ELEMENT STEWARDSHIP ABSTRACT

for

Paspalum notatum Flüggé

Bahia grass, Bahiagrass

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THE NATURE CONSERVANCY

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SCIENTIFIC NAME

Paspalum notatum Flüggé

SYNONYMS

Paspalum cromyorhizon Trin. ex Döll
Paspalum distachyon Willd. ex Döll
Paspalum saltense Arechav.
Paspalum saurae (Parodi) Parodi
Paspalum taphrophyllum Steud.
Paspalum uruguayense Arechav.

COMMON NAMES

Bahiagrass, Bahia grass

DESCRIPTION AND DIAGNOSTIC CHARACTERISTICS

Paspalum notatum is a sod-forming, deep-rooted, warm-season perennial grass (Watson & Burton 1985). The individual short rhizomes of *P. notatum* are tough, stout, and are often covered with the overlapping bases of old leaf sheaths. The live leaf bases at the terminus of each rhizome usually have a purplish hue. The culms (stems) of *P. notatum* are ascending, usually ranging from 20 to 75 cm tall, and the dark green leaves are 4 to 10 mm wide and linear-elongate in shape. The leaf blades are typically 6 to 25 cm long and the leaf sheaths are generally 4 to 20 cm long and slightly inflated. The membranous ligule is less than 1.5 mm long (Hickman 1993; Diggs et al. 1999).

The inflorescences have two to several spicate branches 4-12 cm long, and each branch (or raceme) has two rows of spikelets. These spikelets are either paired or positioned with one slightly below the other. The spikelets are broadly ovate or broadly obovate (rarely elliptic), 3 to 4 mm long, and 1.0 to 2.5 mm wide (Long & Lakela 1971; Hickman 1993). The margins of the upper glume and lower floret lemma are smooth and can be distinguished from *Paspalum distichum* by having an entirely smooth upper glume.

Several cultivars of *P. notatum*, such as the hardy 'Pensacola' or 'Paraguay' strains, were introduced into North America for forage and erosion control. 'Pensacola' is the most common cultivar in Florida (Werner & Burton 1991). *P. notatum* cultivars can be distinguished from most other sod-forming pasture grasses by their characteristic short scaly rhizomes, their distinctive inflorescences, and by their dark green leaves (Hitchcock 1951).

STEWARDSHIP SUMMARY

P. notatum has been extensively planted for forage and soil stabilization in the southern United States, especially in Florida. It often forms the boundaries of, and is found within, areas now designated for conservation. Despite its decreasing productivity with age, *P. notatum* continues to dominate pastures decades after abandonment. Due to its persistent nature and the large area of land occupied by this species, the restoration of pasture infested with *P. notatum* has become a major land management challenge.

P. notatum dominates over two million hectares in the southeastern U.S. (Beatty & Powell 1978) and impedes restoration in many southeastern plant communities. For example, native long-leaf pine forests (*Pinus palustris)* are generally able to re-establish in abandoned pastures following cultivation or grazing

(Uridel 1994), but the presence of *P. notatum* in these pastures inhibits the regeneration of these forests. *P. notatum* can also inhibit the regeneration of slash pine (*Pinus elliottii*) (Fisher & Adrian 1981). *P. notatum* forms a tough, extensive sod that does not allow native species to survive. The removal of this sod layer is probably the most effective way of eliminating *P. notatum,* but it is difficult to do so. Even when the sod layer is removed, *P. notatum* has been known to reestablish itself via its seed bank and remaining rhizomes.

Repeated herbicide treatments can also work to control *P. notatum*, but the best control approach is to combine mechanical removal in combination with herbicide treatments. Several herbicides such as imazaquin, imazameth (formerly AC 263,222), imazethapyr, and sulfometuron-methyl, can all suppress *P. notatum* growth and seedhead production (Gonzalez et al. 1984; Turner & Dickens 1984; Johnson 1990; Goatley et al. 1996). These herbicides are often been used in turfgrass situations or along roadsides, but does not result in a reduction of P*. notatum* numbers or range. In other turfgrasses where *P. notatum* is a problem, dalapon, glyphosate, sulfometuron, or atrazine, have been applied successfully to control *P. notatum* while leaving *Cynodon dactylon* (bermudagrass) or *Eremochloa ophiuroides* (centipedegrass) relatively intact. Reddy & Singh (1992) also found that the use of organosilicone adjuvants can increase the efficacy of glyphosate applications against *P. notatum*. Herbicide applications, however, can be expensive. Therefore, mechanical treatments such as repeated disking or sod removal are favored for its control when these are appropriate options (Gordon et al. 1999).

