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Risk assessment for water spinach (*Ipomoea aquatica*) in Texas

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ABSTRACT

Water spinach (*Ipomoea aquatica*) is a member of the morning glory family (Convolvulaceae) that is native to India and Southeast Asia but has been widely cultivated in many tropical areas around the world. Despite initial predictions of potential invasiveness, water spinach appears to be a relatively low-risk species, even in the states where it was most likely to establish such as Texas, Florida, and southern California. Risk analysis suggests that it is a very low-risk species in Texas. After 20 to 30 yr of commercial production in California, Florida, and Texas, it is currently found outside of cultivation in only four counties in the continental United States, and is easily controlled with herbicides. Since water spinach seems to be incapable of growing outside of greenhouses in the vast majority of states, it is probably not the major invasive species threat it was once thought to be and poses little risk to Texas and most of the continental United States.

Key words: invasive, noxious species, nuisance species, risk assessment, water spinach.

INTRODUCTION

Water spinach (*Ipomoea aquatica*) is a member of the morning glory family (Convolvulaceae), which contains somewhere between 1,600 and 1,700 other species, including potatoes. The genus *Ipomoea* alone has 600 to 700 species, including the sweet potato. Water spinach is native to India and Southeast Asia, but has been widely cultivated in many tropical areas around the world including Southeast Asia, China, Taiwan, India, Malaysia, the West Indies, Africa, Fiji, the Virgin Islands, and South and Central America (Edie and Ho 1969, Palada and Crossman 1999). It is adapted for tropical or near-tropical conditions, which may explain why water spinach has only been found outside of cultivation in California, Florida, Hawaii, and Puerto Rico (USDA 2016) in the United States. In Florida, it was found and treated outside of cultivation in eight counties (Bay, Charlotte, Glades, Highlands, Orange, Osceola, Pinellas, and Polk) between 1988 and 2016, but it has only been documented and treated in Highlands County for the past 3 yr and each year only 0.04 ha were treated (R. Kipker, Florida Fish and Wildlife Commission, pers. comm.). In California, it has been found in only three counties (EDDMapS 2016). Although there is one report of 405 ha in Marengo County, Alabama, that report is in error and in fact there are no reports of water spinach in Alabama (P. Robbins, U.S. Army Corps of Engineers Mobile District, pers. comm.). In the United States, water spinach is cultivated in California, Florida, Texas, and the U.S. Virgin Islands. In Asia, water spinach is known by many names including ong choy, swamp cabbage, ong tsoi, weng kai, kang kong (China and Taiwan), tra kuon (Cambodia), asagao na and yu sai (Japan), and rau muong (Vietnam). Austin (2007) provides a more complete list with more than 120 names and languages.

According to Cook (1990a) water spinach is usually a perennial species but may occasionally become annual. The stems typically grow as a trailing vine but can grow erect. Sharma (1994) also reported that water spinach grows in a vinelike prostrate growth form but may climb vertically and wrap around other plants. The plant stems are hollow and contain a milky sap. Water spinach is a heliophyte that may grow as either an emergent- or floating-leaved plant. Leaves are alternate with glabrous petioles 3 to 14 cm long (Center for Aquatic Invasive Plants 2009). Leaf blades are variable and may be cordate (heart shaped), sagittate (arrowhead shaped), triangular, or linear. The inflorescence has one to several flowers and is cymose (each floral axis terminates in a single flower). Flowers are funnel shaped and purple to near white in color, typically with a purple or pink center. The fruit is a capsule with either four valves or splits irregularly with four or fewer seeds (Cook 1990a).

Water spinach reproduction is either vegetative or by seed production. Seed production ranges from 175 to 245 per plant (Patnaik 1976). However, reproduction is primarily by fragmentation (Edie and Ho 1969, Patnaik 1976, Schardt and Schmitz 1990). Patnaik (1976) reported that the branches with roots at each node could each grow into independent plants.

