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Is the Aquatic Weed Hygrophila, *Hygrophila polysperma* (Polemoniales: Acanthaceae), a Suitable Target for Classical Biological Control?

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Abstract

Hygrophila, *Hygrophila polysperma* (Roxb.) T. Anderson, is an aquatic plant that was introduced into Florida waters by the aquarium plant industry in the 1950s. It is a prohibited species in Florida and a federally listed noxious weed that is considered by the Florida Exotic Pest Plant Council to be one of the state's most invasive non-indigenous aquatic plants (Category I). The submersed growth habit of hygrophila causes problems in canals and drainage ditches in south Florida by forming dense mats that impede water flow, clog irrigation pumps, and displace native vegetation. Hygrophila also creates problems as an emergent plant in shoreline areas. This exotic plant is a threat to all Florida waterways because it is capable of tolerating a wide range of water temperatures, and the seeds or viable fragments it produces can be transported unintentionally to new locations. Established hygrophila infestations are difficult to control with current EPA registered aquatic herbicides. Stocking rates with the herbivorous triploid grass carp, *Ctenopharyngodon idella* Val (Cuvier and Valenciennes), that control many aquatic weed species are ineffective in controlling hygrophila because the plants appear to be unpalatable to these fish. The Peschken-McClay scoring system was used to determine the suitability of hygrophila as a possible target for classical biological control. Without any information on potential natural enemies in the weed's native range, hygrophila is considered a good candidate based on the available means of control, beneficial aspects, geographical area where the weed is native, and habitat stability in the area of introduction.

Keywords: hygro, Miramar weed, oriental ludwigia, aquatic weed, biocontrol.

Selecting a weed as a target for classical biological control is probably the most important step of a biological control program. If the wrong target is selected and the project fails, millions of dollars may be invested in research and development with little or no return on the investment. The long time lag (up to 20 scientist-years) from initiation to completion of the project is another important consideration. This sentiment was echoed in a recent statement by Palmer and Miller (1996), "Any project that attempts biological control of a weed is almost invariably an expensive, long-term, risky process."

In theory, selecting a target weed for classical biological control should be based upon factual information that takes into account various aspects of the weed's biology and ecology, the availability of suitable control agents (Harley and Forno 1992), the relative seriousness of the weed, and degree to which practical controls exist (Pemberton 1996). In reality, target weeds are usually selected because of the expense and/or failure of the other methods combined with political pressure to solve the problem (Huffaker 1964, Buckingham 1994). Because biological control is often considered as a last resort, Buckingham (1994) stated that the availability of funding is often directly related to current rather than potential infestations. He argued that projects should begin as soon as the weed's potential is recognized and cited the aquatic weed hydrilla, *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae), as a good example. If projects are initiated when the weed's invasiveness is first detected, then "early reduction of the aggressiveness of a weed through stress from biological control agents might prevent a weed from achieving its full potential" (Buckingham 1994).

To minimize the risk of failure, specific criteria for ranking weeds as suitable targets for classical biological control must be identified and carefully considered. Greater emphasis is now being placed on the number of congeneric native species (especially those that are endangered) as well as economic relatives of the target weed (Pemberton 1996). Various guidelines, or checklists, for selecting target weeds have been published to provide a framework for setting priorities (Huffaker 1964; Andres *et al.* 1976; DeLoach 1978, 1997; Harley and Forno 1992; Buckingham 1994; Pemberton 1996).

During the past few years, there has been a trend to use more quantitative methods for selecting and/or prioritizing new targets for biological control (McClay 1989, Peschken and McClay 1995, Palmer and Miller 1996). The scoring system of Peschken and McClay (1995), for example, allows the researcher to objectively rank potentially invasive non-native weeds for their suitability as targets for classical biological control, especially when the weed is not a target but its biology, distribution, damage and other control methods are being investigated.