The best control of *P. notatum* occurs with a combination of sod removal and herbicide applications. Sod removal should occur in the spring before seedhead production for the best results (Violi & Menges 1999). Helen Violi (pers. comm.) reports that using a rotary plow (20 cm deep), however, is not completely effective. The rhizomes and seeds of *P. notatum* are capable of producing new plants following sod kill or removal. Following sod removal, Helen Violi recommends using an application of glyphosate (at 21.9 L a.i./ha) using a hand sprayer in the spring for effective control (pers. comm.).

The use of prescribed fire is not effective in controlling *P. notatum,* as it is fire-adapted and resprouts from underground rhizomes following a burn. *P. notatum* changes the behavior of fire in ecosystems with otherwise patchy vegetation cover because it forms a continuous sod fuel layer. By altering fire behavior, it changes ecosystem function.

In areas that can be manipulated by different hydrological regimes, flooding can be an effective tool in the control of *P. notatum*. David (1999) found that a single inundation period of 5 months of at least 40 cm in depth controlled *P. notatum*, and that repeated inundations resulted in a complete elimination of *P. notatum* by the second year. Additionally, the native *Pontederia cordata* (pickerelweed) and *Panicum hemitomon* (maidencane) became established soon-after *P. notatum* removal.

The reintroduction of native vegetation into *P. notatum*-dominated pastures often requires re-seeding or the planting of native propagules. In general, wetter sites require less restoration efforts (Gordon et al. 1999). Other more challenging exotic invasive species can also invade restoration sites. Native ruderal species such as dog fennel (*Eupatorium capillifolium*) can impede the restoration of pre-pasture plant communities (E. Wertschnig, pers. comm. 1999).

P. notatum was listed as a Category I Exotic Pest Species in Florida, but was recently removed from this list due to questions regarding its ability to invade intact ecosystems (Austin 1998). It has been observed to rapidly spread vegetatively into disturbed soil on plow lines and roads adjacent to planted areas. Sharon Hermann (personal communication) has observed *P. notatum* invade approximately 10 meters over 3 years into a plowed utility right-of-way. Gordon et al. (1999) evaluated the ability of *P. notatum* to invade established native vegetation in Florida, and determined that while it might have expanded from the area in which it was originally sown, its invasion beyond areas of disturbed vegetation was not biologically significant.

RANGE

P. notatum is native to South Brazil, Uruguay, the Chaco region of North Argentina, and northwestern Paraguay (Quarin et al. 1984; Tischler et al. 1990). It may also be native to the West Indies (Watson & Burton 1985). *P. notatum* has been introduced as a turf and forage grass into Australia, Japan, Mexico, and the United States. It is found in most Central and South American countries (West & Marousky 1989). It is widely cultivated in low-altitude pastures of south-western Japan and is a popular forage grass on the north coast of New South Wales and on the south coast of Queensland (Hirata 1996).

P. notatum was introduced to the USA from Brazil in 1913 by the Bureau of Plant Industry at the Florida Agricultural Experiment Station, Gainesville (Scott 1920). Different cultivars for forage and erosion control were soon introduced, such as 'Paraguay' in 1947 to Georgia, and 'Argentine' in 1945 into Florida by the USDA (Baker 1996). 'Wilmington' and 'Pensacola' varieties were soon discovered in the southern U.S. in the 1940s, and today, several varieties of *P. notatum* are thought to cover over two million hectares in the south-eastern U.S. (Beatty & Powell 1978).

In North America, *P. notatum* can be found from southern California to eastern Texas, from southern Florida to New Jersey, and from central Tennessee to Arkansas (Chase 1929; Watson & Burton 1985). Reported occurrences of *P. notatum* include: Alabama, Arkansas, California, Florida, Georgia, Louisiana, Missouri, New Jersey, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, Puerto Rico and the Virgin Islands (USDA PLANTS database 1997).

IMPACTS AND THREATS POSED BY *PASPALUM NOTATUM*

P. notatum can invade pastures and disturbed rights-of-way, and impede the growth and survival of native species by the formation of dense mats of vegetation. *P. notatum* can dominate the habitat, and its stands can resist invasion by other plant species. It has not, however, been documented to invade intact native systems (Gordon et al. 1999). *P. notatum* persists under even intense grazing regimes (Adjei et al. 1989). Rhizomes from well-fertilized *P. notatum* pastures can contain enough resources to persist for 2-3 years (Chambliss 1991). In the southeastern U.S., some cultivars are no longer a desirable forage grass, and *P. notatum* may be considered a weed (Eichhorn 1995).