Unlike most other aquatic plants, water spinach is grown as a vegetable (Boyd 1974, Joyce 1990). Young stems and leaves are typically cooked in oil or boiled, but they may also be eaten raw in salads. Water spinach is generally considered nutritious (Yamaguchi 1990). The leaves can be used to treat gastric and intestinal disorders, and the plant has been used in purgatives, diuretics, and medicines for biliousness and jaundice (Patnaik 1976, Sculthorpe 1985). Lehtonen (1993) also reported its use as an antidote for opium and as a way to reduce high blood pressure. Additionally, Huang et al. (2005) as well as Malakar and Choudhury (2015) concluded that water spinach could be used as a source of natural antioxidants and as a food supplement.

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Two basic forms of water spinach are generally recognized (Worldcrops 2016). One has red–purple-tinged stems, dark green leaves and petioles, and pale pink to lilac-colored flowers. The other has green stems, green leaves with green/white petioles, and white flowers. There is at least one "upland" form that has been cultivated. Although it is sometimes known as *Ipomoea reptans*, DNA fingerprinting suggests that it should still be considered *I. aquatica* (Van and Madeira 1998). According to Worldcrops (2016) the variety grown in moist soil is called ching quat, or "green stem" water spinach, and has narrow leaves and white flowers. Pak quat, the "white stem" water spinach, has arrow-shaped leaves and pink flowers, sometimes has red–purple-tinged stems, and is typically grown in aquatic situations. This is consistent with the fact that the upland, or moist-soil, cultivar grown in Florida has white flowers and green stems, roots in noninundated soils, and is grown commercially in raised beds (Van and Madeira 1998). Visual inspection suggests that the same upland form is the one being cultivated in Rosharon, TX. Growers in Rosharon often take multiple harvests from one crop by cutting the shoots above the ground by hand, thus encouraging regrowth (pers. obs.). These growers note that when plants are cultivated on moist soil, hand weeding is required frequently. Cultivation using wetlands methods is illegal in Texas. Under ideal conditions, water spinach can grow up to 10 cm d^{-1} (McCann et al. 1996), and some stems have been reported to be over 21 m long (National Parks Board [Singapore] 2013). Dense stands form large floating mats of vegetation at the water surface. Patnaik (1976) found evidence that water spinach was able to effectively compete against water lettuce (*Pistia stratiodes*), mosquito fern (*Azolla* spp.), and bladderwort (*Utricularia* spp.).

Water spinach may be grown using either wetland or dryland cultivation techniques. Edie and Ho (1969) provide extensive information about both techniques. Wetland cultivation, by far the more common method in Hong Kong, may yield an average of 90,000 kg ha^{-1} yr^{-1}.

Dryland cultivation is used in Texas year round (pers. obs.). Typically, an upland variety of water spinach is used that has green stems and white flowers. Seed is either sown directly onto these beds, or seedlings are transplanted from a nursery. In both cases, the plants are spaced at approximately 12-cm intervals by the time they are 15 to 30 cm tall. They are often fed with fertilizer and organic manures. In Texas, plants are grown in greenhouses. During the summer, greenhouse temperatures may exceed 48.9 C. Plants are harvested about every 10 d in the summer and every 4 to 6 wk in the winter. Texas growers do not allow the plants to go to seed (pers. obs. and interviews).

Water spinach is a high-yield plant. Jain et al. (1987) reported average annual fresh weight production of 90 t ha^{-1} for Hong Kong, with 70 and 100 t ha^{-1} reported from Fiji and the Netherlands, respectively. Sophea and Preston (2001) reported yields of over 20 t ha^{-1} in a 28-d period. The equivalent of 20 to 90 t ha^{-1} yr^{-1} was recorded by Sonetra (2002).

In the continental United States, major production centers appear to be California, Florida, and Texas. Lang (2003) reported that nearly 90% of U.S. production comes from the Gilroy area of California.

Table 1. States where water spinach is a regulated species (USDA 2017).