The sudden increase of East Indian Hygrophila (hygrophila), *Hygrophila polysperma* (Roxb.) T. Anderson (Acanthaceae), in Florida during the last decade provided us with an opportunity to apply the Peschken-McClay scoring system to an aquatic weed. East Indian Hygrophila, hereinafter referred to as hygrophila, is now causing serious problems in many locations formerly occupied by hydrilla (Sutton 1995). Also known as hygro, East Indian hygro, green hygro, Miramar weed, oriental ludwigia, Indian swampweed, *Justicia polysperma* Roxb., and *Hemidelphis polysperma* (Roxb.) Nees, this invasive plant is primarily a rooted submersed weed which also can grow as an emersed plant in shallow water areas and on saturated shorelines. Hygrophila was introduced into the United States by the aquarium trade in 1945 as oriental ludwigia (Innes 1947), and was first collected in Florida as an escapee from cultivation in 1965 (Les and Wunderlin 1981). Hygrophila is a federally listed noxious weed (USDA 1999) that is also listed as a Category II prohibited aquatic plant by the Florida Department of Environmental Protection (formerly, the Florida Department of Natural Resources) (Ramey 1990), and a Category I species by the Florida Exotic Pest Plant Council (FLEPPC 1999).

Langeland and Burks (1999) describe hygrophila as a perennial aquatic herb with squarish stems that are ascending or creeping (Fig. 1). The stems are mostly submersed and usually rooted in the substrate, but hygrophila also roots freely at the floating nodes. The leaves of hygrophila are opposite, up to 8 cm long and up to 2 cm wide. The leaves are usually broader toward the tip, and are sessile with the bases joined at the nodes by ciliated flanges of tissue. Sutton (1995) observed that hygrophila does not exhibit hetero-

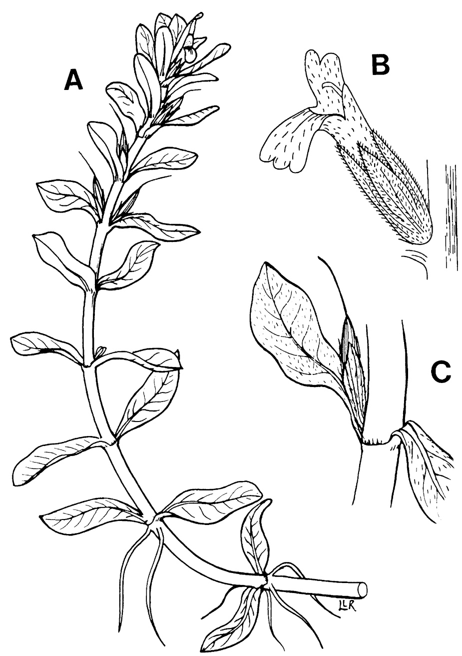

Fig. 1. *Hygrophila polysperma*. A. Distal portion of submersed stem showing adventitious roots; B. Flower; C. Fruit. Illustration provided by IFAS, Center for Aquatic and Invasive Plants, University of Florida, Gainesville.

phylly, a condition in some aquatic plants where leaves on the same plant differ markedly in shape depending upon whether the leaves are submersed or emersed. However, leaves of submersed stems tend to be considerably larger than those on emersed plants. The stems and leaves are covered with raised lines or dots that contain accumulations of calcium carbonates formed in the epidermal cell walls that are referred to as cystoliths (Sutton 1995). The bluish white flowers of hygrophila are small, solitary and nearly hidden in the uppermost leaf axils, and the fruit is a narrow capsule that splits longitudinally to release tiny round seeds.

According to Sutton (1996), hygrophila grows as a submersed and emersed plant year-round in south Florida. Plant growth begins in the spring (April to May) with growth rates increasing as a function of water temperature and daylength. Maximum biomass production occurs during the summer and early fall (June to October), after which the growth rate slows as water temperature decreases and day length shortens. Biomass is considerably less during the winter months. Flowers form on the emersed shoots in late October and continue until late February or early March. Mature seed capsules have been observed in December and February on plants growing in the Tampa Bay area of Florida (Schmitz and Nall 1984). Ambient temperature, nutrients in the sediments, and day length are three major factors influencing the growth of hygrophila.