P. notatum has altered the natural fire regime in many areas within the southeastern U.S. Since the 1940s, cattle ranchers have used winter burns to stimulate the growth of forage species, including *P. notatum* (Hilmon & Lewis 1962). Native understory vegetation, such as wiregrass (*Aristida beyrichiana*), responds best to late summer and fall burns (Abrahamson 1984).

In addition to changes to fire regimes, the installation of *P. notatum* pastures has also resulted in changes to hydrological regimes. Ditches and canals constructed to establish and maintain these pasture grasses alter historic drainage patterns and water levels. These changes can negatively affect neighboring wetlands. Therefore, in large-scale restoration plans, additional time and money must be spent to identify the nature of the hydrological changes and possible ways to reduce or eliminate further habitat deterioration due to existing drainage systems.

P. notatum's impact on native soil communities are largely unknown, but it has been widely used as a host for commercially valuable mycorrhizal fungi or as a companion plant (Ishii & Kadya 1994; Ishii et al. 1997; Poole & Sylvia 1990; O'Donnell et al. 1992). The mycorrhizae in *P. notatum* pastures have been documented to be negatively affected by the addition of some nutrients, primarily phosphorus (Douds & Schenck 1990; Douds 1994). Although it is difficult to determine the possible effects of pasture conversion and *P. notatum* presence on the native soil community, there is speculation that a shift in the composition and spore numbers of vesicular-arbuscular mycorrhizae (VAM) may influence the growth and survival of native plants (Douds et al. 1994).

HABITAT

P. notatum is best adapted to moist, sandy soils in sub-tropical and temperate climate zones (Anon. 1987; Baker 1996). It is adapted to both upland and lowland areas, and has been found on open ground, savannas, and pastures from elevations at sea level to 2000 m in Central and South America (Chase 1929). *P. notatum* easily invades disturbed pastures, roadsides, and rights-of-way, but does not appear to invade intact, undisturbed, native systems.

BIOLOGY AND ECOLOGY

Light, moisture and temperature

P. notatum easily invades open, disturbed habitats. It is well-adapted to low-nutrient soils. It is relatively flood tolerant (Mislevy et al. 1991; Hatcher 1996) and drought tolerant (Tischler et al. 1990). It does well in climates that receive 750 to 1200 mm of precipitation per year. In its native range, *P. notatum* is often found on sandy soils in areas where there are periods of heavy precipitation followed by up to six months of extreme drought (Tischler et al. 1990). In sub-tropical and temperate climate zones it grows best in sandy soils with a pH of 5.5 to 6.5 in (Baker 1996). *P. notatum* is moderately frost tolerant, but the degree of tolerance varies among cultivars.

Growth

P. notatum infestations enlarge by seed dispersal or by spreading clonally via rhizomes. Rates of clonal growth have been documented at approximately 0.24 to 0.49 m per year. Under favorable conditions, the 'Pensacola' cultivar can spread vegetatively at a rate of 0.30 to 0.45 m per year (Werner & Burton 1991). In the southeastern United States, growth rates are highest between March and October (Chambliss 1991). Individual plants are able to produce a bunch-culm basal diameter of 500 mm in one growing season (Werner & Burton 1991).

Phenology

P. notatum is a long-day plant that is strongly influenced by photoperiod (Marousky & Blondon 1995) and temperature (Marousky et al. 1991). Flowering is induced when daylight exceeds 13.5 hours per day (Marousky & Blondon 1995). Floral inflorescences emerge in early May to early July. Flowering in a given population usually occurs over a 4-week period (Marousky et al. 1991). In Florida, seeds of *P. notatum* mature from June through the summer (Watson & Burton 1985).

Reproduction

Varieties and cultivars of *P. notatum* generally have different ploidy levels, which influence how they each reproduce. The tetraploid varieties are generally considered obligate apomicts, and reproduce by unfertilized but viable seeds. The diploid forms reproduce sexually (Burton 1982), and are usually highly cross-pollinated (Werner & Burton 1991). The sexually reproducing varieties are wind-pollinated. Seeds of *P. notatum* are typically dispersed by ruminants. *P. notatum* can also spread vegetatively.