State	Listed Name	Category
Alabama	Chinese water spinach	Class A noxious weed
Arizona	Morning glory	Prohibited noxious weed
Arkansas	Morning glory	Noxious weed—regulated
California	Chinese water spinach	Quarantine
Florida	Water spinach	Prohibited aquatic plant
Lousiana	Water spinach	Prohibited
Massachuestts	Chinese water spinach	Permit required
North Carolina	Water spinach	Class A noxious weed
Oklahoma	Water spinach	Noxious aquatic weed
Oregon	Chinese water spinach	Exempted from quarantine
South Carolina	Water spinach	Invasive aquatic plant
Texas	Water spinach	Harmful or potentially harmful
Vermont	Chinese water spinach	Class A noxious weed

Water spinach has created a variety of problems for fishery management, navigation, irrigation, and ecology of native plants in several areas around the world (Harwood and Sytsma 2003). Intertwined stems of floating stands can cover the water surface, shading native submersed plants and effectively competing with native plant species (Langeland and Burks 2000). In the Philippines, water spinach is considered the second greatest problem plant (Gangstadt 1976, Holm et al. 1979, Cook 1990b).

Several control techniques have been tried, with varying results. Manual removal and herbicide treatments have proven to be effective under certain circumstances (Patnaik 1976), whereas there has been less success with biological controls (R. Kipker, Florida Fish and Wildlife Commission, pers. comm.). In Florida, diuron provided control in dry ditches, but the extent of collateral damage to other plant species was unacceptable in areas like the Everglades (Schardt and Schmitz 1990). Imazapyr has shown to be effective at an application rate of 1 to 2 pints per acre. Although grass carp (*Ctenopharyngodon idella*) are generally effective on a wide range of aquatic plant species, they seem to be rather ineffective on water spinach (R. Kipker, Florida Fish and Wildlife Commission, pers. comm.).

As early as 1951, concern in Florida began to grow because water spinach can form dense beds that obstruct the flow of water in drainage systems. In other bodies of water, there has been concern about water spinach displacing native plants and forming dense canopies and thus creating stagnant water conditions that are ideal breeding environments for mosquitoes (Florida FWC 2017). However, water spinach has not spread as fast as first feared. As of 1990, water spinach had been found in only two public lakes in Florida, West Lake Tohopekaliga and Lake Maggiorie (Schardt and Schmitz 1990).

Although water spinach has been prohibited in Florida since 1973 (McCann et al. 1996), commercial production for consumption is allowed and regulated (Florida Department of Agriculture and Consumer Services 2012). Several other states have decided to implement some safeguards as well, and water spinach is currently a regulated plant in 11 states (Table 1).

According to growers, water spinach has been cultivated in Texas for at least 20 yr. Some people in the Houston area

Table 2. Results of the weed risk assessment evaluation for water spinach (modified version of the Australian Weed Risk Assessment, Gordon et al. 2010, Pheloung et al. 1999).

