ELEMENT STEWARDSHIP ABSTRACT
for

Eichhornia crassipes (Martius) Solms

water hyacinth

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THE NATURE CONSERVANCY

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SCIENTIFIC NAME

Eichhornia crassipes (Martius) Solms
Synonym *Piaropus crassipes* (Martius) Britton

COMMON NAME

water hyacinth

DESCRIPTION AND DIAGNOSTIC CHARACTERISTICS

E. crassipes is a free-floating aquatic macrophyte growing generally to 0.5 m in height but to nearly 1 m in height in some southeast Asian locations (Gopal 1987). *E. crassipes* forms dense, floating mats. As a free-floating plant, all its nutrients come from the water column (Sculthorpe 1985). Leaves are thick, waxy, rounded, and glossy and rise well above the water surface on stalks. The leaves are broadly ovate to circular, 10-20 cm in diameter, with gently incurved, often undulate sides. Leaf veins are dense, numerous, fine and longitudinal. Leaf stalks are bulbous and spongy. The stalk is erect, to 50 cm long, and carries at the top a single spike of 8-15 showy flowers. The flowers have six petals, purplish blue or lavender to pinkish, the uppermost petal with a yellow, blue-bordered central splotch. Water hyacinth reproduces vegetatively by short runner stems (stolons) that radiate from the base of the plant to form daughter plants, and also reproduces by seed. Its roots are purplish black and feathery (Gopal 1987).

E. crassipes forms a shoot consisting of a branched, stoloniferous rhizome, 6 cm in diameter and up to 30 cm in length, with several short internodes. Each node bears a leaf and roots. Axillary buds, which can also form stolons, grow at an angle of 60 degrees from the rhizome and remain at that angle or bend upward in dense stands, or become horizontal in open stands. Plants on the edge of a mat form stolon buds while those in the middle may not. Stolons are purplish violet and extend up to 50 cm or more in length and are highly variable in diameter (Gopal 1987).

Leaves form as the axillary bud grows, rupturing a tubular leaf-like structure called a “prophyll.” As the internode between the first leaf and the prophyll elongates, roots are produced at the node bearing the primary leaf. Foliage leaves are formed after. Foliage leaves are petiolate with a glossy sheen, and are arranged spirally, appearing to be in a rosette. Each leaf consists of a petiole, isthmus (between petiole and blade) and blade. The petiole bears a large membranous stipule, which forms a sheath around the next younger leaf. Petioles are spongy and measure up to 5 cm in diameter and 30-50 cm in length (maximum 125 cm). They may be elongated, swollen in the middle and tapering towards the blade or they may form a bulbous float (Gopal 1987) containing air-filled lacunate tissue (Sculthorpe 1985).

As much as 50% of a single water hyacinth’s biomass can be roots. Roots are adventitious and fibrous, 10-300 cm in length. As many as 70 lateral roots per cm give the roots a feathery appearance. They are dark violet to bluish or pinkish violet (though whitish if grown in total darkness) and contain soluble pigments, including anthocyanins that may protect the root from herbivory (Gopal 1987).

Flowers are borne terminally on a lavender spike on an elongated peduncle and are subtended by two bracts. The lower bract has a distinct blade. Each spike has 4-25 flowers (maximum 35) with 8-15 being the most common. Flowers are sessile. The perianth tube is 1.5-1.75 cm long with a green base and pale top. Tepals are ovate to oblong, thin, lilac and up to 4 cm long. The posterior tepal (labellum) has a central bright yellow diamond-shaped region surrounded by a deep blue border with bright red radiating lines. When young, this labellum has a green spot. There are six stamens (sometimes 5 or 7) having curved filaments with glandular hairs. Three are small and close to the perianth tube. Anthers are violet and measure 1.4-2.2 mm long (Gopal 1987).

The gynoecium is tricarpellary and superior. The ovary is nearly conical and produces approximately 500 ovules. The style is variable in length and bears a nearly capitate stigma with three closely appressed lobes. Sometimes the stigma is trifid and may be longer, shorter or intermediate in length compared to the stamens. This heterostyly makes *E. crassipes* trimorphic (Gopal 1987).

The fruit is a thin-walled capsule enclosed in a relatively thick-walled hypanthium developed from the perianth tube. Mature seeds can number 450 per capsule, are 4 x 1 mm, with an oval base and tapering apex. The coat has 12-15 longitudinal ridges (Gopal 1987).

