tropical areas of the world.

Why are African Forage Grasses Prone to Invasiveness?

The selection pressure from continued disturbance by large herbivorous mammals and the long coexistence with *Homo* spp. in Africa may explain the tendency of some African grasses to colonize ruderal habitats and become invasive outside of Africa. The traits associated with value as forage in grasses are also traits that predispose the grasses to invasiveness. Adaptability to a wide range of abiotic conditions, rapid establishment, persistence in the environment with minimal husbandry, high productivity under grazing pressure, and adaptation to disturbance are some of the desirable characteristics of forages, and these same traits may also lead to invasiveness (McIntyre et al. 2005; Driscoll et al. 2014). Similarly, shared attributes between ornamentals and invasive plants has been postulated as a reason that so many ornamental plants have become invasive (Niemiera and Von Holle 2009). The presence of vegetative propagative structures (stolons and rhizomes) characterizes the majority of invasive grasses (10/15), and has also been shown to be associated with invasiveness (Pysek 1997; Kolar and Lodge 2001). In addition, climatic similarity between Florida and subtropical areas of Africa may have increased the probability of establishment and spread.

Propagule pressure (Rejmánek 2000; Simberloff 2009) and hybridization are also likely to have played a role in the invasiveness of forage grasses, as many were introduced repeatedly from several source populations and planted over large areas. The USDA's Genetic Resources Information Network (USDA/GRIN 2015) includes 449 accessions of Guinea grass introduced between 1913 and 2010 and 41 accessions of limpograss introduced between 1964 and 1979. Multiple introductions of species from different geographic areas, coupled with intra- and inter-species hybridization, may have resulted in genotypes that are unique to Florida and more successful than either of the parental populations. Hybridization has been shown to have been an important factor in the invasiveness of several plants (Ellstrand and Schierenbeck 2000; Schierenbeck and Ellstrand 2009). For grasses, the best-studied example of hybridization is in *Spartina* spp., which has occurred in both San Francisco Bay and in the United Kingdom (Ayres et al. 2008; Ainouche et al. 2009). In Florida, ancient hybridization may have played a role in the spread of *Phragmites* Adans., as Lambertini et al. (2012) recently demonstrated that the dominant population in the Gulf Coast, including Florida, is very likely a hybrid of the European *P. australis* (Cav.) Trin. ex Steud. and the African *P. mauritianus* Kunth. The possibility for contemporary hybridization between *Phragmites* types appears possible as well (Meyerson et al. 2010; Paul et al. 2010). Although we are not aware of any specific examples of natural hybridization of forage grasses leading to invasiveness, it certainly seems possible considering the repeated introductions from multiple source populations that characterizes the introduction history of many species. Moreover, purposeful breeding of grasses for improved forage value has been implicated in their proclivity for invasiveness (Driscoll et al. 2014).

Improved Screening of Plant Introductions

A recent development in the effort to limit the introduction of potentially invasive plants into the USA is the establishment of new restrictions by the United States Department of Agriculture–Animal and Plant Health Inspection Service (USDA/APHIS). Plants thought to pose a threat to the United States, either directly as a weed or indirectly by harboring insect pests or pathogens, can now be placed on the "Not Authorized Pending Pest Risk Analysis" list (NAPPRA; USDA/APHIS 2016). Four African grasses are on the NAPPRA list, and three others are included on a proposed list (USDA/APHIS 2016). Persons wishing to import NAPPRA listed plants can petition APHIS to conduct a full risk assessment to determine whether the plant can be removed from the NAPPRA list. To date, risk assessments have been completed on 103 plants, but only one African forage grass, *Echinochloa pyramidalis* (Lam.) Hitchc. and Chase, is included. On the state level, the University of Florida has developed the "Assessment of Nonnative Plants in Florida's Natural Areas" (Lieurance et al. 2013), a tool to predict the invasion risk of both nonnative species that already occur in the state as well as species proposed for introduction. The UF/IFAS Assessment has evaluated more than 770 species, including 97 proposed for introduction or new uses. However, the assessment has not evaluated any African forage grasses that are not already established in Florida.