Question	Number	Response	Score	Citation or Justification for Response
Is the species highly domesticated?	1.01	Yes	−3	Edie and Ho 1969.
Has the species become naturalized?	1.02	No	−1	Not naturalized anywhere in Texas.
Does the species have weedy races?	1.03	No	−1	"A lack of positive evidence for this question results in a 'no' or 'unknown' answer depending on the amount of information available on the taxon." (Gordon et al. 2010).
Species suited to target region?	2.01	Low	0	Climatch was used (http://adl.brs.gov.au:8080/Climatch/). Texas was compared with Cambodia, where most of the Texas growers originated and where water spinach is native. The proportion of climate stations yielding a score of 6 (range 0 to 10) or above is used to determine the strength of a match. A proportion of 0.0 to 0.005 is considered a low match. For the comparison between Texas and Cambodia, 147 stations were used. None had a score of greater than 3, indicating a very low climate match between the two countries.
Quality of climate match?	2.02	Intermediate	1	Reliable specific data score 2, general climate references score 1, broad climate or distribution data score 0 (Gordon et al. 2010).
Broad climate suitability?	2.03	Yes	1	According to Köppen–Geiger climate classification (http://koeppen-geiger.vu-wien.ac.at/present.htm), it is found in at least three "Equatorial" climate regions.
Native or naturalized in areas with similar climate?	2.04	No	0	Distribution includes South and Southeast Asia, tropical Africa, South and Central America, and Oceania (Invasive Species Compendium 2012, http://www.cabi.org/isc). According to Köppen–Geiger climate classification (http://koeppen-geiger.vu-wien.ac.at/present.htm), these areas are classified as "Equatorial", whereas Texas is classified as "Warm Temperate").
Does the species have a history of repeated introductions outside its native range?	2.05	Yes		Widely cultivated in many tropical areas around the world including Southeast Asia, China, Taiwan, India, Malaysia, the West Indies, Africa, Fiji, Virgin Islands, and South and Central America (Edie and Ho 1969; Palada and Crossman 1999).
Naturalized beyond native range?	3.01	Yes	1	Originated in tropical Asia (possibly India), but can now be found in tropical Africa, South and Central America, and Oceania (Invasive Species Compendium 2012, http://www.cabi.org/isc).
Garden/amenity/disturbance weed?	3.02	No	0	Requires warm wet habitat such as a greenhouse.
Recreational weed?	3.03	No	0	Nowhere in the continental United States.
Environmental weed?	3.04	No	0	Nowhere in the continental United States.
Congeneric weed?	3.05	No	0	No. Water spinach is the only aquatic species within the genus *Ipomoea*.
Produces spines, thorns or burrs?	4.01	No	0	Cook (1990).
Allelopathic?	4.02	No	0	Allelopathy is undocumented. http://dnr.wi.gov/topic/Invasives/documents/classification/Ipomoea%20aquatica.pdf
Parasitic?	4.03	No	0	Unable to find any reports of water spinach as a parasite.
Unpalatable to fish and wildlife?	4.04	No	−1	Water spinach is edible and valuable as a food source in rabbit production (Hongthong et al. 2004).
Toxic to animals?	4.05	No	0	Used in rabbit production.
Host for pests and pathogens?	4.06	No	0	The Food and Environmental Hygiene Department of Hong Kong released a food safety report in July 2012 that reported no pests or pathogens associated with water spinach—http://www.info.gov.hk/gia/general/201207/31/P201207310332.htm.
Causes allergies or toxic to humans?	4.07	No	0	The plant is readily eaten by large portions of the human population worldwide.
Creates flood or fire hazard?	4.08	No	0	Documentation of water spinach contributing to flooding or fire is lacking, but has been hypothesized in the case of floods.
Is shade tolerant	4.09	No	0	1) Requires lots of sunlight—http://www.ctahr.hawaii.edu/sustainag/extn__pub/veggie%20pubs/Oriental%20Vegetables/Water%20Spinach.pdf. 2). Requires full sun (Lehtonen 1993). Pest risk assessment on Chinese water spinach (Lehtonen 1993).
Grows in infertile soil or oligotrophic water?	4.1	No	0	Grows best in rich organic soil (Lehtonen 1993). Pest risk assessment on Chinese water spinach (Lehtonen 1993).
Climbing or smothering growth habit?	4.11	No	0	According to Gordon et al. (2010) the answer should be "no" for taxa that do not physically overgrow other vegetation.
Forms dense thickets or mats?	4.12	No	0	Water spinach does not form thickets of dense stem or branch material that obstruct movement (Gordon et al. 2010).
Aquatic?	5.01	Yes	1	May grow either in the water or on moist soil (After consulting with Dr. Gordon from the University of Florida, who had also worked with Pheloung, it was determined that awarding this question a 1 rather than a 5 was appropriate).
Grass?	5.02	No	0	Water spinach is a member of the morning glory family (Convolvulaceae), not a grass.

Table 2. Continued.

