ELEMENT STEWARDSHIP ABSTRACT
for

Cynodon dactylon

Bermuda Grass

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The Nature Conservancy
Element Stewardship Abstract
For Cynodon dactylon

I. IDENTIFIERS

Common Name: BERMUDA GRASS Global Rank: G?

General Description:
Cynodon dactylon is a warm-season, prostrate, perennial grass; it spreads by scaly rhizomes and flat stolons to form a dense resilient turf.

Diagnostic Characteristics:
The distinguishing characteristics of Cynodon dactylon are the conspicuous ring of white hairs of the ligule, the fringe of hairs on the keel of the lemma, and the gray-green appearance of the foliage.

II. STEWARDSHIP SUMMARY

Cynodon dactylon can be an invasive and competitive weed. The extensive stolon and rhizome system provide a means of rapid expansion. However, this species, which requires high temperatures and high light levels to thrive, grows only in disturbed areas. Although extremely drought tolerant, Bermuda grass tends to grow where water is available. The plant is not frost or shade tolerant and the rhizomes and stolons are susceptible to desiccation. A single treatment or combination of clipping, tilling, shading and herbicide application for several years should result in complete eradication of this weed. The site should be re-vegetated once Bermuda grass is initially controlled in order to prevent the invasion of other weeds or the re-sprouting and establishment of the remaining Bermuda grass rhizomes.

III. NATURAL HISTORY

Range:
The date of the initial introduction of Bermuda grass into the United States is uncertain, but most likely it occurred in the mid-1800s (Harlan 1970). By the mid-1900s Bermuda grass had been introduced throughout the southern states and now ranges from California to Florida and occasionally north to Massachusetts and Michigan (Hitchcock 1950).

Habitat:
The common name for all the East African rhizomatous species of Cynodon is Bermuda grass (Harlan 1970, Burton and Hanna 1985). Most of these species originated and have remained in southeast Africa. Cynodon dactylon however, has become a "ubiquitous, cosmopolitan weed" (Harlan and de Wet 1969). The large intra- specific variability in Cynodon dactylon is represented by four varieties which have remained endemic to their

original locale, and by two varieties, most notably Cynodon dactylon var. dactylon (from here on referred to by the species name), which have spread to other countries (Harlan 1970).

Cynodon dactylon grows throughout the warmer regions of both hemispheres. In the United States it occurs at elevations under 6000 feet, primarily in waste places, agricultural fields, and roadsides (Crampton 1974, Humphrey 1977, Burton and Hanna 1985). Although widespread, this species "thrives only under extreme disturbance and does not invade natural grasslands or forest vegetation" (Harlan and de Wet 1969). In areas of low rainfall it commonly grows along irrigation ditches and streambeds (Crampton 1974, Humphrey 1977, Burton and Hanna 1985). Bermuda grass, especially the cultivar Coastal, is extremely drought tolerant, however moisture significantly increases its growth rate (Humphrey 1977, Burton et al. 1987).

Ecology:
Warm temperatures are necessary for the plants to thrive, and long periods of freezing weather or short durations of extremely low temperatures are detrimental to the plants (Gould 1951). Average daily temperatures above 24 C are necessary for substantial growth and temperatures of 38 C result in maximum growth rates (Holm et al. 1977, Burton and Hanna 1985).

In addition to high temperatures, Bermuda grass requires high light intensities. Cynodon dactylon needs direct sunlight in order to grow and dies out with increased levels of shade. This characteristic can be utilized in the control of Bermuda grass (Holm et al. 1977).

Cynodon dactylon tolerates a wide range of soil types and conditions. Growth is greater on heavy clay soils than on light sandy soils in dry regions; this may be due to the greater water holding capacity of the clay (Burton and Hanna 1985). Bermuda grass can survive long periods of flooding, but little to no growth occurs without adequate soil aeration (Burton and Hanna 1985). It grows on soils with a wide range of pH values, however alkaline soils are tolerated more than acidic ones. Growth is promoted by the addition of lime to soils with a pH of 5.5 (Burton and Hanna 1985). A large amount of available nitrogen is required for maximal above-ground growth; this element is often the limiting factor for Cynodon dactylon. Nitrogen fertilizers are routinely used in order to increase the forage and turf value of Bermuda grass (Humphrey 1977).

