United States Department of Agriculture

United States
Department of
Agriculture

Animal and Plant
Health Inspection
Service

April 29, 2016

Version 1

Weed Risk Assessment for *Cryptocoryne beckettii* Thwaites ex Trimen. (Araceae) – Beckett's water trumpet

Habit (left), root system (upper right), and dense patch (bottom right) of *Cryptocoryne beckettii* (source: David E. Lemke; Lemke, 2015).

Agency Contact:

Plant Epidemiology and Risk Analysis Laboratory
Center for Plant Health Science and Technology

Plant Protection and Quarantine
Animal and Plant Health Inspection Service
United States Department of Agriculture
1730 Varsity Drive, Suite 300
Raleigh, NC 27606

Introduction

Plant Protection and Quarantine (PPQ) regulates noxious weeds under the authority of the Plant Protection Act (7 U.S.C. § 7701-7786, 2000) and the Federal Seed Act (7 U.S.C. § 1581-1610, 1939). A noxious weed is defined as "any plant or plant product that can directly or indirectly injure or cause damage to crops (including nursery stock or plant products), livestock, poultry, or other interests of agriculture, irrigation, navigation, the natural resources of the United States, the public health, or the environment" (7 U.S.C. § 7701-7786, 2000). We use the PPQ weed risk assessment (WRA) process (PPQ, 2015) to evaluate the risk potential of plants, including those newly detected in the United States, those proposed for import, and those emerging as weeds elsewhere in the world.

The PPQ WRA process includes three analytical components that together describe the risk profile of a plant species (risk potential, uncertainty, and geographic potential; PPQ, 2015). At the core of the process is the predictive risk model that evaluates the baseline invasive/weed potential of a plant species using information related to its ability to establish, spread, and cause harm in natural, anthropogenic, and production systems (Koop et al., 2012). Because the predictive model is geographically and climatically neutral, it can be used to evaluate the risk of any plant species for the entire United States or for any area within it. We then use a stochastic simulation to evaluate how much the uncertainty associated with the risk analysis affects the outcomes from the predictive model. The simulation essentially evaluates what other risk scores might result if any answers in the predictive model might change. Finally, we use Geographic Information System (GIS) overlays to evaluate those areas of the United States that may be suitable for the establishment of the species. For a detailed description of the PPQ WRA process, please refer to the *PPQ Weed Risk Assessment Guidelines* (PPQ, 2015), which is available upon request.

We emphasize that our WRA process is designed to estimate the baseline—or unmitigated—risk associated with a plant species. We use evidence from anywhere in the world and in any type of system (production, anthropogenic, or natural) for the assessment, which makes our process a very broad evaluation. This is appropriate for the types of actions considered by our agency (e.g., Federal regulation). Furthermore, risk assessment and risk management are distinctly different phases of pest risk analysis (e.g., IPPC, 2015). Although we may use evidence about existing or proposed control programs in the assessment, the ease or difficulty of control has no bearing on the risk potential for a species. That information could be considered during the risk management (decision making) process, which is not addressed in this document.

***Cryptocoryne beckettii* Thwaites ex Trimen. – Beckett's water trumpet**

Species

Family: Araceae

Information Synonyms: *Cryptocoryne petchii* Alston[1] (The Plant List, 2015). *Cryptocoryne beckettii* is one of four species in the *C. beckettii* complex (Jacono, 2002; Reumer, 1984). Wunderlin and Hansen (2015) list this species (in addition to *C. axelrodii*, *C. undulata*, *C. wendtii*, and *C. willisii*) as a synonym of *C. walkeri* Schott., but other major taxonomic databases maintain it as a separate species (ITIS, 2015; NGRP, 2015; The Plant List, 2015). Consistent with these databases and the most recent treatment of Sri Lankan *Cryptocoryne* species (Jacobsen, 1976), we treat this taxon as *C. beckettii*.

Common names: Beckett's water trumpet (NRCS, 2015).

Botanical description: *Cryptocoryne beckettii* is a perennial, rhizomatous aquatic herb occurring either as emerged or submerged plants (Mansor and Masnadi, 1994; Rosen, 2000). Leaf blades are ovate to narrowly ovate (about 9 x 1.5 cm), green on top and with reddish-brown coloration underneath (Rosen, 2000; Windeløv, 2004). The Sri Lankan *Cryptocoryne* species are relatively young as a group and have not completely differentiated (Reumer, 1984). Floral traits are needed to distinguish some members of the species complex (Jacono, 2002). Because plants rarely flower in cultivation, "positive identification of cryptocorynes is a constant problem for both the grower and consumer" (Kane et al., 1995). However, plant gibberellins can be used to promote flowering for identification (Kane et al., 1995).