Question	Number	Response	Score	Citation or Justification for Response
Nitrogen fixer?	5.03	No	0	Water spinach is a member of the morning glory family (Convolvulaceae), not a legume, and as such does not harbor the nitrogen-fixing *Rhizobium* bacterium.
Geophyte?	5.04	No	0	Water spinach does not form tubers, corms, or bulbs like a true geophyte.
Evidence of substantial reproductive failure in native habitat?	6.01	No	0	Documentation of substantial reproductive failure in its native habitat is lacking.
Produces viable propagules?	6.02	Yes	1	Water spinach may reproduce by fragmentation or seed production (Patnaik 1976; Edie and Ho 1969; Schartz and Schmitz 1990).
Hybridizes naturally?	6.03	No	−1	Hybridization among the cultivars is apparent; however, evidence of hybridization with other species is lacking.
Self-compatible or apomictic?	6.04	No	−1	Literature searches using various search engines found no evidence of apomixis in water spinach.
Requires special pollinators?	6.05	No	0	60 to 65% of pollination is by self-pollination rather than pollinators (Grubben 2004).
Reproduction by vegetative fragmentation?	6.06	Yes	1	Patnaik (1976).
Minimum generative time	6.07	1 yr	1	Flowering peaks in December and January in India (Patnaik 1976).
Propagules are likely to be dispersed unintentionally?	7.01	Yes	1	Seeds are small and could be carried by water.
Propagules dispersed intentionally by people?	7.02	Yes	1	Water spinach is a commercially transported species.
Propagules likely to disperse as a produce contaminant?	7.03	No	−1	Not grown or shipped in conjunction with other species.
Adapted to wind dispersal?	7.04	No	−1	No evidence of adaptation for wind dispersal.
Adapted to water dispersal?	7.05	Yes	1	Seeds have air pockets that allow them to float.
Adapted to bird dispersal?	7.06	No	−1	No reported evidence.
Adapted to dispersal by animals?	7.07	No	−1	No reported evidence.
Propagules survive through gut passage?	7.08			Evidence is lacking.
Prolific (> 2,000 propagules/m^2)?	8.01	No	−1	Seed production only ranges from 175 to 245 per plant (Patnaik 1976).
Persistent propagule bank formation?	8.02			Positive evidence is lacking.
Well controlled by herbicides?	8.03	Yes	−1	Imazapyr is an effective topical treatment—Rob Kipker, Florida Fish and Wildlife Commission, personal communication, 2009.
Tolerates or benefits from disturbance?	8.04	Yes	1	It is unclear how much this species may benefit from disturbance. However, since it grows from fragments, disturbances that disrupt vegetation and fragment plants could facilitate the spread of water spinach.
Effective natural enemies present?	8.05	No	1	We have observed no insect damage on plants growing in Texas.
Total score			−2	

claim that cultivation began in the mid-1970s with the influx of Southeast Asian refugees after the Vietnam War. During most of that time, regulators were unaware of the industry. In 1989, Texas Parks and Wildlife Department (TPWD) was given legislative authority to regulate aquatic plant species, and water spinach was placed on a list of prohibited harmful or potentially harmful aquatic plants because of some of the problems it had caused overseas. At that time, TPWD was unaware of the growing water spinach production industry, and growers were unaware of TPWD regulations. In 2003, TPWD became aware of water spinach cultivation facilities in Rosharon, TX near Houston. At that time, there were in excess of 60 growers in the area. A public meeting was held with the Vietnamese-American Chamber of Commerce of Houston to discuss the issue since it was learned that water spinach was a vital part of the culture and diet of many persons of Southeast Asian descent. As a result, TPWD staff decided to re-evaluate the threat posed by water spinach to the ecology of Texas. Currently there are 63 growers with permits to legally grow and sell water spinach. The purpose of this risk assessment is to evaluate the potential for water spinach establishment in the state of Texas and the continental United States.