The drought and alkali tolerance, and high temperature and sunlight requirements of Bermuda grass explains its success in the Southwest; it is the most common and best performing grass in Arizona (Gould 1951). In southern Arizona Cynodon dactylon grows abundantly along sandy washes and near alkaline seeps (Gould 1951). A rapidly growing variety, which can grow over hedges 2 m tall, was introduced to Hawaii and Arizona in the early 1900s. A substantial amount of the world's salable seeds of this "giant" Bermuda grass is grown near Yuma, Arizona (Kearney and Peebles 1951, Harlan and de Wet 1969). Large amounts of Bermuda grass, including the giant-type, grow along the edge of

Roosevelt dam in Arizona, where it survives submergence under water for part of the year and provides food for cattle during the dry periods (Munz and Keck 1959).

Shading drastically affects both above- and below-ground growth (Burton et al. 1959, McBee and Holt 1966, Schmidt and Blaser 1969, Hart et al. 1970, Burton et al. 1988). In Georgia, forage yield is dramatically reduced after the middle of September, with an average June yield of 2907 kg/ha and an average October yield of 295 kg/ha (Burton et al. 1988). Daylength and solar radiation, but not rainfall and minimum temperature, were significantly correlated with forage yield; 64%, 43% and 29% of the normal light intensity resulted in a reduced annual dry matter yield of 68%, 42% and 30%, respectively, of unshaded plants (Burton et al. 1988). Half the amount of rhizome and root growth occurred in the 64% shade treated-plants than in the control plants (Burton et al. 1959). Tall dense trees greatly reduce Bermuda grass growth, and complete canopy cover eventually kills the grass (Burton et al. 1959, Schmidt and Blaser 1969). The decrease in growth due to shading is intensified by high temperatures; this may be explained by an increase in respiration rate relative to photosynthetic rate (McBee and Holt 1966). Increasing the level of nitrogen while maintaining a low light setting results in a further reduction in growth; nitrogen fertilizer increases the retarding effect of low light on shoot, root and rhizome yield, and decreases the amount of reserve carbohydrates while increasing the amount of crude proteins (Burton et al. 1959).

Carbohydrate levels in Bermuda grass do not generally follow a consistent pattern (Weinmann 1961). The cultivar and the environmental conditions greatly influence the reserve carbohydrate quantity and quality. In general, total available carbohydrates in the rhizomes increases in the fall, peaking between November and December, decreases in late winter and begins increasing in late spring, reaching a second, but lower, peak in May, and then decreasing in the summer (Horowitz 1972b). In Mauritius, the carbohydrate reserves do not decrease in the late winter, instead they increase steadily from fall to spring, and then the pattern fluctuates the rest of the summer depending on the variety (Rochecouste 1962a). Seasonal rhizome bud germination does not appear to be correlated with the carbohydrate level (Horowitz 1972b).

Temperature affects the level of carbohydrates by altering the ratio between the respiration and photosynthetic rate, thus influencing the growth rate (McKell et al. 1969). The greatest amount of growth occurred at 30 C/24 C (day/night temperatures) whereas the greatest amount of starch in the stem bases and rhizomes of Coastal Bermuda grass occurred in the 13 C/7 C treated-plants (McKell et al. 1969).

Increasing the level of nitrogen results in a decreased amount of reserve carbohydrate (White 1973, Burton et al. 1959). Nitrogen fertilizers increase the glucose in leaves by decreasing the amount of sucrose and fructosan in stems, stolons, rhizomes and roots (Adegbola and McKell 1966). Nitrogen fertilizers are used to increase the above ground growth of Bermuda grass. When nitrogen is limiting, and the growth conditions unfavorable, fructosans accumulate in the rhizomes (Adegbola and McKell 1966). Storage carbohydrate utilization in nitrogen metabolism is thus connected with increased shoot growth (Schmidt and Blaser 1969).

An increase in nitrogen fertilizer from 0 to 900 pounds per acre results in an increase in height (2.5 inches to 6.5 inches), percent protein, yield (1.6 tons to 11.0 tons of hay), stem length (6.0 to 17.0 inches), internode length and node number, and a decrease in leaf percentage and seed head frequency (5% to 2%) (Prine and Burton 1956). An increase in nitrogen from 0 to 80 kg/ha results in a 5 times greater above-ground biomass (Skousen et al. 1989).

Bermuda grass is susceptible to desiccation. Long rhizome fragments and dormant stolons require long periods of drying in order to destroy the activity of the buds (Webb 1959, Horowitz 1972d). Air drying of one-node rhizome fragments for seven days resulted in the inhibition of sprouting and a 53% weight loss, however three-node rhizome fragments continued to sprout after seven days of desiccation (Horowitz 1972d). Actively growing stolons are more susceptible to desiccation than post-dormant stolons. Greater than 48 hours of drying over an ammonium chloride solution kills actively growing stolons, whereas greater than 96 hours is required to destroy post-dormant fragments (Webb 1959). The critical moisture level for stolons is 39% and for the harder to control rhizomes 15% (Webb 1959, Horowitz 1972d). Bermuda grass rhizomes cannot be drowned. Submergence of fragments for eight days in running water or four weeks in stagnant water had no effect on sprouting ability (Horowitz 1972d). Thus water is likely to be an efficient means of spreading rhizomes.