Initiation: PPQ received a market access request for *C. beckettii* for propagation from the Ministry of Food, Agriculture and Fisheries, the Danish Plant Directorate (MFAF, 2009). Because this species is not native to the United States (NGRP, 2015) and poses a risk to threatened and endangered species (Alexander et al., 2008), the PPQ Weeds Cross-Functional Working Group initiated this assessment.

Foreign distribution: *Cryptocoryne beckettii* is native to Sri Lanka (NGRP, 2015; Reumer, 1984). It has been cultivated by aquarium enthusiasts for about 60 years (Windeløv, 2004). It is cultivated in Australia (Randall, 2007) and New Zealand (Champion and Clayton, 2001), and is imported to several European countries (Brunel, 2009), but we found no evidence that it has escaped in these areas.

U.S. distribution and status: *Cryptocoryne beckettii* was first detected occurring outside of cultivation in the United States in 1993 in the San Marcos River in Texas (Bowles and Bowles., 2001). It is now naturalized in two counties in Texas (NRCS, 2015) and one in Florida (Jacono, 2002; Jacono, 2015; Kartesz, 2015). Because of the threat to threatened and endangered species in Texas (see Imp-N4 in App. A), "the San Marcos National Fish Hatchery and Technology Center, U.S. Fish and Wildlife Service (USFWS) initiated an effort to remove Beckett's water trumpet from the upstream end of its range in the San Marcos River (SMR) to

---

[1] *Cryptocoryne petchii* is the triploid form of *C. beckettii* (APC, 2015).

create a larger buffer between Beckett's water trumpet and Texas wild rice" (Alexander et al., 2008). Although the work was manually intensive, they successfully removed populations from one segment of the river using a dredge suction technique. Alexander et al. (2008) believe that the entire population can still be eradicated. *Cryptocoryne beckettii* is cultivated and sold in the United States (e.g., APC, 2015; eBay, 2015). It is one of the *Cryptocoryne* species reported to be regularly available in trade (APC, 2015; Kasselmann, 2003); however, it is not as common as other *Cryptocoryne* species (e.g., Anonymous, 2015). One European seller lists this species on eBay and specifically says they will ship it to the United States (eBay, 2015).

WRA area[2]: Entire United States, including territories.

1. *Cryptocoryne beckettii* analysis

Establishment/Spread Potential *Cryptocoryne beckettii* is an aquatic plant that reproduces primarily through vegetative means (Jacono, 2002). Like many other aquatics, plants readily fragment, and those fragments can establish new populations (Alexander et al., 2008; Jacono, 2002). This species readily grows in shady areas (Jacobsen, 1976) and can form dense patches through vegetative growth (Anonymous, 2012; Jacono, 2002). This species has demonstrated that it can establish and spread rapidly in one river in the United States (Rosen, 2000). During a 28-month study period, the number of individual colonies in that river increased from 11 to 63, and the total areal coverage increased from 171 to 646 m^2. (Doyle, 2001). Although *C. beckettii* has been cultivated for 60 years, very little is known about its biology, which resulted in a high level of uncertainty for this risk element.

Risk score = 11 Uncertainty index = 0.23

Impact Potential The relatively recent naturalization of *C. beckettii* in the United States (Rosen, 2000) is the first known establishment of this species beyond its native range. Since it has not been well studied, there is little information about its impacts. However, where it occurs in Texas, it has formed dense patches that exclude other species (Jacono, 2002; Tu, 2005) and will likely prevent the establishment of others (see image on cover page). *Cryptocoryne beckettii* occurs at water depths and flow velocities similar to those of the endangered Texas wild rice (*Zizania texana*; Alexander et al., 2008). Its threat to this and other threatened and endangered species prompted the U.S. Fish and Wildlife Service to control and eradicate this species from some portions of the San Marcos River in Texas (Alexander et al., 2008; Kleinsasser, 2013). As the species is better studied, additional impacts may emerge. We had an average amount of uncertainty for this risk element.

---

[2] "WRA area" is the area in relation to which the weed risk assessment is conducted (definition modified from that for "PRA area") (IPPC, 2012).

Risk score = 1.9 Uncertainty index = 0.17

Geographic Potential Because there were no point-referenced localities for this species in the Geographic Information Facility Database (GBIF, 2015), and only a few herbarium records, we based this analysis on general reports of the distribution of *C. beckettii* and the distribution of the genus, which is limited to southeastern Asia. Using this approach, we estimate that about 16 percent of the United States is suitable for the establishment of *C. beckettii* (Fig. 1). The map for *C. beckettii* represents the joint distribution of Plant Hardiness Zones 8-13, areas with 20-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: Tropical rainforest, tropical savanna, humid subtropical, and marine west coast.