MATERIALS AND METHODS

Environmental comparisons

Water spinach is easily grown as a crop when mean temperatures are above 25 C (Edie and Ho 1969, Patnaik 1976). Mean daily temperatures in the Houston/Galveston area only exceed 25 C during June through September (National Weather Service 2009). Because of this, all commercial production in the area is in greenhouses. Lang (2003) reported that in areas where the mean temperature does not exceed 25 C, water spinach must be grown in greenhouses.

Using a climate match program (Climatch) developed in Australia by the Department of Agriculture, Fisheries and Forestry (ADAFF 2012), Texas was compared with Cambodia, where water spinach is native. The proportion of climate stations yielding a score of 6 (range 0 to 10) or above

is used to determine the strength of a match. A proportion of 0.0 to 0.005 is considered a low match.

Weed risk assessment

A slightly modified version of a weed risk assessment developed by Pheloung et al. (1999) was conducted to help determine the risk associated with water spinach establishment in Texas. Gordon et al. (2010) was utilized for guidance in answering and scoring weed risk-assessment questions. The analysis consists of 49 questions that address issues of climate matching, reproduction, invasive potential, etc. The analysis does not require that all 49 questions be answered. Typically, a score above 6 indicates that a plant is a high risk and should be rejected (not allowed in the area of concern), a score of less than 1 indicates a low-risk species, and a score between 1 and 6 indicates that further evaluation is necessary to determine risk. Biological, physiological, and ecological information found in published literature or provided by recognized experts was used to answer the questions in the risk assessment.

Surveys

In addition to the formal weed risk assessment that was conducted, survey information was analyzed to determine the presence and extent of any water spinach infestations in Texas. In 2003, TPWD personnel examined ditches and waterways near the commercial growing facilities around Rosharon (where at least 60 growers were producing water spinach at the time) to determine if water spinach had escaped cultivation and become established in the wild. Additionally, as a result of several tips about people privately growing water spinach in the Houston area, TPWD personnel examined sites in and near Houston that were thought to be the most likely sites for water spinach establishment. Between 1999 and 2009, TPWD personnel conducted 639 vegetation surveys on 136 public water bodies around the state. In 2009, vegetation survey requirements were expanded. Ninety-five water bodies were surveyed between 2009 and 2012.

TPWD also conducted a series of on-the-ground and on-the-water surveys in 2009 in metropolitan areas where commerce in water spinach was known to occur. A circular area of approximately 23 square miles (5-mile diameter) was identified in each metropolitan area, and staff surveyed waters and ditches with public access in search of water spinach. Single areas were identified in Austin and San Antonio, and two areas were identified in both Dallas–Fort Worth and Houston. These surveys were repeated in 2010 after commercial production of water spinach became legal with a TPWD-issued permit, and again in 2011.

RESULTS AND DISCUSSION

In the Climatch comparison between Texas and Cambodia, 147 stations were used. None had a score of 6 or greater. Indeed, there were no scores greater than 3. This result indicated a very low climate match between the two areas. Additionally, results of the Pheloung-type weed risk assessment yielded a score of −2, indicating that it has a low risk of establishment in Texas (Table 2). Typically, when using Pheloung-type risk assessment the questions "Does the species have a history of repeated introductions outside its native range?" and "Naturalized beyond native range?" are major indicators of whether or not a species is a risk and worth prohibiting. However, although water spinach has a history of invasiveness, it seems to be invasive only in tropical areas. All of Texas, and most of Florida are considered subtropical. When one looks at the three states where water spinach is primarily grown—California, Florida, and Texas—only the southern tip of Florida can be classified as tropical.

Table 3. Summary of water spinach purchases (by weight) and wholesale prices, as reported to law enforcement by markets or restaurants in Austin, Dallas–Fort Worth, Houston, and San Antonio[1]

City	Monthly Amount Purchased	Wholesale Cost lb.$^{-1}$
Austin	0–1,500	$0.80–1.80
Dallas–Fort Worth	100–18,000	$0.80–1.80
Houston	5–4,000	$0.60–2.00
San Antonio	1–1,000	$0.50–1.00

[1]Surveys indicate that the retail price was about twice the wholesale cost.