Seed germination

The germination of *P. notatum* seeds is slow and intermittent. There are differences in germination rates between cultivars (West & Marousky 1989; Busey 1992). These differences in germination rates can ensure stand establishment over time (Gates & Dewald 1998; Gates & Mullahey 1997). *P. notatum* seeds can germinate between 21.0 and 37.5° C, and optimal temperatures for seed germination and seedling growth are between 32 and 37.5°C (Marousky & West 1988).

Germination rates of *P. notatum* can be increased by passing the seeds through the intestinal tract of a ruminant animal (Jones & Neto 1987; Gardener et al. 1993), mechanical or acid scarification (Marousky & West 1988; West & Marousky 1989; Mullahey & Fischer 1993), and by the presence of mulch (Dudeck &

Peacock 1986). Soil characteristics (such as the proportion of sand in the soil matrix) can also influence rates of *P. notatum* seed germination (Aaronson & Hawkes, unpubl. data).

Predation and diseases

P. notatum is relatively free of damaging insects and diseases (Chambliss 1991). It hosts fewer species and lower overall abundances of insects than does bermuda grass (*Cynadon dactylon*) (Lynch & Burton 1993). The two most damaging insects to *P. notatum* are mole crickets (*Scapteriscus* spp.) and army worms (*Spodoptera frugiperda*). Mole crickets were introduced from South America (Walker 1982) and are considered the most destructive insect pest to pasture grasses in Florida (Hudson 1985; Kepner 1985). Mole crickets damage *P. notatum* by feeding and tunneling within the plant (Walker 1982).

Fungi and other pathogens which occur on *P. notatum* include: *Rhizoctonia solani*, fairy rings (*Chlorophyllum* sp. and *Marasmius* sp.), root rots (*Pythium* spp.), and slime molds (*Physarum* spp. and *Fuligo* spp.). These infections generally do not cause great damage to *P. notatum* in the southeastern U.S. (Atilano et al. 1982). The seedheads of certain cultivars (for example, 'Argentine') of *P. notatum* have also been documented to be sometimes significantly damaged by ergot (*Fusarium* spp. and *Claviceps paspali*), but this is not prevalent in most other cultivars in the U.S. (Chambliss 1991).

ECONOMIC USES

P. notatum is widely planted and used in the United States for forage and erosion control.

MANAGEMENT

Potential for restoration of invaded sites

In most situations, *P. notatum* does not appear to be a highly invasive plant. It can dominate pastures and areas where it has been intentionally planted, and then spread into disturbed fields and roadsides; however, it does not seem to invade intact communities. There is no evidence that it recruits into ruderal sites exclusively by seed (Austin 1998). Nor does *P. notatum* appear to spread from pastures into adjacent forested areas. The dense mats of vegetation created by *P. notatum,* however, present major obstacles to the successful restoration of pastures to native sandhill or forest communities. Successful restoration of *P. notatum*-dominated sites typically involves the mechanical removal of *P. notatum* sod, repeated plowing/disking, and herbicide applications. If this can be done, the potential for native restoration is probably medium to high.

Control measures

Various techniques including disking, sod removal, burning, and/or herbicides, have been tested to control the spread and extent of *P. notatum* for restoration projects in Florida. Most of these restoration projects have been conducted on sites that were originally scrubby, mesic and hydric flatwoods, sandhill, or wetland communities.

The most effective method for controlling *P. notatum* is a combination of mechanical removal and herbicide applications (Violi & Menges 1999). All studies showed that plowing/disking or sod removal (to a depth of 20 cm) was the most effective method for reducing the aboveground cover of *P. notatum* (Uridel 1994; Hatcher 1996). In former flatwoods communities, however, a single disking and a combination of disking and prescribed burning was ineffective at controlling *P. notatum* (Segal et al. 1999; Violi & Menges 1999), and actually promoted the growth of other problematic exotic species. Further, *P. notatum* is able to re-invade sites via pieces of rhizomes and from the soil seed bank (Bisset pers. comm.; Wertschnig pers. comm.; Gordon et al. 1999; Violi & Menges 1999). Repeated disking, therefore, or complete sod removal may be necessary to control *P. notatum*.

Single herbicide treatments using glyphosate (e.g. RoundUp) were also ineffective at controlling *P. notatum.* Repeated treatments of herbicide or a combination of mechanical and herbicide treatments (glyphosate at 21.9 L a.i./ha) were the most successful (Beresford et al. 1999; H. Violi, pers. comm.).