E. crassipes can be distinguished from most other floating and mat-forming aquatic plants by its highly glossy leaves, the almost one-sided swelling of its petioles (Holm et al. 1991), and its showy lilac flowers. *E. crassipes* can float freely, unlike its congener *E. azurea* which must root to the substrate and is therefore confined to shallow ponds and the edges of lakes and rivers (Barrett 1989). *E. azurea* is a USA federal noxious weed which has been imported from South America to decorate ponds and occasionally escaped into local environments. It often produces a much more showy inflorescence than *E. crassipes*, one sometimes carrying more than 60 flowers (Gopal 1987).

PEST WEED STATUS

The species is listed as a noxious weed in Arizona. It is often regarded as the most troublesome aquatic weed in the world (Holm et al. 1991).

STEWARDSHIP SUMMARY

E. crassipes is thought to be native to the Amazon River Basin. It possesses specialized growth habits, physiological characteristics, and reproductive strategies that allow for rapid growth and expansion in freshwater environments. Water hyacinth has spread rapidly throughout the tropics and subtropics. It has become a serious weed in freshwater habitats in rivers, lakes and reservoirs in tropical and warm temperate areas worldwide, where it displaces native aquatic plant and animal communities, causes substantial economic hardships and interferes with water uses.

E. crassipes forms large, free-floating, monospecific mats that compete with other aquatic species for light, nutrients and oxygen. Mats reduce dissolved oxygen levels and light and significantly alter invertebrate and vertebrate communities. As biomass from mats decomposes, organic input to sediments increases dramatically (Gopal 1987). Fish spawning areas may be reduced and critical waterfowl habitat may be degraded (Schmitz et al. 1993).

Very small infestations of water hyacinth can be controlled by pulling, but herbicidal and biological controls are most effective. Herbicides which control *E. crassipes* also, however, damage or kill other aquatic organisms, and may have only limited usefulness in wildland settings. They include copper sulfate, 2,4-D, and the Rodeo formulation of glyphosate. Over 100 species of insects and some fungi have been investigated as possible water hyacinth biocontrols. Two weevils and a moth, all introduced in the 1970s from Argentina, have been shown to have significant although erratic impacts on *E. crassipes* populations. Two fungi, one of them native to North America, have also been shown to have some effect on water hyacinth populations.

E. crassipes has a nearly worldwide range throughout the tropics. Thought to be native to the Amazon River basin, it has spread to more than 50 countries on five continents (Mansor 1996; Barrett 1989; Gopal 1987). In North America, jurisdictions which list the species in the Natural Heritage Program database are: Alabama(SR), Arizona(SR), Arkansas(SU), California(SR), Florida(SR), Georgia(SR), Hawaii(SR), Kansas(SRF), Kentucky(S?), Louisiana(SR), Mississippi(SR), Missouri(SR), New York(SR), North Carolina(SE), Ontario(SEI), Sonora(S?), South Carolina(SR), Tennessee(SR), Texas(SR), and Virginia(SE).

HABITAT

E. crassipes grows in shallow temporary ponds, wetlands and marshes, sluggish flowing waters and large lakes, reservoirs, and rivers. Plants can tolerate extremes of water level fluctuation and seasonal variations in flow velocity, and extremes of nutrient availability, pH, temperature and toxic substances (Gopal 1987).

E. crassipes forms dense, monospecific, free-floating mats in still to slow moving waters. Winds or currents may disperse these mats. It may be found in association with a variety of other deep water or free-floating aquatic plants. Water hyacinth is thought to have originated in the Amazon basin and the extensive lakes and marshes of the Pantanal region of western Brazil. Water levels of lakes in this area fluctuate dramatically because of seasonal changes in rainfall. The Amazon River can rise and fall 10 meters annually. The region contains many nutrient-rich pools that become interconnected during the rainy season, allowing for explosive growth of *E. crassipes* during high water periods (Barrett 1989).

Salinity

E. crassipes has been found to tolerate salinity levels up to 0.24% in Indonesia (Kikuchi et al. 1997). Invertebrates may use or colonize roots and above surface parts of the mat and some macrophytes may germinate and grow on large mats. *E. crassipes* mats reduced dissolved oxygen and light levels and increase water temperature.