Because this analysis was based on the distribution of the entire genus, there is much uncertainty around the area of the United States shown to be climatically suitable (Fig. 1). Furthermore, although *C. beckettii* is a tropical species, it is possible that it could survive in colder environments if the water temperature remained relatively warm and stable. For example, the closely related *C. wendtii* has escaped in thermal outflows in Austria (Essl and Rabitsch, 2002). We did not include this occurrence of *C. wendtii* in our analysis for *C. beckettii* because it is a rather unusual scenario. If *C. beckettii* could survive in similar thermal outflows, then very specific niches in the Pacific Northwest would also be suitable. Other environmental variables may further limit the areas in which this species is likely to establish. *Cryptocoryne beckettii* occurs in relatively pristine rivers and springs, and seems to prefer shady areas with rapidly flowering water (Alexander et al., 2008; Jacono, 2002; Rosen, 2000; Tu, 2005). “In North America, weedy infestations of *Cryptocoryne beckettii* sensu lato may be limited to karstic spring environments of the southern states” (Jacono, 2002). Some *Cryptocoryne* species have been shown to obtain their carbon predominately from dissolved bicarbonate in high pH environments (cited in Jacono, 2002).

Entry Potential We did not assess the entry potential of *C. beckettii* because it is already present in the United States (Jacono, 2002; NRCS, 2015; Rosen, 2000).

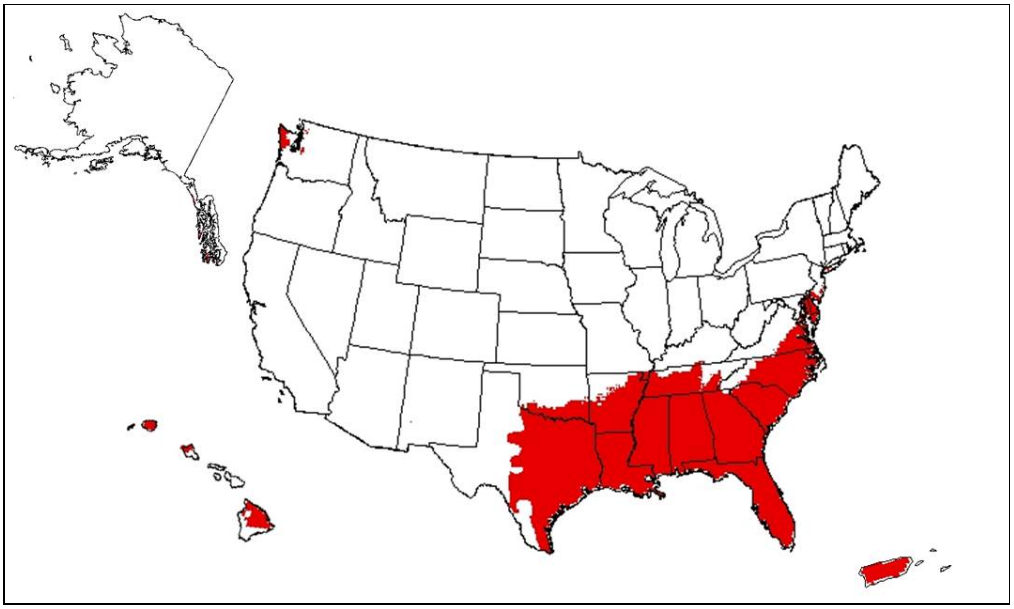

Figure 1. Predicted distribution of *Cryptocoryne beckettii* in the United States based on the distribution of the genus. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

<u>2. Results</u>

Model Probabilities:	P(Major Invader) = 40.1%
	P(Minor Invader) = 55.5%
	P(Non-Invader) = 4.3%