Surveys conducted in and around the Rosharon production area in 2003 found no water spinach growing outside of greenhouses. Similarly, investigations in the Houston area found no water spinach outside of cultivation. In 2011 and 2012, a few plants were observed growing outside within a few meters of greenhouses in the Rosharon area, but none became established. Additionally, no water spinach was found during the 639 water body surveys conducted between 1999 and 2009. The 95 water body surveys with expanded vegetation requirements conducted between 2009 and 2012 again found no water spinach. On-the-ground and on-the-water surveys conducted in metropolitan areas from 2009 to 2011 did not find any water spinach.

In 2005, TPWD modified regulations regarding water spinach and made production legal with an exotic species permit and possession for personal consumption legal. However, as a result of various legal issues, no permits were issued until early 2010. In 2009, TPWD game wardens conducted a survey of 56 groceries, restaurants, and distributors in the same four metropolitan areas in an effort to help determine how widespread water spinach commerce was in Texas. They found that the amount of water spinach purchased per month by individual dealers ranged up to 1,000 lbs. in San Antonio, 1,500 lbs. in Austin, 4,000 lbs. in Houston, and 18,000 lbs in the Dallas–Fort Worth metroplex. Typically, wholesale prices ranged from $0.50 to $2.00 per lb. (Table 3).

Fifty-two of the 56 establishments surveyed said they obtained their water spinach from sources within Texas. Four declined to say where their supply came from. At least half of the water spinach came from the Houston area (including Rosharon). The survey suggested that over 60,000 lbs. a month were being produced in the Rosharon area.

Accurate figures on the amount of water spinach produced in Texas are currently difficult to determine because of how some details in reporting requirements are

legally interpreted. However, cultivation of water spinach in Texas, primarily for the Asian food market, has grown into a small industry, with at least 63 permitted growers. Despite extensive production estimated at thousands of pounds per day in some cases, there is no evidence of establishment outside production facilities. This is consistent with the fact that although water spinach has spread throughout many tropical areas of the world, there is little evidence of it becoming established outside of tropical regions. As a result of the requirement for tropical conditions, California and Washington (Harwood, pers. comm.) as well as Oregon (Harwood and Sytsma 2003) consider water spinach a low risk of becoming a nuisance plant species. Even in Florida, with its more tropical climate, water spinach has established relatively minor populations (in most cases 0.04 ha or less) that are easily treated.

As a result of the current risk analysis conducted by TPWD staff, the Texas Parks and Wildlife Commission determined that water spinach is a relatively low-risk species in Texas. Therefore, cultivation and consumption is currently permitted. Commercial cultivation may take place only in TPWD-permitted facilities to reduce the risk of accidental establishment in the wild. Possession for personal consumption is unrestricted. Wholesale and retail outlets may possess water spinach and sell it only for personal consumption; however, they must retain invoices from permitted growers within Texas and from persons selling water spinach legally from outside the state. The water spinach industry in Texas is growing, with an 11% increase in permits from 2011 to 2012. The largest concentration of growers in Texas is in Rosharon, but it is also being cultivated in other areas as well.

CONCLUSION

Despite initial predictions of potential invasiveness in the early 1990s (Lehtonen 1993), water spinach appears to be a relatively low-risk species, even in the states where it was most likely to establish such as Texas, Florida, and southern California. Data suggest that it poses little risk to Texas, has not become invasive in other states, and is easily controlled with herbicides. After 20 to 30 yr of commercial production, water spinach has been found outside of cultivation in only small easily treated stands in California and Florida. A risk analysis published by Harwood and Sytsma (2003) found that there was no evidence that water spinach would grow outside of tropical areas. As a result, Harwood and Sytsma concluded that water spinach was a low-risk species in Oregon. Since water spinach seems to be incapable of establishing outside of greenhouses except in tropical climates, it is probably not the major invasive species threat it was once thought to be and poses little risk to Texas and most of the continental United States.

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