ECOLOGY AND BIOLOGY

Mat Development

During mat development, plants allocate most production to root biomass with little increase in average plant size. As plants mature, they increase in average biomass and production of daughter plants with reduced allocation to roots. At peak density, daughter-plant production is reduced but average plant size continues to increase, resulting in plant mortality (Madsen 1993). Young plants in low-density mats form a great deal of float tissue. In higher density mats, the proportion of float tissue decreases as surrounding plants support each other (Sculthorpe 1985).

In existing mats, plants reapportion biomass to the emergent shoots following winter. In early spring, branching and ramet production increase, resulting in high leaf densities and high foliar height diversity. In late spring, leaf size increases, but the number of leaves per rosette becomes stable. Some smaller plants are lost, resulting in lower absolute density (Center and Spencer 1981).

Reproduction

E. crassipes reproduces both vegetatively and sexually, though vegetative reproduction is more important. *E. crassipes* grows and spreads rapidly under favorable temperature and nutrient conditions. Stolon buds develop that bear offshoots from axillary buds.

Sexual reproduction is very limited, though seeds and seedlings have been found in both the native and adventive ranges of the species. Although the plant flowers profusely, few observers have seen seeds or seedlings in the field. Seeds can survive on waterway banks and on *E. crassipes* mats. The number of fruits per inflorescence varies greatly (4 from 139 plants to 16 fruits per inflorescence). The number of capsules per inflorescence ranges from none to more than 20. The number of seeds per fruit is also highly variable, ranging from 3 to over 450 (Gopal 1987).

High temperature and low relative humidity result in low fruit set. Maximum fruiting occurs in 90% humidity and at 22.5-35º C (Gopal 1987).

Several species of bee pollinate the flowers. Pollination on bright days and in the morning produced more seeds than pollination at other times. Several researchers report a high level of self-compatibility. This may be related to the ability of *E. crassipes* to float free, an adaptation to extreme water level fluctuation (Gopal 1987).

Seeds

Seeds have been reported as remaining viable up to twenty years. Viability seems to be unaffected by storage in wet or dry conditions. Requirements for germination are unclear. Some researchers have found that seeds will germinate if left in water for seven days while others report that alternating wet and dry periods are needed to open the seed coat. Where seedlings are reported in nature, they appear on mud banks, lending support to the theory that a dry period is needed. Seeds kept in wet conditions may germinate sooner than those kept dry, though the percentage of seeds germinating does not appear different between the two conditions. Buried seeds do not germinate. High light intensity and alternating high and low temperatures (5-40º C) favor germination (Gopal 1987).

ECONOMIC IMPACTS

E. crassipes causes major detrimental impacts on water use. In drainage canals it greatly reduces flow, which can result in flooding and damage to canal banks and structures. In irrigation canals it impedes flow and clogs intakes of pumps used for conveying irrigation water. Water flow patterns have been disrupted in utility cooling reservoirs. *E. crassipes* can severely interfere with navigation of both recreational and commercial craft. In addition to interfering with boating by fisherman and water-skiers in recreational waters, *E. crassipes* interferes with swimming, displaces native vegetation communities, and can adversely impact sports-fish populations. Limitations on water use can reduce real estate values and tourism. As *E. crassipes* mats decompose, sedimentation increases and dissolved oxygen levels are reduced.

There has been some use of *E. crassipes* for removal of nutrients and heavy metals from sewage and sludge ponds (Vietmeyer 1975).

MANAGEMENT

Potential for Restoration of Invaded Sites

Restoration potential is likely to be lowest where, by whatever mechanisms, an invasive pest species possesses unusual reproductive vigor and a wide range of adaptability, and, in its present settings, has few pests and predators; where it is well-established both in terms of numbers and range; and where the use of common and cost-effective control measures will also negatively impact native flora. *E. crassipes* has unusual reproductive vigor and is highly adaptable. There are no known important native insect pests of *E. crassipes*. (Some insects that feed on the species in its native habitats, however, have been imported to and established in the United States and have caused some *E. crassipes* populations in some locations to decline. Fungi and other microorganisms have also been reported to reduce water hyacinth populations. At least one such fungus has undergone testing for commercial development.) *E. crassipes* is widespread and often a severe pest. And in wildlands, the application of even selective herbicides such as 2,4-D can kill other aquatic plants. Unless and until biological controls become biologically and economically feasible, the potential for large-scale restoration of wildlands infested with is *E. crassipes* probably moderate to very low.