Risk Result = High Risk
Secondary Screening = Not Applicable

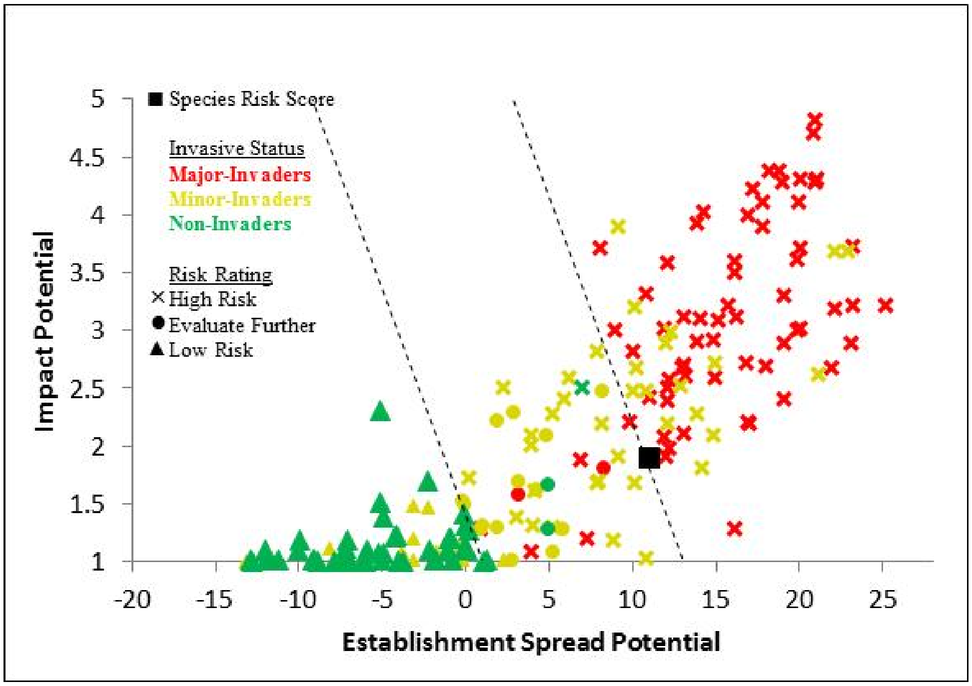

Figure 2. *Cryptocoryne beckettii* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

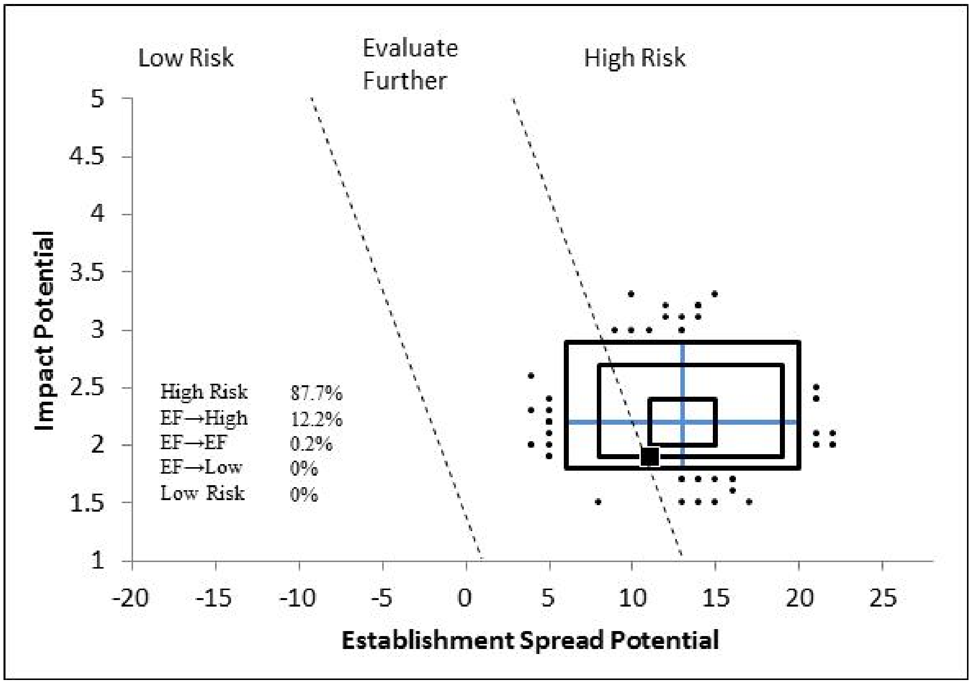

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *C. beckettii*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *C. beckettii* is High Risk (Fig 2). Although this species' risk score is adjacent to the high risk threshold, our Monte Carlo simulation suggests that its risk score could increase as we learn more about it (Fig. 3). The U.S. occurrence of this species is the first known record of its naturalization. In the San Marcos River in Texas, *C. beckettii* has been behaving as an invasive species. During the course of one study, the areal coverage of this population increased by about 80 percent each year (Doyle, 2001). The little that we know about this species suggests that it may be limited to aquatic environments that have a high pH and a relatively stable temperature with flowing water (Doyle, 2001; Jacobsen, 1976; Jacono, 2002; Kasselmann, 2003). However, when it occurs in these environments, it can form dense patches and dominate the plant community (Doyle, 2001). At the time of his report, Doyle (2001) believed the population could still be eradicated given that it was limited to a 1.7-km section of the river. The U.S. Fish and Wildlife Service appears to have eradicated it from the upper portion of the river, but it may be spreading further downstream (Kleinsasser, 2013).

Because there is so little known about the biology of this species and other members of this genus, there was an average to high level of uncertainty for this analysis. Additional information about the current status of this species in Texas and Florida would be useful for policy makers. Furthermore, because this species is difficult to distinguish from others in its complex, better laboratory diagnostics may be needed to accurately identify *C. beckettii* when it is not blooming.

Interestingly, in its native range in Sri Lanka, *C. beckettii* is an endangered species (Anonymous, 2012), probably because it is collected from the wild and exported as an aquarium plant (Rosen, 2000). Members of the *C. beckettii* complex have declined due to habitat destruction and commercial collecting (Jacono, 2002).