COMPETITIVE RELATIONSHIPS: Plant residues and actively growing plant parts of Cynodon dactylon may pose a direct threat to the growth of neighboring plants (Friedman and Horowitz 1970, Horowitz and Friedman 1971). Light textured soils mixed for four months with extracts from decaying Bermuda grass plants caused an inhibition of radicle elongation in barley and mustard seedlings (Friedman and Horowitz 1970). Incubation of test plants for two months with Bermuda grass results in a high degree of inhibition (Horowitz and Friedman 1971). In addition to the importance of the duration of exposure, is the concentration. The inhibition is proportional to the concentration of plant material. In general, root growth and germination are both affected by decaying residues and actively growing Cynodon dactylon plants (Horowitz and Friedman 1971). The importance of the allelopathic substances produced by Bermuda grass in the field is unclear. Threats due to completely decayed residues should not be overlooked.

In addition to the allelopathic effects of Cynodon dactylon is the direct competition for space and nutrients by this rapidly growing perennial grass. Bermuda grass's notoriety as a tremendous colonizer comes from the spreading ability of both the rhizomes and stolons (Horowitz 1973). The open growth pattern of Bermuda grass's stolons provides for greater land coverage than seen with species which lack stolons, such as Sorghum halepense; the average monthly area increase in the warm season for Cynodon dactylon and Sorghum halepense is 1.6 m2 and 1.3 m2, respectively (Horowitz 1973). Aerial growth from shoots, tillers and previous season's rhizomes produce an abundance of stolons, which in turn produce more shoots, rhizomes and roots (Horowitz 1972a). This growth pattern explains the tremendous spreading capacity of Bermuda grass; the highest monthly area increase was 6 m2 during July and August (Horowitz 1972a). However, the average area increase for Cynodon dactylon is only 0.9 m2 per month. This growth rate is far less than other perennial grasses; Cyperus rotundus has a mean area increase of 2.8 m2 per month (Horowitz 1972a).

Rhizomes grow in the same configuration as the above-ground growth and are not found growing outside of the sod perimeter. The subterranean dry weight averages 0.6 kg per m3 of soil within a 1 m radius from the center of the plant. Rhizome depth is comparable under the center of the plant and at the edge of the sod. The depth of penetration is restricted by compaction and aeration (Horowitz 1972a). With roots extending from stolons and rhizomes, a vast area can be utilized for uptake of water and nutrients.

The competitive ability of Cynodon dactylon depends on the competing plant species and the nutritional level of the soil. Bermuda grass yields were reduced by 40%, 27% and 13% when grown with Johnson grass, Torpedo grass and Cogon grass, respectively for one year (Wilcut et al. 1988). However Bermuda grass had a greater inhibitory effect on the competing plants, with a reduction in the yield of Johnson grass, Torpedo grass and Cogon grass by 55%, 38% and 43%. After two years of competition Johnson grass reduced the yield of Bermuda grass by 99% (Wilcut et al. 1988). Native vegetation recovery, due to the competitive ability of knotgrass (Paspalum sp.), began within one year after cattle were removed from a riparian ecosystem in which Bermuda grass was abundant (Richter pers. comm.).

Cynodon dactylon and Acacia smallii were grown in mixed and mono-culture plots, with and without added fertilizer in order to study the competitive ability and mechanism of the two species (Cohn et al. 1989). C. dactylon grew 1.5 to 2.4 times larger in mixed cultures than in mono-cultures, with a yield increase of 30% to 50% when grown with Acacia. Cynodon dactylon's competitiveness is thought to stem from its ability to reduce the level of nutrients to below the necessary amount needed by Acacia smallii; this assumption is based on the increase in Cynodon dactylon's growth in the mixed over the mono-culture treatments, its drastic increase in the fertilized, mixed culture plots, and the growth reduction by 70% to 90% of Acacia smallii in the fertilized mixed plots (Cohn et al. 1989).

Studies on competition in mixed plots of wheat and Cynodon dactylon showed similar intra- and inter-specific competition for nutrients when plants were planted at the same time (Ramakrishnan and Kumar 1971). Stunted growth of Cynodon dactylon occurred in high wheat density plots. A reduction in dry weight, leaf area and seed output was most likely due to the large size of the wheat plants which caused shading of the Bermuda grass. Low density mono-culture plots of Cynodon dactylon promoted early vegetative spreading growth with delayed reproductive development, whereas in high density plots the period of vegetative growth was shortened and floral development was hastened. In addition, seed production decreased with increased densities of Bermuda grass (Ramakrishnan and Kumar 1971).