Hand Pulling

Very small infestations of water hyacinth can be controlled by pulling (Randall and Meyers-Rice. unpublished), but herbicidal and biological controls are most effective. Herbicides which control *E. crassipes* also, however, damage or kill other aquatic organisms, and may have only limited usefulness in wildland settings.

Herbicides

Several herbicides are effective against *E. crassipes*. One key factor affecting efficacy of herbicides is translocation from stolons to other parts of the plant, particularly the roots. Younger plants translocate these substances faster. However, older plants and flowering plants may be more susceptible to stress from treatment. Warmer temperatures result in more rapid translocation of some herbicides. Mats consisting of older plants take longer to sink after herbicide application than mats of younger plants (Sculthorpe, C.D. 1985).

The Rodeo formulation of glyphosate, a non-selective herbicide, applied at 2kg/ha has caused complete kill in 8 weeks (Gopal 1987). The Rodeo formulation is non-toxic to fish and slightly toxic to aquatic invertebrates.

2,4-D (2,4-dichlorophenoxyacetic acid) applied at ranges of 1-12 kg/ha, generally by aerial spray, has proved the most effective chemical control, especially if applied during hot weather. Warmer temperatures result in more rapid translocation of 2,4-D. The herbicide is a phenoxy compound, and variants have also proven effective (Gopal 1987). 2,4-D is selective for broad-leaved plant species and some monocots like *E. crassipes*; it does not kill grasses. It is slightly to moderately toxic to birds (including waterfowl), and ester formulations can be toxic to fish and aquatic invertebrates. Salt formulations of 2,4-D are less toxic to aquatic animals and therefore more appropriate for use against *E. crassipes*. Brand names include Aqua-Kleen and others.

When applied at a rate of 3.5 mg/l, copper sulfate and copper chelate are non-selective herbicides (and the former is a widely used agricultural fungicide) that inhibit the growth of *E. crassipes*. Doses of 103 mg/kg dry weight of copper sulfate are lethal to *E. crassipes* (Gopal 1987). However, copper sulfate and copper chelate can be toxic to fish, particularly trout and other salmonids, and to some mammals, aquatic invertebrates and soil organisms. Both copper sulfate and copper chelate are more toxic to animals in acidic and/or soft waters. Brand names include Agritox, Basicap, Cutrine, Komeen, and others.

Biological Control

Biological treatments include insects and herbivorous fish including Chinese grass carp (*Ctenopharyngo idella* and hybrids), as well as *Tilapia melanopleura* and *T. mossambica*.. Chinese grass carp or white amur are used throughout the United States to reduce aquatic plant densities in water bodies used for sport fishing. Release is often restricted to specific water bodies as there are no guaranteed methods of recapture. These have a low reproductive rate requiring continual stocking to provide enough fish to have an impact. In many cases, state agencies require that Chinese grass carp to be stocked are sterile so as not to outcompete native or other stocked fish. These fish prefer other foods, feeding on *E. crassipes* only in dense stand and if other food is in short supply, so that large stocking rate required. Therefore, they are not considered effective for controlling *E. crassipes* (Gopal 1987). Since Chinese grass carp prefer food other than *E. crassipes*, the likely impact on natural areas, and even managed systems, is a reduction in the overall abundance of native aquatic plants, and potential reduction in food and habitat for invertebrates, other fish and waterfowl.

Over 100 species of insects, including several lepidoptera, coleoptera, hemiptera, dermaptera, diptera, and orthoptera which feed on *E. crassipes*, have been investigated as possible biocontrol (Gopal 1987). Julien and Griffiths (1998) report that the following biocontrol agents are in use in the U.S.:

Neochetina bruchi, water-hyacinth weevil (in Coleoptera) is widely established in Florida, and established but uncommon in Louisiana, Texas and California, where *E. crassipes* nonetheless remains a troublesome pest. It has been reported to be largely responsible for some declines in California populations of *E. crassipes*. The organism was introduced from Argentina in 1974 (Julien and Griffiths 1998).

Neochetina eichhorniae, water-hyacinth weevil (in Coleoptera) is well established throughout the range of *E. crassipes* in the southeastern U.S. It may be responsible for major reductions in water hyacinth populations in Texas. It has been reported that herbicides commonly used on *E. crassipes* have negatively impacted weevil populations. The organism was introduced from Argentina in 1972 (Julien and Griffiths 1998).