4. Literature Cited

7 U.S.C. § 1581-1610. 1939. The Federal Seed Act, Title 7 United States Code § 1581-1610.

7 U.S.C. § 7701-7786. 2000. Plant Protection Act, Title 7 United States Code § 7701-7786.

Alexander, M. L., R. D. Doyle, and P. Power. 2008. Suction dredge removal of an invasive macrophyte from a spring-fed river in central Texas, USA. Journal of Aquatic Plant Management 46:184-185.

Alfasane, A., M. Khondker, and Z. N. T. Begum. 2010. Growth and regeneration of *Cryptocoryne ciliata* (Roxb.) fisch. Ex wydler (araceae) under Ex-situ conditions. Bangladesh Journal of Botany 39(1):115-118.

Anonymous. 2012. Environmental impact assessment on the proposed surface water extraction from a reservoir across Per Aru, Vavuniya District:

Volume 1 - Main report. National Water Supply & Drainage Board of the Ministry of Water Supply and Drainage, Sri Lanka. 271 pp.

Anonymous. 2015. Aquagreen: Australian native water plants for aquariums. Aquagreen. Last accessed August 5, 2015, http://www.aquagreen.com.au/index.html.

APC. 2015. Aquatic Plant Finder [Online Database]. Aquatic Plant Central (APC). http://www.aquaticplantcentral.com/forumapc/plantfinder/index.php. (Archived at PERAL).

APHIS. 2015. Phytosanitary Certificate Issuance & Tracking System (PCIT). United States Department of Agriculture, Animal and Plant Health Inspection Service (APHIS). https://pcit.aphis.usda.gov/pcit/faces/index.jsp. (Archived at PERAL).

Arnett Jr., R. H. 2000. American Insects: A Handbook of the Insects of America North of Mexico, Second edition. CRC Press, Boca Raton, FL, U.S.A. 1003 pp.

Bowles, D. E., and B. D. Bowles. 2001. A review of the exotic species inhabiting the upper San Marcos River, Texas, U.S.A. Texas Parks and Wildlife Department, Austin, Texas. 30 pp.

Brunel, S. 2009. Pathway analysis: Aquatic plants imported in 10 EPPO countries. EPPO Bulletin 39(2):201-213.

Champion, P. D., and J. S. Clayton. 2001. Border control for potential aquatic weeds Stage 2. Weed risk assessment. New Zealand Department of Conservation, Wellington, New Zealand. 30 pp.

de Graaf, A., and J. C. Arends. 1986. The occurrence of *Cryptocoryne* and *Lagenandra* (Araceae) on Sri Lanka. Nordic Journal of Botany 6(6):757-764.

Doyle, R. D. 2001. Expansion of the exotic aquatic plant cryptocoryne beckettii (araceae) in the San Marcos River, Texas. SIDA, Contributions to Botany 19(4):1027-1038.

eBay. 2015. Listings Database. ebay.com. Last accessed August 7, 2015, http://www.ebay.com/.

EPPO. 2015. PQR - EPPO's Plant Quarantine Data Retrieval System Version 5.3.5. . European and Mediterranean Plant Protection Organization (EPPO), Paris, France.

Essl, F., and W. Rabitsch. 2002. Neobiota in Österreich. Umweltbundesamt, Wien, Austria. 432 pp.

GBIF. 2015. GBIF, Online Database. Global Biodiversity Information Facility (GBIF). http://data.gbif.org/welcome.htm. (Archived at PERAL).

Heap, I. 2015. The international survey of herbicide resistant weeds. Weed Science Society of America. http://weedscience.org/. (Archived at PERAL).

Heide-Jorgensen, H. S. 2008. Parasitic Flowering Plants. Brill, Leiden, The Netherlands. 438 pp.

IPPC. 2012. International Standards for Phytosanitary Measures No. 5: Glossary of Phytosanitary Terms. Food and Agriculture Organization of the United Nations, Secretariat of the International Plant Protection Convention (IPPC), Rome, Italy. 38 pp.

IPPC. 2015. International Standards for Phytosanitary Measures No. 2: Framework for Pest Risk Analysis. Food and Agriculture Organization of the United Nations, Secretariat of the International Plant Protection Convention (IPPC), Rome, Italy. 18 pp.

ITIS. 2015. Integrated Taxonomic Information System (ITIS), Online Database. United States Government. http://www.itis.gov/. (Archived at PERAL).

Jacobsen, N. 1976. Notes on *Cryptocoryne* of Sri Lanka (Ceylon). Bot. Notiser 129:179-190.

Jacobsen, N., J. D. Bastmeijer, P. J. Edwards, R. J. Johns, N. Takahashi, and S. Wongso. 2014. A new variety of *Cryptocoryne versteegii* (Araceae) from Irian Jaya Tengah, Indonesia. Willdenowia 44(3):385-391.