RESPONSE TO MANIPULATIONS AND ABIOTIC FACTORS: The effects of fire on Cynodon dactylon are variable and dependent on the season and prevailing environmental conditions at the time of burning. Odum et al. (1973) burned a four year old fallow field during the late winter in Georgia. The burn resulted in a drastic reduction in Bermuda grass from 14.7 g/m2 to 0.2 g/m2 as compared to the increase in Johnson grass from 0.2 g/m2 to 27.4 g/m2. However, with the exception of extremely dry conditions or long periods of fire suppression, both of which result in hot fires that may damage the rhizomes, most rhizomatous grasses, such as Cynodon dactylon tend to benefit from fire (Rensburg 1970). Winter burning of Bermuda grass is performed in several southern states in the U.S. in order to hasten spring growth, resulting in increased yield and quality of forage (Hardison 1974).

The increase in the amount of Cynodon dactylon due to cattle grazing is well documented (Weinmann 1961, White 1973, Belsky 1986a&b). Unlike many other plants, intensive grazing on Bermuda grass results in an increase in carbohydrate accumulation in the below-ground structures (Weinmann 1961). This explains the rapid regrowth and establishment that was seen in overgrazed plots in the Serengeti National Park (Belsky 1986a&b). Grazing does not significantly affect growth of rhizomatous and stoloniferous plants that have a prostrate growth form (White 1973).

Clipping may have a greater affect than grazing on Cynodon dactylon due to the potential for removal of all tillers and shoots (White 1973). The mowing of Bermuda grass three times a week throughout the growing season had no significant effect on the carbohydrate content or weight of the rhizomes and roots; however, systematic cutting of each individual aerial structure with a scissor resulted in a significant reduction in the reserve carbohydrate level and weight of the below ground structure (Weinmann 1961). Removal of greater than 40% of the shoots reduced root growth and many roots failed to resume growth when severely clipped (Risser et al. 1981). Plants with prostrate growth and high, fluctuating levels of reserve carbohydrates, such as Cynodon dactylon, are difficult to control by clipping (Weinmann 1961).

Reproduction:

VEGETATIVE GROWTH: The principle means of propagation of Cynodon dactylon is through the rhizomes and stolons (Holm et al. 1977). These structures are often severed from the plant by burrowing animals and animal hooves; the fragments are then transported by contaminated animals, hay, and machinery, as well as by running water (Holm et al. 1977).

The following is a description of the general life-cycle of Cynodon dactylon. In the spring when the temperature begins to increase new stolons elongate and aerial shoots sprout (Horowitz 1972a). The characteristic prostrate growth of Bermuda grass lasts for one to several months, early in the season, before flowering culms develop. Most of the lateral growth, produced in concentric circles from the original rhizome, occurs throughout the summer (Horowitz 1972a&b, Holm et al. 1977).

Single-bud rhizomes were planted and monitored throughout several growing seasons (Rochecouste 1962a). In the first month a primary shoot and four roots develop from the rhizome. Elongation of the internodes on the shoot is followed by the development of up to twenty buds per node. As many as 12 tillers sprout and three dormant rhizome buds develop from these shoot buds. Horizontal growth commences when the primary shoot and tillers reach 10 cm to 15 cm long, resulting in the formation of stolons. New stolons and roots are continually formed at the nodes of the spreading stolons. The dormant rhizome buds at the basal node of the primary shoot begin to grow at the commencement of the wet warm season. These rhizomes growing deep in the soil provide an over-wintering structure as well as, when they surface, additional above-ground growth (Rochecouste 1962a).

Rhizomes are the primary over-wintering structure (Holm et al. 1977). Cynodon dactylon's success as a weed is thought to be a result of the adaptive rhizome characteristics. The rhizome system is superficial as well as deep, which may account for the ability of this species to infest both arable and waste lands in a variety of conditions. Horowitz (1972a) found approximately 70% of the rhizome weight of two and a half year old plants in the upper 20 cm of the soil and no rhizomes below 40 cm (Horowitz 1972a). Other investigators report the existence of rhizomes 1 m deep (Holm et al. 1977). Concentric growth, outward from the original rhizome sprout, of the rhizomes corresponds to the circular above-ground growth pattern (Horowitz 1972a). A decrease in rhizome dry weight correlates with an increase in distance from the original rhizome. Greater than 60% of the subterranean weight (600 g/m3) occurs within 1 m of the plant center, 30% in the next meter, with the remaining 10% in the 2 to 3 m range (Horowitz 1972a). This growth pattern ensures both rapid spreading and strong establishment of the plants.