Niphograpta albiguttalis (synonym *Sameodes albiguttalis*), water-hyacinth moth (in Lepidoptera) is established in Florida, Louisiana, and Mississippi. It is reported to have significant impacts on new, developing colonies of water hyacinth but otherwise offers only sporadic and patchy control (Julien and Griffiths 1998).

The larvae of *Bellura densa* (synonym *Arzama densa*) (in Lepidoptera*)* have been found on taro (*Colocasia*) growing in Florida. Field releases of the laboratory-raised animals had little impact, although field releases of larvae dipped in 2,4-D provided total suppression in small plots in Louisiana. The organism was introduced from Argentina in 1977 (Julien and Griffiths 1998).

The fungus *Orthogalumna terebrantis* has been known in the U.S. since 1968, but was probably introduced here from South America on *E. crassipes*. It provides no substantial control, but in combination with other fungi may have a locally severe but temporary impact on water hyacinth populations. The fungus *Cercospora rodmanii*, which is native and widespread in the southeastern U.S., provides generally low levels of control. When present in epidemic proportions, however, it may provide high levels of control. The organism has undergone testing for commercial development (Julien and Griffiths 1998).

MANAGEMENT PROGRAMS

Because *E. crassipes* is a free-floating plant, a small, isolated mat can be moved by wind or current and quickly become a problem within a water body. In Florida, the U.S. Army Corps of Engineers attempted mechanical removal in the early 1960’s, but few machines could operate in shallow waters. The herbicide 2,4-D has been applied effectively as a control agent in Florida waters since the 1960’s. Several biocontrol agents, including the water-hyacinth weevils, *Neochetina eichhorniae* and *N. bruchi,* and the water-hyacinth moth, *Niphograpta albiguttalis,* have been used with varying degrees of success since the 1970s in the southeastern U.S. and in California (Julien and Griffiths 1998). These agents slow rates of growth and make plants more susceptible to other causes of mortality such as frost, herbicides and other pathogens (Simberloff et al. 1997).

MONITORING

In general, the objectives of monitoring should track those of management. Abundance (cover) is often measured following control applications. Most areas subject to management for *E. crassipes* are of economic or recreational importance (e.g., recreational lakes, canals, and irrigation systems). In those locations the goal is eradication of *E. crassipes* to a degree sufficient to permit continued economic or recreational uses. Monitoring is generally designed to monitor changes in abundance of *E. crassipes* alone. In natural areas management, monitoring programs will likely combine changes in abundance of *E. crassipes* with changes in abundance of species or changes in community attributes that are the targets of management. Such programs should have explicit objectives that can be measured and that are meaningful from both a biological and management standpoint. These objectives may vary depending on the abundance of *E. crassipes* and other invasive aquatic plants.

In terms of effort (number of plots established and monitored), transects or long, linear plots are more effective in providing sufficient statistical power to determine change than square or broadly rectangular or otherwise regularly shaped plots. However, such techniques are more difficult to apply in aquatic situations, so that careful measurement and placement of plots may not always be feasible. While generally a research technique, measuring change, or lack thereof, in control (unmanaged) areas can be an effective way of assuring that changes are actually resulting from management and not from other factors.

In Mexico, monitoring has been done on changes in planktonic and benthic communities in waters flowing into and out of impoundments (the primary target of control) and of herbicidal (2,4-D) residues in water, sediment and tissues of edible fish species (Gutierrez et al. 1996). In Nigeria, fish populations were monitored before and after application of glyphosate. Fish populations increased dramatically after reduction in the extent of the *E. crassipes* mats following herbicide treatment (Olaleye et al. 1996).

RESEARCH

A great deal is known about the biology of this species. Further work is needed on the effectiveness of replanting native species to slow reinvasion by *E. crassipes* following control (Madsen 1997).

Extensive research on the biology and management of this species has been done and is ongoing. Several journals, such as the Journal of Aquatic Plant Management, regularly carry articles on management of this species. However, there is little research on management and restoration of natural areas where native species are targets of conservation. Further work is needed on the application of biocontrol agents and of the potential impacts of such agents on native species and natural ecosystems. Work is needed on the use of plant growth regulators such as flurprimidol and paclobutrazol, which reduce plant growth but do not cause mortality. In addition, work is needed on integrated management strategies that combine herbicide use with biological control and restoration techniques (Madsen 1997).

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