Hygrophila is continuing to expand its range and become increasingly more abundant. Once established, hygrophila causes environmental and economic problems. Furthermore, practical solutions for its long term control are not readily apparent. The purpose of this paper is to examine whether hygrophila is an appropriate target for classical biological control by applying the scoring system of Peschken and McClay (1995).

Materials and Methods

The Peschken-McClay (1995) scoring system consists of 2 sections. The first section examines various economic aspects of the target weed in the following 6 categories: economic losses, infested area, expected spread, toxicity, available means of control, and beneficial aspects. The second section focuses on biological aspects of the target in 12 categories: infraspecific variation, geographical area where weed is native, relative abundance, success of biological control elsewhere, number of known agents, habitat stability,

Table 1.
Application of the Peschken and McClay (1995) scoring system to the aquatic weed *Hygrophila polysperma*.

CATEGORY	RANK	SCORE
A. ECONOMIC ASPECTS		
Economic Losses	Severe	20
Infested Area	Small	0
Expected Spread	Extensive	10
Toxicity	None or small	0
Available Means of Control		
Environmental damage	High	20
Economic justification	Low	20
Beneficial Aspects	None or small	0
B. BIOLOGICAL ASPECTS		
Infraspecific Variation	Small	10
Native Range	Outside USA	30
Relative Abundance		0
Success Elsewhere	Not attempted	0
Number of Known Agents		1
Habitat Stability	High	30
Economic Species in Genus	None	3
Economic Species in Tribe	None	4
Ornamental Species in Genus	1 to 5	1
Ornamental Species in Tribe	1 to 15	1
Native Species in Genus	1 to 20	1
Native Species in Tribe	1 to 40	2
TOTAL		153

References on which these assessments are based are provided in the text.

and number of economic, ornamental and native species in the same genus/tribe. A numerical score was selected and assigned to each category by surveying the published literature on hygrophila. A total score was obtained by adding together the individual scores in both sections.

A. Economic Aspects

Economic Losses. Hygrophila forms dense stands that occupy the entire water column and easily fragments, clogging irrigation and flood-control systems (Schmitz and Nall 1984, Sutton 1995) and interfering with navigation (Woolfe 1995). This aquatic weed is also capable of competitively displacing native submersed plants in shallow water

(Spencer and Bowes 1985) and river ecosystems (Angerstein and Lemke 1994). Hygrophila will successfully compete with hydrilla in some flowing water systems (Vandiver 1980, Les and Wunderlin 1981, Anonymous 1986, Van Dijk *et al.* 1986). Krombholz (1996) reported that hygrophila is even a threat to rice fields. More importantly, conventional control measures currently being used to manage hygrophila infestations are costly and do not provide long-term control of the weed (see Available Means of Control).

Infested Area. Until recently, hygrophila was thought to be restricted to Florida because of its tropical origin (Les and Wunderlin 1981, Schmitz and Nall 1984, Wunderlin *et al.* 1995). However, the plant also is naturalized in Texas (Angerstein and Lemke 1994) and northern Mexico (Kasselmann 1994) (Fig. 2). The Texas herbarium specimens, which were incorrectly identified as *Hygrophila lacustris* (Schlecht. and Cham.) Nees or *Ludwigia repens* Forst., indicate that hygrophila had been established in the San Marcos River in Hays County, Texas, for at least 25 years (Angerstein and Lemke 1994).