New rhizomes form only at temperatures greater than 15 C to 20 C; sprouting of rhizome buds is maximal at temperatures between 23 C and 35 C and is inhibited by temperatures below 10 C (Horowitz 1972b). No dormancy period is found in rhizomes; sprouting occurs once apical suppression is relieved by fragmentation (Horowitz 1972b). Growth of rhizome buds varies depending on depth in soil and age of rhizome. The year-long average sprouting rate for rhizomes in the top 15 cm of soil is 34% and for deeper rhizomes 24% (Horowitz 1972b). Young rhizomes sprout much more readily than do older ones. New rhizomes are capable of growing once several distinct internodes have developed. Subterranean growth begins earlier in the spring than aerial growth. The rhizome dry weight increases in April, followed by rhizome elongation (Horowitz 1972b). The total rhizome length of single node rhizome fragments planted in July increases from 36 m per plant in December to 95 m the following July, indicating greater rhizome growth in early summer than in late summer (Horowitz 1972b).

New stolons are formed at the basal node of shoots which had developed from over-wintering rhizomes (Horowitz 1972a). New stolons can grow 75 cm in the first six weeks after sprouting (Horowitz 1972a). Within three and a half months eight stolons from the main shoot and seven stolons from secondary shoots develop, resulting in 570 cm of stolon length (Horowitz 1972a). The initial stolons move away from the center shoot in straight lines. This is followed by the secondary stolons growing in all directions to form dense circular mats of sod (Horowitz 1972a). In two and a half years the average sod area of a single plant is 25 m2, with a maximum growth rate of 2 m2 per month in the summer months (Horowitz 1972a). Above ground growth is limited by temperatures below 18 C, and dies at -2 C (Horowitz 1972b). The high temperature requirements explain the five times greater increase in sod area for June through November than for December through May (Horowitz 1972a).

Roots develop from rhizomes and stolons. Roots produced at the distal end of the stolon are much longer and more abundant than those close to the original stem (Rochecouste 1962a). Depending on the cultivar, soil texture and nitrogen availability roots can reach 245 cm below the soil surface, however the majority of roots are found in the top 30 cm (Burton et al. 1954).

SEXUAL GROWTH: Asexual reproduction, not sexual reproduction, is responsible for the spread of most Bermuda grass. Most biotypes are infertile, and those that are fertile tend to produce sparse amounts of seeds (Rochecouste 1962a, Holm et al. 1977). However, southwestern United States varieties often have a good seed set. The tiny seeds remain viable after passing through livestock and after submergence in water for 50 days (Holm et al. 1977). There are approximately 4.4 million seeds in one kilogram (Holm et al. 1977). In California, 450 kg of hulled seeds are harvested per hectare in July (Burton and Hanna 1985). All biotypes, regardless of their fertility, produce inflorescences which range in height from 5 cm to 40 cm (Rochecouste 1962a). Inflorescences develop on the center shoot one and a half months after late spring planting (Horowitz 1972a). Inflorescences form during the summer and their production terminates in November; flowers occur throughout the sod at the end of the season, with a maximum of 99 inflorescences per plant. The sod area is proportional to the number of inflorescences with an average of 78 inflorescences per square meter of sod the first year. The second year of growth results in a drastic increase in the number of inflorescences with the maximum of 1125 per plant and an average of 87 inflorescences per square meter of sod (Horowitz 1972a).

Impacts:
Spreading of Cynodon dactylon is exacerbated by the continued planting of this turf and forage crop. Bermuda grass is difficult to control once it has been nurtured and has become established (Holm et al. 1977, Burton and Hanna 1985). The rhizomatous and stoloniferous growth and, depending on the cultivar, the abundance of minuscule seeds, leads to the extensive spreading capabilities of Bermuda grass. However, Bermuda grass is sensitive to shade and frost damage, and only invades disturbed land. Thus, although abundant throughout the world, the threat from the invasion of this plant is limited to warm, sunny, disturbed sites.

Bermuda grass's high pollen production leads to its notoriety as a major contributor to allergies (Gould 1951). Forty years ago Bermuda grass was considered the leading cause of hay fever in Arizona (Kearney and Peebles 1951).

In addition to competing with native plants for nutrients, Cynodon dactylon presents a direct threat to agricultural crops and possibly to natural vegetation by acting as an alternate host to eleven arthropods, twelve nematodes and numerous viruses (Holm et al. 1977, Akobundu 1987).