Lessons Learned

The introduction history and outcomes associated with African forage grasses, and with agricultural plant introductions in general, are difficult to trace due to the lack of a comprehensive and transparent tracking system. The USDA established the Plant Genetic Resources Conservation Unit (PGRCU) at Griffin, Georgia, in 1949, with the mandate to "preserve plant genetic resources for present and future researchers and educators" (USDA/ARS/PGRCU 2016). The unit "acquires, characterizes, conserves, evaluates, documents, and distributes genetic resources of agronomic and horticultural crops." Plant material is acquired through collection and donation by foreign cooperators or international germplasm collections. There is no requirement for germplasm to be deposited in the PGRCU or other National Plant System Germplasm repository (NRC 1991), but it appears that many accessions introduced for agricultural purposes are included. The distribution of germplasm from the repositories is recorded, but the identities, affiliations, and locations of persons receiving germplasm are not disclosed due to privacy concerns. Multiple accessions of a plant species may be distributed to researchers at numerous institutions across the USA and overseas, with no independent ability to follow the dissemination of germplasm. If a plant eventually causes economic or environmental harm, the origin and pathway of dissemination cannot be determined. In addition to potential issues of liability, this lack of transparency could also affect management efforts, particularly biological control. The best-adapted biological control agents are often found in the area where the genotype of an invasive weed originated (Harley and Forno 1992; Goolsby et al. 2006), but without a tracking system available to the public, determination of the introduction history of the weed population is compromised. We recommend adoption of a more transparent "cradle to grave" management system similar to that used for pesticides. It should be a requirement that all germplasm introduced for agricultural purposes be deposited in the PGRCU, and the distribution of germplasm to institutions, if not individuals, should be available to the public, and easily tracked within GRIN. Moreover, the locations and areas planted with the original germplasm received from the PGRCU should be recorded and made available to the public.

Multiple introductions from several source populations characterize the invasion history of many forage grasses, but often there is little or no information available about which genotypes established. Cogongrass was introduced first as packing material from Japan, later from the Philippines for testing as a forage, and an ornamental variety, Japanese blood grass, may have been introduced on multiple occasions (MacDonald 2009). There are at least five genetic lineages of cogongrass established in the southeastern USA, along with the putatively native species, *Imperata brasiliensis* Trin. (Lucardi et al. 2014; Burrell et al. 2015). Studies to determine the origin of the two most invasive lineages are underway in order to prioritize geographic areas to explore for biological control candidates (Burrell et al. 2015). Molecular studies would also be useful for disentangling the origins of other invasive grasses. Guinea grass was first introduced into the USA around 1813 (Parsons 1972), but an additional 449 accessions from numerous locations around the world have been deposited in the PGRCU. The pathways of dissemination of those accessions are not available. Similar to cogongrass, a biological control program against Guinea grass has been initiated (Mercadier et al. 2009; Bon et al. 2011) and, therefore, it is important to know the origin(s) of the invasive populations.

The benefit/cost ratio of the introduction of forage grasses into Florida appears to be tilted toward the cost side of the equation. At present, only a few forage grasses are promoted in Florida for livestock production, but many pose serious ecological threats to native plant communities (Table 1). The harm caused by some African grasses appears to outweigh their benefits for livestock production, and further importation should be restricted. Lonsdale (1994) reviewed the introduction history of forage plants into Australia and found that of 186 pasture grasses introduced, only 11 (6%) proved useful, including eight that were also weedy, while 24 species were solely weedy with no apparent redeeming value. We have not done a similar calculation for Florida because of the lack of a comprehensive list of grasses introduced for forage, but clearly very few species are in use today. The Florida Forage Handbook (Newman et al. 2014) includes eight exotic warm-season forage grasses, but the numbers of forage grasses introduced into Florida is undoubtedly much higher. The PGRCU lists 477 species of warm-season forage grasses introduced into the USA, but the number tested in Florida is unknown. Regardless, an obvious lesson is that as a group, African forage grasses are highly prone to invasiveness, and great caution should be taken when moving them from one geographic area to another.

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