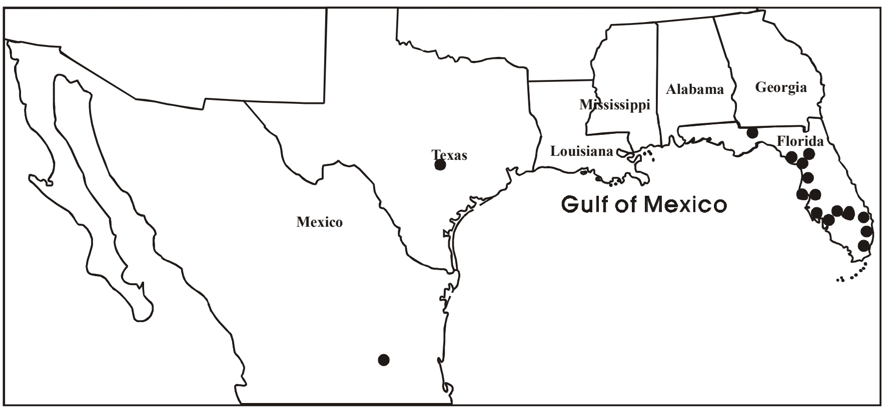

Fig. 2. Distribution of *Hygrophila polysperma* in North America. Data from Schmitz and Nall 1984, Kasselmann 1994, Angerstein and Lemke 1994, Wunderlin *et al.* 1995, and the Invasive Plant Management Division, Florida Department of Environmental Protection.

Expected Spread. A combination of factors suggests the northern (and possibly western) expansion of hygrophila will continue. According to Reams (1950, 1953), hygrophila was established in lakes in Richmond, Virginia, for 15 to 20 years where it tolerated freezing temperatures for brief periods. Unlike hydrilla that can only invade aquatic habitats, hygrophila often grows terrestrially along the shore as a ditchbank weed (Spencer and Bowes 1985). Hygrophila has a high growth rate and is capable of rapidly expanding a population ten-fold in one year (Vandiver 1980). Rooted nodes of small pieces of the easily fragmented stems have the potential to develop new stands (Les and Wunderlin 1981). Spencer and Bowes (1985) showed the regrowth potential of hygrophila from stem fragments surpasses that of hydrilla (Fig. 3). The lack of seasonal variation in biomass, low light compensation and saturation points, a low CO_2 compensation point, and the ability to rapidly change resource acquisition in response to changing environmental conditions also make hygrophila a good competitor (Spencer and Bowes 1985, Kovach *et al.* 1992).

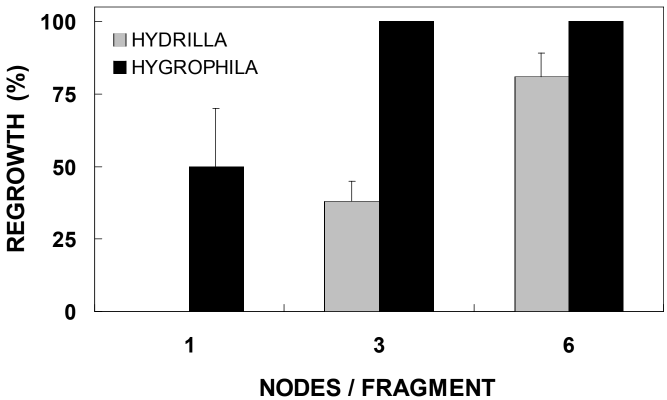

Fig. 3. Comparative regrowth capacities of *Hygrophila polysperma* and *Hydrilla verticillata* from stem fragments with one to six nodes per fragment. Data from Spencer and Bowes (1985).

Even herbicide treatments for controlling hydrilla may contribute to the spread of hygrophila by leaving open areas that are susceptible to invasion by the more herbicide tolerant hygrophila (Schmitz and Nall 1984, Spencer and Bowes 1985, Sutton 1995).