Jacono, C. C. 2002. *Cryptocoryne beckettii* complex (Araceae) introduced at a Florida spring. SIDA, Contributions to Botany 20(2):819-832.

Jacono, C. C. 2015. *Cryptocoryne*. Personal communication to A. L. Koop on July 7, 2015, from Colette Jacono, Assistant Research Scientist, Florida Museum of Natural History.

Kane, M. E., G. L. Davis, T. D. Hoffner, and R. J. Henny. 1995. Gibberellins promote flowering in two *Cryptocoryne* species. HortScience 30(2):380.

Kartesz, J. 2015. The Biota of North America Program (BONAP). North American Plant Atlas. http://bonap.net/tdc. (Archived at PERAL).

Kasselmann, C. 2003. Aquarium Plants. Krieger Publishing Company, Malabar, Florida. 518 pp.

Keller, R. P., and D. M. Lodge. 2007. Species invasions from commerce in live aquatic organisms: Problems and possible solutions. BioScience 57(5):428-436.

Kleinsasser, R. 2013. After dredging the San Marcos River to remove an invasive plant species, geomorphic monitoring continues. Texas Watersheds Winter:9.

Koop, A., L. Fowler, L. Newton, and B. Caton. 2012. Development and validation of a weed screening tool for the United States. Biological Invasions 14(2):273-294.

Kulkarni, A. R., D. Dosi, and V. M. Manoj. 1990. Fruit and seed structure in Araceae. Proceedings of the Indian Academy of Sciences-Plant Sciences 100(1):61-69.

Lemke, D. E. 2015. Looking for some pictures of *Cryptocoryne beckettii*. Personal communication to A. L. Koop on August 7, 2015, from David E. Lemke, Professor, Texas State University.

Les, D. H., and C. T. Philbrick. 1993. Studies of hybridization and chromosome number variation in aquatic angiosperms: evolutionary implications. Aquatic Botany 44(2–3):181-228.

Mansor, M., and M. Masnadi. 1994. *Cryptocoryne elliptica*, an endangered amphibious plant in Pondok Tanjung forest reserve, Peninsular Malaysia. Aquatic Botany 47(1):91-96.

Martin, P. G., and J. M. Dowd. 1990. A protein sequence study of the dicotyledons and its relevance to the evolution of the legumes and nitrogen fixation. Australian Systematic Botany 3:91-100.

MFAF. 2009. Aquarium plants in growing medium – Denmark - Pre-Requisite Requirements for Commodity Risk Assessments. Ministry of Food, Agriculture and Fisheries (MFAF), The Danish Plant Directorate, Denmark, Lyngby, Denmark. 4 pp.

NGRP. 2015. Germplasm Resources Information Network (GRIN). United States Department of Agriculture, Agricultural Research Service, National Genetic Resources Program (NGRP). http://www.ars-grin.gov/cgi-bin/npgs/html/index.pl?language=en. (Archived at PERAL).

NRCS. 2015. The PLANTS Database. United States Department of Agriculture, Natural Resources Conservation Service (NRCS), The National Plant Data Center. http://plants.usda.gov/cgi_bin/. (Archived at PERAL).

Ørgaard, M., and N. Jacobsen. 1998. SEM study of surface structures of the spathe in *Cryptocoryne* and *Lagenandra* (Araceae: Aroideae: Cryptocoryneae). Botanical Journal of the Linnean Society 126(3):261-289.

Owens, C. S., J. D. Madsen, R. M. Smart, and R. M. Stewart. 2001. Dispersal of native and nonnative aquatic plant species in the San Marcos River, Texas. Journal of Aquatic Plant Management 39:75-79.

Pieterse, A. H., and K. J. Murphy. 1990. Aquatic Weeds: The Ecology and Management of Nuisance Aquatic Vegetation. Oxford University Press, New York. 593 pp.

PPQ. 2015. Guidelines for the USDA-APHIS-PPQ Weed Risk Assessment Process. United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ). 125 pp.

Randall, J. M. 2007. The Introduced Flora of Australia and its Weed Status. CRC for Australian Weed Management, Department of Agriculture and Food, Western Australia, Australia. 528 pp.

Randall, R. P. 2012. A Global Compendium of Weeds, 2nd edition. Department of Agriculture and Food, Western Australia, Perth, Australia. 1107 pp.

Reumer, J. W. F. 1984. Cytotaxonomy and evolution in *Cryptocoryne* (Araceae). Genetica 65(2):149-158.

Rosen, D. J. 2000. *Cryptocoryne beckettii* (Araceae), a new aquatic plant in Texas. SIDA, Contributions to Botany 19(2):399-401.

Santi, C., D. Bogusz, and C. Franche. 2013. Biological nitrogen fixation in non-legume plants. Annals of Botany 111(5):743-767.