IV. CONDITION

Restoration Potential:
Although Cynodon dactylon is considered the world's weediest grass, eradication appears to be feasible. Bermuda grass poses no problem in undisturbed, cold and shady areas. Thus if land adjacent to invaded areas remains covered by natural vegetation, Bermuda grass will be unable to spread into it.

V. MANAGEMENT/MONITORING

Management Requirements:
Cynodon dactylon, in disturbed sites, is a competitive and invasive weed. The best management strategy is to remove all plant parts at first sighting. Invasion will be limited by tall plants. Spot herbicide and manual tilling may be adequate in controlling native fields with patchy weed distribution. A more drastic control plan is necessary in sites heavily infested with Bermuda grass. The appropriate manipulation is dependent on the location, humidity, temperature, soil type and precipitation at the specific site. Burning, herbicide application, clipping and shading have all been effective in controlling Bermuda grass under various conditions. In order to prevent the sprouting and establishment of the remaining Bermuda grass rhizomes, native plants and shade material should be installed immediately after the eradication stage.

The best management practice is to avoid the initial invasion of Cynodon dactylon by limiting soil disturbances and maintaining a vegetation cover. Areas where the soil and native plants are kept intact should have little problem from Bermuda grass since it mainly invades disturbed lands (Crosswhite pers. comm., Diamond pers. comm., McWhorter pers. comm., Weigel pers. comm.).

Management strategies depend on the extent of Bermuda grass and the height of the native vegetation.

1a. Sites with established Bermuda grass where restoration projects include re-vegetating with tall-stature plants: A single season of controlling the Bermuda grass following by the transplanting or seeding of native plants will most likely be a sufficient control measure. Periodic spot control or shade mats placed around the young plants may be necessary during the establishment of the native plants. As already stated, the control technique employed is dependent on the site parameters. Herbicide application in conjunction with tilling and desiccation may be the most effective control technique.

1b. Sites with established Bermuda grass where restoration projects include re-vegetating with short-stature plants: A more severe eradication procedure is necessary when the native vegetation will not shade the Bermuda grass. Several repeated tilling and herbicide applications may be required to remove the maximum amount of underground rhizomes and stolons prior to the re-vegetation phase. Many years of spot control may be required until all remaining Bermuda grass is removed or until the ground is covered by the native vegetation.

2a. Uninfested sites with complete canopy cover surrounded by areas containing Bermuda grass: Most likely this situation will not require any active management since Bermuda grass rarely invades undisturbed sites.

2b. Uninfested sites with bare or unshaded spots surrounded by areas containing Bermuda grass: If the site is undisturbed than most likely Bermuda grass will not invade it. However, careful monitoring may show this to not be the case. If appropriate, planting of tall plants between the invaded and non-invaded sites may prevent spreading into the exposed area. Removal of the weed in the adjacent land may be required if invasion occurs frequently.

Several techniques are helpful in controlling Bermuda grass. Depending on the extent of coverage by the weed and on the site parameters a combination of the following manipulations may aid in controlling Bermuda grass: mowing and clipping, tilling and plowing, burning, shading, and chemical control.

MOWING AND CLIPPING: Removal of the aerial portion of perennial plants may slow the growth by limiting the accumulation of carbohydrates (Lorenzi and Jeffery 1987). The temperature, moisture and clipping frequency influence the amount of subsequent growth. Cutting Bermuda grass on hot, dry days has a much greater inhibitory effect than cutting on cool, moist days (Prine and Burton 1956, Jameson 1963). Weekly clippings at soil level during the moist season reduced yield by 50% whereas clipping during the dry season reduced the yield by 65% (Prine and Burton 1956). Monthly clipping of Bermuda grass reduced the amount of regrowth in the following year, whereas bi-weekly clipping from spring through winter resulted in the complete inhibition of regrowth the following year (Horowitz 1972c). In addition to reducing the regrowth of shoots, the initial clipping inhibited the formation of flowering stalks (Jameson 1963, Horowitz 1972c). The removal of aerial portions of the plant as a control measure is only efficient on small scale problem sites due to the labor and time intensity of the necessary frequent repeated clippings.

Eliminating aerial growth reduces the carbohydrate availability in the rhizomes. However understanding the annual carbohydrate cycle is not helpful since rhizome sprouting is not correlated with carbohydrate levels, thus clipping should proceed throughout the entire growing period (Horowitz 1972b). The depletion of carbohydrates is related to nitrogen concentrations. Nitrogen fertilizers decrease the amount of carbohydrate reserves; clipping increases the translocation of nitrogen from the soil to the roots and carbohydrate reserves are depleted during the above-ground utilization of nitrogen (White 1973, Skousen et al. 1989). Care must be taken to remove all aerial growth repeatedly throughout the growing season when clipping and mowing are used as a control measure.