Schmitz and Nall (1984) offer some alternative explanations as to why hygrophila is causing increased problems in Florida. These include adaptation of the plant to Florida's waterways, that hygrophila is only now reaching public water bodies after being cultivated elsewhere, eutrophication of Florida's public lakes and rivers due to the state's population growth, and it simply may have escaped detection due to its similarity to alligator weed, *Alternanthera phylloxeroides* (Mart.) Griseb. (Amaranthaceae). Whatever the reason(s), a noticeable increase in the number of public lakes and rivers with hygrophila has occurred in Florida since 1990 (Langeland and Burks 1999), as shown in Fig. 4.

Toxicity. In the absence of published reports to the contrary, hygrophila is apparently not poisonous to humans or livestock. However, dense stands of hygrophila may contribute indirectly to human and animal health problems. The architectural characteristics of the stems of hygrophila are not unlike that of water pennywort, *Hydrocotyle umbellata* L. (Apiaceae), a native species that occurs throughout the southeastern United States

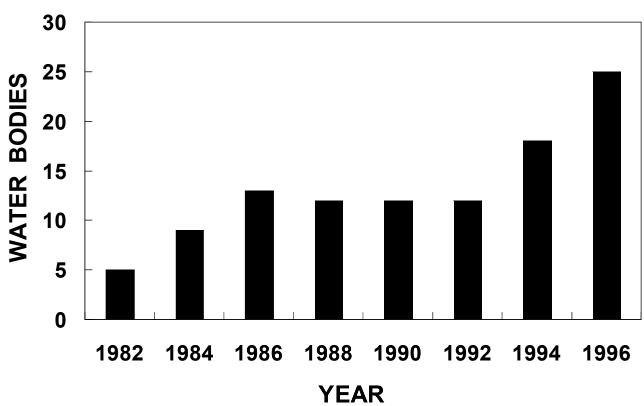

Fig. 4. Number of public lakes and rivers in Florida with *Hygrophila polysperma.* Data are from the Florida Department of Environmental Protection, Invasive Plant Management survey database, 1982-1996.

and is widespread in Florida (Hoyer *et al.* 1996). Both aquatic plants are characterized by the presence of floating or creeping stems with adventitious roots forming at the nodes (Gleason and Cronquist 1991, Langeland and Burks 1999). In Florida, the immature stages of a very annoying mosquito *Coquillettidia perturbans* (Walker) (Diptera: Culicidae) attach to the submerged roots of *H. umbellata* where they obtain oxygen and complete their development (Callahan and Morris 1987, Morris *et al.* 1990). If systematic surveys reveal the presence of the aquatic stages of this mosquito on the roots of hygrophila, then the uncontrolled growth of the plant could have public health implications because *C. perturbans* is known to vector eastern and western equine encephalomyelitis (Lounibos and Escher 1983).

Available Means of Control. The control of hygrophila in south Florida canals involves an integrated approach that combines mechanical and/or herbicidal methods with the triploid grass carp *Ctenopharyngodon idella* Val (Cuvier and Valenciennes) (Pisces: Cyprinidae) (Sutton 1995). Each method has its advantages and disadvantages. For example, mechanical control may be useful for removing the floating mats, but harvesting hygrophila increases the number of stem fragments that can be transported to other areas where they can infest new water bodies (Sutton 1995). The triploid grass carp *C. idella*, a polyphagous fish that was introduced into Florida in the 1970s primarily for controlling hydrilla (Sutton and Vandiver 1986), will feed to a limited extent on submersed hygrophila in the absence of preferred food plants (Sutton 1995). However, larger fish and stocking rates higher than for other aquatic weed problems must be used (Sutton 1995). Because grass carp prefer to graze on the soft tips of young tender plants, hygrophila may be less palatable than hydrilla and other preferred aquatic weeds due to the accumulations of calcium carbonates in the cystoliths covering the stems and leaves of the plant.