Singh, R. K., Garg, and P. G. Diwakar. 2013. *Cryptocoryne cognata* Schott and *Rotala ritchiei* (C.B. Clarke) Koehne - the critically endangered aquatic herbs on verge of extinction. Current Science 105(4):437-438.

Stanly, C., A. Bhatt, and C. Keng. 2011. An efficient in vitro plantlet regeneration of *Cryptocoryne wendtii* and *Cryptocoryne becketti* through shoot tip culture. Acta Physiologiae Plantarum 33(2):619-624.

The Plant List. 2015. The Plant List, Version 1 [Online Database]. Kew Botanic Gardens and the Missouri Botanical Garden. http://www.theplantlist.org/. (Archived at PERAL).

Tu, M. 2005. Weed Alert! *Cryptocoryne beckettii* Thwaites ex Trimen (watertrumpet). The Nature Conservancy. 2 pp.

USFWS. 1985. San Marcos recovery plan. United States Fish and Wildlife Service (USFWS), Albuquerque, New Mexico. 109 pp.

Walker, R. 2014. Parasitic Plants Database. Rick Walker. http://www.omnisterra.com/bot/pp_home.cgi. (Archived at PERAL).

Wang, H., G. Zhong, H. Yan, H. Liu, Y. Wang, and C. Zhang. 2012. Growth control of cyanobacteria by three submerged macrophytes [Abstract]. Environmental Engineering Science 29(6):420-425.

Windeløv, H. 2004. Tropica Aquarium Plants Catalogue. Tropica Aquarium Plants, Egå, Denmark. 97 pp.

Wunderlin, R. P., and P. F. Hansen. 2015. Atlas of Florida Vascular Plants. University of South Florida, Department of Biology, Institute for Systematic Botany. http://florida.plantatlas.usf.edu/Default.aspx. (Archived at PERAL).

Appendix A. Weed risk assessment for *Cryptocoryne beckettii* Thwaites ex Trimen. (Araceae). Below is all of the evidence and associated references used to evaluate the risk potential of this taxon. We also include the answer, uncertainty rating, and score for each question. The Excel file, where this assessment was conducted, is available upon request.

Question ID	Answer - Uncertainty	Score	Notes (and references)
ESTABLISHMENT/SPREAD POTENTIAL			
ES-1 [What is the taxon's establishment and spread status outside its native range? (a) Introduced elsewhere =>75 years ago but not escaped; (b) Introduced <75 years ago but not escaped; (c) Never moved beyond its native range; (d) Escaped/Casual; (e) Naturalized; (f) Invasive; (?) Unknown]	f - low	5	*Cryptocoryne beckettii* is native to Sri Lanka (Jacobsen, 1976; NGRP, 2015; Reumer, 1984). It has been cultivated by aquarium hobbyists for about 60 years (Windeløv, 2004). It has been introduced to Australia (Randall, 2007) and New Zealand (Champion and Clayton, 2001), but we found no evidence that is has escaped in these countries. It is cultivated in the United States and has naturalized in two counties in Texas (NRCS, 2015) and one in Florida (Jacono, 2002; Jacono, 2015; Kartesz, 2015). Several naturalized populations occur in the San Marcos River in Texas (Rosen, 2000), and the "species is currently expanding rapidly within the lower portions of the upper San Marcos River. The distribution and areal extent of the species was quantified on three occasions between April 1998 and August 2000. During this 28-month period, the number of individual colonies increased from 11 to 63, and the total areal coverage increased from 171 to 646 m^2" (Doyle, 2001). A survey in 2005 showed its coverage increased to 1951 m^2 (Alexander et al., 2008). Based on its behavior in this one site in Texas we answered "f," but used low uncertainty because it is unknown if it would behave similarly elsewhere. Alternate answers for the Monte Carlo simulation were both "e."
ES-2 (Is the species highly domesticated)	n - negl	0	*Cryptocoryne beckettii* is cultivated as a fresh water aquarium plant (Mansor and Masnadi, 1994; Windeløv, 2004). Because it can be difficult to propagate *Cryptocoryne* species for resale, efficient micropropagation methods have been developed for it using shoot tip explants (Mansor and Masnadi, 1994; Stanly et al., 2011). While it has been crossed with other *Cryptocoryne* species (Les and Philbrick, 1993), we found no evidence that *C. beckettii* is highly domesticated or that it has been bred to reduce traits associated with weed potential. Because this species is propagated primarily through vegetative methods (Mansor and Masnadi, 1994; Stanly et al., 2011) and isn't subject to repeated selection associated with sexual reproduction, we used negligible uncertainty.
ES-3 (Weedy congeners)	n - low	0	There are about 55 species in the genus *Cryptocoryne* (Jacobsen et al., 2014). Three others have been reported as weeds: *C. ciliata*, *C. crispatula*, and *C. wendtii* (Randall, 2012). However, we did not find any evidence indicating that these are significant weeds.
ES-4 (Shade tolerant at some stage of its life cycle)	y - negl	1	In its native range it grows in shady, sheltered places in rivers (Jacobsen, 1976). In Texas, it grows in shaded pools in the San Marcos River (Doyle, 2001). It grows in the shade in Florida (Jacono, 2002). It does not need a lot of