TILLING AND PLOWING: Hand hoeing is practical only where the concentration of Bermuda grass is low. Shallow cultivation using sharp hoes, shovels, knives or hand pulling will remove the plants and rhizomes from the upper portion of the soil without dividing or pulling up deep rhizomes (Heathman et al. 1986, Lorenzi and Jeffery 1987). This technique is impractical in large scale infestations. Repeated plowing throughout the summer growing period will fragment the rhizomes and bring them to the surface; this will aid in the desiccation of the rhizomes and stolons (Burton and Hanna 1985). Small actively growing rhizome and stolon fragments are susceptible to drying within one week (Webb 1959, Horowitz 1972b). Hot, dry weather facilitates desiccation. An alternative to desiccation is freezing. Tilling in the winter will expose the rhizomes to freezing temperatures (Lorenzi and Jeffery 1987).

BURNING: Inconsistent results have been obtained on the effects of burning as a control for Bermuda grass. In general, if conducted at the correct time, burning will slow down the growth of perennial grasses (Lorenzi and Jeffery 1987). A late winter fire in Georgia drastically reduced the amount of Bermuda grass (Odum et al. 1973). However most burning experiments conducted in swampy areas result in the increase in abundance of Bermuda grass (Rensburg 1970). In wet areas, the rhizomes are protected from the heat of the fire. Due to the variable outcome of burning, this method is not recommended for controlling Cynodon dactylon.

SHADING: This plant requires high light intensity to thrive. With high levels of shade the plant can no longer grow; thus shading can be used as a control method (Kearney and Peebles 1951). Increased amounts of shade results in a decrease in the following: underground carbohydrate level, root weight, rhizome weight and herbage yield (Jameson 1963). Plants grown under 65% shade resulted in a 68% reduced yield (Burton et al. 1988). Results on the survival of Bermuda grass growing under trees indicate that the grass will die when completely shaded by closed canopies (Burton et al. 1988). Successful weed control resulted from the use of mats (bought at garden supply shops) which cover the ground and shade the Bermuda grass growing around the base of irrigated trees (Tiller pers. comm.). A thick layer of organic or inorganic mulch may provide adequate shading.

CHEMICAL CONTROL: Herbicides are helpful in controlling Bermuda grass. However, pre-emergence herbicides are not recommended. These reduce the competition of annual grasses allowing the rhizomes and stolons of Bermuda grass to thrive (Holm et al. 1977). An increase in the growth of Bermuda grass is seen in fields where pre-emergence herbicides are used to control annual weeds (Horowitz 1972a).

Glyphosate (commercial name -- Roundup, produced by Monsanto) is mildly toxic and decays rapidly in the soil. This foliar spray, which should not be used in galvanized steel sprayers, is absorbed in the leaves and translocated to growing regions throughout the plant (Kelly 1983, Ross 1986). Glyphosate, sprayed from helicopters, trailer sprayers or backpack sprayers, at a concentration of 2% will result in an 85% to 95% control after the first year (Hamilton pers. comm., Heathman pers. comm., Silberman pers. comm., Wildman pers. comm., Kelly 1983).

The best time to spray is when the carbohydrates are being translocated down to the rhizomes at the time of maximum rhizome growth. A downward movement of the herbicides most likely coincides with the spring and fall rhizome growth period (Rochecouste 1962b). Silberman (pers. comm.) and Brookbank (pers. comm.) recommend the fall spraying of herbicides for maximum effectiveness.

A successful restoration project, restoring cottonwoods and willows to a 40 acre Bermuda grass pasture in California, resulted in maximum control with glyphosate alone (Tiller pers. comm., Silberman pers. comm.). Combinations of herbicides and tilling were less effective. In September while the plants where in full bloom, one week before spraying 2% glyphosate from a boom-sprayer, the field was irrigate to encourage growth. A 95% control was seen after the single application. Trees were planted later, placed on a drip irrigation system and fertilized. Hand weeding and spot herbicide treatment continued for the following year. The greatest regrowth occurred around the irrigated trees. Four feet by four feet shade mats (mulch) were placed around the trees to reduce the sprouting of the remaining rhizomes.

Management Programs:
The following people are involved in either actively managing or planning the management of Cynodon dactylon:

Val Little, Preserve Manager, Hassayampa River Preserve, The Nature Conservancy, Box 1162, Wickenburg, AZ 85358; (602) 684- 2772.