In places where the hydroperiod can be controlled, flooding is also a viable control method for *P. notatum*. A minimum of 5 months at least 39.5 cm deep is necessary for good control (David 1999). Repeated inundation in following years will eventually eliminate *P. notatum*, and can promote the establishment of native wetland species.

PASPALUM NOTATUM MANAGEMENT AND RESTORATION TECHNIQUES

Restoration efforts conducted by Nancy Bissest (The Natives, Inc.), Beth Wertshnig (CF Industries), and The Nature Conservancy (Gordon et al. 1999) demonstrate that the direct seeding of native propagules collected from nearby plant communities can successfully establish native species to improved pastures following multiple herbicide and disking treatments (Bisset et al. 1998). At the Reedy Creek Mitigation Site in Florida, seed bed preparation involved repeated herbicide applications of glyphosate on *P. notatum*, followed by a month of repeated disking. The site was then smoothed-down using a water-filled roller followed by another herbicide application. Native seeds were then introduced to the site during the winter, using a broadcast seeding method. A more detailed description of the site preparation and native plant seeding/planting techniques used in these and other pasture restoration projects in Florida has been compiled by Walker (1999).

Despite the repeated disking and herbicide treatments used in site preparation, *P. notatum* seedlings were still observed on the more xeric portions of the site. The pre-emergent herbicide imazapic (tradename Plateau) is currently being tested for its effectiveness in reducing the germination of *P. notatum* and other undesirable species. Preliminary results show that imazapic effectively reduces the germination of *P. notatum* and other exotics, but also reduces the rates of germination of desirable native species (Bisset 1999).

When restoring *P. notatum* infestations to cutthroat grass (*Panicum abscissum*) communities in Florida, transplanted plugs of native species may be necessary because cutthroat grass infrequently flowers (USFWS 1998; Violi & Menges 1999). Other native plants such as beaksedge (*Rhynchospora* spp.) and witchgrass (*Dicanthelium* spp.) may be valuable in protecting these and other transplanted herbs. For example, Uridel (1994) found that the native gayfeather (*Liatris* spp.), wiregrass (*Aristida* spp.), and other transplanted herbs showed increased rates of survival, despite high densities of other exotic plants such as senna (*Cassia* spp.) and flatsedge (*Cyperus* spp.) in plowed and herbicide-treated plots. These native species are hypothesized to aid in the survival of transplanted herbs by providing shade and reducing soil moisture loss during drought conditions. It was also observed that the presence of already established herbs reduced rates of herbivory on newly transplanted gayfeather plants (Uridel 1994).

Other restoration attempts experimented with introducing native plants into pastures without first controlling *P. notatum* . Results indicate that native plant survival two years post-planting was high, but *P. notatum* seems to be uninhibited by the presence of the native species (NeSmith 1999).

Overall, sod removal or repeated disking/plowing, and repeat herbicide treatments, were the most effective techniques for controlling *P. notatum*, and typically result in increases in native plant species diversity. In general, the mechanical and herbicide combinations resulted in high colonization by undesirable species (invasive ruderal and exotic species found problematic in restorations). Additionally, these combination treatments generally did not prove to be significantly more effective in controlling *P. notatum* than mechanical treatments alone.

MONITORING

Following control treatments and restoration plantings, monitoring is necessary to determine results. Viability of *P. notatum* seeds in the seed bank may influence how long monitoring at a particular site needs to be continued.

Variations of the point-intercept method are often used to obtain pre-treatment and post-treatment plant species cover estimates. On large-scale projects, or when time and funds are limited, visual estimates of vegetation cover within small plots (at least 0.25 m in diameter) are appropriate if enough plots are sampled.

The monitoring method should be selected based on the goals of the restoration project. For example, if information is sought regarding the treatment response of individual native species, a more detailed sampling design may be needed. Trained botanists are required to determine which grassland species are native and which are potentially problematic non-native species. Monitoring data must be analyzed to determine whether the management objectives are being met and if modifications to the control treatment are needed.

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RESEARCH NEEDS

The following research topics need attention:

1) Long-term monitoring of restoration sites in Florida to determine competitiveness of native plant species with re-invading *P. notatum*.

2) Continue and expand on studies examining the invasiveness of *P. notatum* into natural systems.

3) Determine which *P. notatum* cultivars pose the greatest problem to restoration projects, and which, if any, may have the potential to invade and spread into intact native plant communities.

4) Conduct further research to identify which native species are good competitors and how best to introduce those species into restoration sites.

5) Continue projects to find native alternatives to *P. notatum* for highway shoulders and other non-agricultural areas

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