Hygrophila is difficult to control with herbicides currently registered for the control of hydrilla (e.g., fluridone) and is apparently resistant to other herbicides registered for aquatic use (Sutton *et al.* 1994a, b; Sutton 1996). Endothall will provide temporary control of both submersed and emersed forms of hygrophila, but regrowth occurs 4 to 8 weeks post treatment during peak biomass production in the summer (Sutton 1995). Multiple applications of endothall are required to keep hygrophila under maintenance control (Sutton 1995).

Herbicides typically used for controlling hygrophila also are expensive, costing between $988 to $1482 per hectare. Treatment costs are even higher when labor and equipment are included. An extreme case involved the use of fluridone in a flowing water system. Control of hygrophila was achieved for a period of 20 months at a cost of $34,580 per hectare (Sutton 1996). Clearly, non-biological methods currently being used for controlling hygrophila are unacceptable in environmental as well as economic terms.

Beneficial Aspects. Before its designation as a prohibited species in Florida (Schmitz 1990, Coile 1995) and listing as a federal noxious weed (USDA 1999, Schmitz 1990), hygrophila was considered one of the most important crops of the Florida aquarium plant industry (Schmitz and Nall 1984), and is still sold by Florida growers outside Florida. Because of its popularity elsewhere, the banning of hygrophila for sale in the state of Florida probably had little or no negative impact on the industry overall (B. McLane, Florida Aquatics, personal communication).

Some aquatic plant growers have reported using hygrophila as an indicator plant, or miner's canary, for detecting deficiencies in the growing conditions in aquaria (Krombholz 1996).

B. Biological Aspects

Infraspecific Variation. Hygrophila exhibits extremely well-developed vegetative reproduction and is probably autogamous based on the high percentage of seed set in Florida populations (Les and Wunderlin 1981). The stems of hygrophila are brittle and fragment easily. Adventitious roots form at the nodes along the stem which aids in the rooting of dispersed fragments (Vandiver 1980, Sutton 1995). Although little information is available on what role stem fragments actually play in the spread of hygrophila, it is generally believed that the stem fragments are a major source of vegetative material to infest new areas. Even detached leaves or their fragments are capable of rooting and developing into new plants (Rataj and Horeman 1977, Kasselmann 1994, Sutton 1995).

Geographical Area Where Weed Is Native. Hygrophila is an Old World species that is native to the southeastern Asiatic mainland (Vandiver 1980, Les and Wunderlin 1981, Mühlberg 1981, Schmitz and Nall 1984, Spencer and Bowes 1985, Schmitz 1990, Kovach *et al.* 1992, Angerstein and Lemke 1994, Kasselmann 1994, Sutton *et al.* 1994b, Coile 1995, Sutton 1995, Pemberton 1996, Langeland and Burks 1999).

Relative Abundance. According to Pemberton (1996), the distribution and relative abundance of hygrophila in its native range is unknown.

Success of Biological Control Elsewhere. Classical biological control of hygrophila has not been attempted elsewhere because there are no published reports indicating that this aquatic plant is invasive in countries other than the United States (Holm *et al.* 1979, Cook 1985).

Number of Known Promising Biological Control Agents. Surveys of the native natural enemies of hygrophila are needed because there is no information available on potential natural enemies of this aquatic plant (Buckingham 1994, Pemberton 1996). However, even if extensive surveys in Asia produce few or no promising agents on the target species hygrophila, the possibility exists that the plant could be controlled with insects collected from one of its congeners. In India, the larva of an agromyzid fly *Melanagromyza* sp. (Diptera: Agromyzidae) bores into the stems of *Hygrophila auriculata* (Schumach.) Heine (Lucknow) (=*Asteracantha longifolia* (L.) Nees), visibly damaging the plant (Sankaran and Rao 1972, Sankaran 1990).

Habitat Stability. Permanent aquatic habitats are considered relatively stable ecosystems (DeLoach 1997) where biological control has been used successfully against other aquatic plants (Julien and Griffiths 1998). Since most of the canals, rivers and lakes infested with hygrophila in North America are infrequently disturbed, this introduced aquatic weed should be an ideal target for biological control if potential natural enemies can be identified.