Oren Pollack, Stewardship Ecologist, California Regional Office, The Nature Conservancy, 785 Market St., 3rd Floor, San Francisco, CA 94103; (415) 777-0487.

Ron Tiller, Preserve Manager, Kern Preserve, The Nature Conservancy, P.O. Box 1662, Weldon, CA 93283; (619) 378-2531.

Monitoring Requirements:
Monitoring the size of the area of land infested by Bermuda grass would be beneficial in determining the optimal control technique. Since Bermuda grass is low growing and not always readily apparent, some type of marking system should be employed in order to expedite the yearly measurements. Knowledge of the extent of the underground rhizome and root system is important for manipulating the entire infested area; no additional

measurements are required since the underground growth pattern parallels the aerial development.

Yearly summer monitoring of Bermuda grass should determine whether the aerial extent is diminishing with the employed control measure. Tagging the edge of each cluster yearly may help in visually assessing the expansion or reduction in the infested area and in rapidly locating the problem site.

Both the sod area and maximum extension are useful measurements. Changes in sod area can be determined by comparing the area of the annual concentric circle growth size drawn on a contour map, plotted by making a grid with poles spaced 1 m apart and then subtracting the size of the bare areas (Horowitz 1972a). A random sampling of segments of the infested field may provide sufficient information for large scale problems. Maximum extension is measured by determining the distance from the center of the sod to the tip of the furthest stolon. Measuring the number of inflorescences produced each summer is helpful with fertile varieties (Horowitz 1972a). Germination tests will determine the fertility status of the variety in question.

Monitoring Programs:
Presently no formal monitoring programs of Bermuda grass are known. The following people "eyeball" the distribution of the grass:

Val Little, Preserve Manager, Hassayampa River Preserve, The Nature Conservancy, Box 1162, Wickenburg, AZ 85358; (602) 684- 2772.

Ron Tiller, Preserve Manager, Kern Reserve, The Nature Conservancy, P.O. Box 1662, Weldon, CA 93282; (619) 378-2531.

Jeff Weigel, Director of Stewardship, The Nature Conservancy, P.O. Box 1440, San Antonio, TX 78295-1440; (512) 224-8774.

VI. RESEARCH

Management Research Programs:
No specific research on Bermuda grass control in natural plant communities is being conducted presently. However, ongoing research on the eradication of perennial weedy grasses with the use of newly synthesized herbicides in the agricultural milieu takes place in most of the southern land-grant universities (Hamilton pers. comm.).

Management Research Needs:
An extensive amount of information on Cynodon dactylon is available. The genetics, life-cycle, environmental requirements, phenology, beneficial and deleterious characteristics, and control of Bermuda grass are all well documented. However, the information pertaining to controlling this species pertains to agricultural crop fields and not to the

natural environment. Most of these techniques are not economically or practically feasible in a non-agricultural setting.

Information on controlling Bermuda grass in a natural setting is needed. Two major stages, not necessarily temporally separated, are essential for restoring the native flora: eradication of the weed and encouragement of native plants, preferably large, if appropriate. The extensive rhizome system essentially prevents the complete removal of Bermuda grass, thus once controlled, periodic manipulation of the weed is necessary. The early establishment of native plants which can shade the Bermuda grass is important to eradication, maintenance and re-vegetation.

Information on both optimal manipulation and native competitor establishment must be specific for the problem site. The temperature, precipitation, humidity and elevation will determine the optimal control technique.

Experimental plots should be employed for long term studies of various manipulation techniques. Controlled burning at various times of the year and assorted repetition cycles from single burns to yearly repeated burns should be analyzed (Cox pers. comm.). Various schedules of mowing, grazing, tilling, desiccating and herbicide applications should be studied at different locations. The percent coverage, timing of shading and types of shading material, such as shade cloth, shade mats, trees and other plants, should be studied in order to maximize the shade sensitivity of the species. The effects on carbohydrate reserves of nitrogen amendments to shaded plants should be analyzed. The interaction of several manipulation techniques should also be examined.

Rapid recovery of native vegetation, once most of the Bermuda grass has been removed, is essential in order to prevent invasion by other weeds or re-sprouting and establishment of the remaining Bermuda grass rhizomes. Studies to determine the optimal native species to be used and re-vegetation schedule to be followed must be conducted (Newman 1989). If appropriate, the establishment of large native plants will provide both a shading device and re- vegetation material.

VII. ADDITIONAL TOPICS

VIII. INFORMATION SOURCES

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IX. DOCUMENT PREPARATION & MAINTENANCE

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