Number of Economic Species in the Same Genus. If economic species are considered those plants that are used commercially as a source of food and/or fiber, then the genus *Hygrophila* R. Brown contains no economically important species.

Number of Economic Species in the Same Tribe. According to Long (1970), hygrophila belongs to the subfamily Ruellioideae, tribe Ruellieae, and subtribe Hygrophilinae. The genus *Hygrophila* comprises the subgenera *Asteracantha* and *Hygrophila*. There are no known economic species in the tribe Ruellieae.

Number of Ornamental Species in the Same Genus. Four non-native species of *Hygrophila* are available commercially as decorative aquarium plants: giant hygro

[*Hygrophila angustifolia* R. Brown], temple plant [*H. corymbosa* (Blume) Lindau], water-wisteria [*H. difformis* (L.f.) Blume], and red stem hygro [*Hygrophila* sp. 'Reddish'] (Coile 1995).

Number of Ornamental Species in the Same Tribe. The tribe Ruellieae includes the genera *Blechum* P. Brown, *Dyschoriste* Nees, *Hygrophila* and *Ruellia* L. (Long 1970). Thirteen species are considered ornamentals outside the genus *Hygrophila*: one in the genus *Blechum*, four in *Dyschoriste* and eight in *Ruellia* (LHBHS 1976, AFNN 1998).

Number of Native North American Species in the Same Genus. *Hygrophila costata* Nees *et al.* [=*H. lacustris*, =*H. brasiliensis* (Spreng.) Lindau] is the only North American representative of the genus (Wunderlin 1998).

Number of Native North American Species in the Same Tribe. According to Correll and Johnston (1970) and Kartesz (1994), 26 species in the tribe Ruellieae are native to North America: six are in the genus *Dyschoriste* and 20 in *Ruellia*. The genus *Blechum* has no native North American representatives.

Results and Discussion

Hygrophila received a total of 153 points according to the Peschken and McClay (1995) scoring system (Table 1). The maximum score attainable when biological control agents are unknown is 179. Hygrophila ranked higher numerically than scentless chamomile, *Matricaria perforata* Mérat (Asteraceae), a weed that is officially targeted for biological control in Canada (Peschken and McClay 1995). The high score for hygrophila resulted from a combination of several critical elements which included the need for alternative control methods, no apparent beneficial value of hygrophila in North American freshwater ecosystems, the geographical area where the plant occurs naturally, and stability of the habitat where the plant is now considered an invasive aquatic weed.

Hygrophila is a major weed problem in south Florida that is spreading northward to other warm water areas across the state. The reports of naturalized populations of hygrophila in Texas and Mexico also should be cause for some concern. The extensive canal systems in the Imperial Valley of California that are vital to the region's agricultural production could experience rampant growth of hygrophila if it were to become naturalized in this area.

The experience in south Florida indicates that practical solutions for long term control of hygrophila are not readily apparent. Alternative methods are needed to prevent the rapid regrowth and spread of these plants to other warm water areas of North America. Buckingham (1994) recommends "when a foreign plant is found to be naturalized, an assessment should be made of its weed potential. If that assessment identifies a major risk to the environment or to man's activities, then the initial steps for a biological control program should be taken along with other controls." The Peschken-McClay scoring system produced an objective assessment of hygrophila's weed potential that should stimulate interest in this aquatic plant as a suitable target for classical biological control.

The initial steps for a hygrophila biological control program would involve garnering political and financial support for the project. Surveys in the native and introduced ranges should be undertaken as soon as adequate funding is made available in order to determine what arthropods and pathogens are attacking hygrophila. The domestic and foreign surveys also would give some indication about the relative abundance of the plant in its native range and whether or not a lack of natural enemies in the introduced range is one of the reasons why hygrophila is now causing problems.

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