Question ID	Answer - Uncertainty	Score	Notes (and references)
			light in aquariums (Windeløv, 2004). Other *Cryptocoryne* species grow in shaded habitats (Jacobsen, 1976; Mansor and Masnadi, 1994).
ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes)	n - negl	0	This species is not a vine; it is an aquatic herb (Jacono, 2002; Mansor and Masnadi, 1994).
ES-6 (Forms dense thickets, patches, or populations)	y - negl	2	*Cryptocoryne beckettii* forms thick mats in its native range (Anonymous, 2012). In Florida, a mixed and morphologically integrated population of *C. beckettii*, *C. undulata*, and *C. wendtii* formed a dense mat (Jacono, 2002). Plant density values were 1480 plants per square meter for *Cryptocoryne beckettii* (senso lato) and 1880 plants per square meter for *C. undulata* (Jacono, 2002). Under cultivation "[t]he brownish rosettes, after taking root, can spread comparatively quickly and will soon form thick colonies in the aquarium" (APC, 2015). Also see the bottom right image on the cover page.
ES-7 (Aquatic)	y - negl	1	It is an emergent or submerged aquatic herb (Jacono, 2002; Mansor and Masnadi, 1994; Rosen, 2000).
ES-8 (Grass)	n - negl	0	This species is not a grass; it is an herb in the Araceae family (NGRP, 2015).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	It is an herbaceous plant (Mansor and Masnadi, 1994) and not woody. Furthermore, it is not in a plant family known to contain nitrogen-fixing bacteria (Martin and Dowd, 1990; Santi et al., 2013).
ES-10 (Does it produce viable seeds or spores)	? - max	0	Although this species blooms under cultivation and in the wild (Doyle, 2001; Jacono, 2002), we found no information about fruit production, much less seed viability. *Cryptocoryne* species rarely produce fruit (Kasselmann, 2003). Without additional information, we answered unknown. Note that *C. ciliata* produces viable seeds (Alfasane et al., 2010).
ES-11 (Self-compatible or apomictic)	? - max	0	Unknown.
ES-12 (Requires specialist pollinators)	n - high	0	Plants in the genus *Cryptocoryne* have a specialized pollination system that involves flies in the family Phoridae (Jacobsen et al., 2014). In *Cryptocoryne*, the spathe forms a tube through which insects enter to pollinate female flowers (Ørgaard and Jacobsen, 1998). After about 12 hours, a flap on the inside of the tube closes off the interior chamber where the flowers are located and traps any insects inside. During this time, the female flowers lose their receptivity and the male flowers begin shedding pollen. On the third day, the flap moves again, allowing the insects to escape with pollen from the male flowers (Ørgaard and Jacobsen, 1998). *Cryptocoryne versteegii* and *C. cognata* smell like rotting meat (Jacobsen et al., 2014; Singh et al., 2013). Although this pollination system is specialized, it is not clear if only certain species of phorid flies can successfully pollinate the species or if any fly from this family can. We answered no because Phoridae flies are present in the United States (Arnett Jr., 2000).

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
ES-13 [What is the taxon's minimum generation time? (a) less than a year with multiple generations per year; (b) 1 year, usually annuals; (c) 2 or 3 years; (d) more than 3 years; or (?) unknown]	b - high	1	We found no information on generation time for either sexual or vegetative reproduction. Plants form rhizomes, stolons, and vegetative offshoots at the base of parent plants (Jacono, 2002). Given that this is a small herbaceous species that reproduces vegetatively, it seems likely that it would produce, at a minimum, one generation per year. Given the rate of colony expansion reported in Texas (Doyle, 2001), we suspect that it may produce multiple generations per year. Consequently we answered "b" with high uncertainty, and used "a" for both alternate answers.
ES-14 (Prolific reproduction)	n - low	-1	We found no information on fruit production for this species. Florida and Texas studies of naturalized populations do not mention any fruit production (Doyle, 2001; Jacono, 2002). Because *Cryptocoryne* species rarely fruit (Kasselmann, 2003), it is unlikely that this species has prolific sexual reproduction.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - mod	1	Although we found no direct evidence of unintentional dispersal, other evidence suggests people may disperse it unintentionally. This species' occurrence in the San Marcos River in Texas is likely due to the cultivation or dumping of aquarium plants (Rosen, 2000). A U.S. Fish and Wildlife Service recovery plan for the river indicated that one of the threats to native species was due to the introduction and harvesting of exotic aquatic plant species for aquaria (USFWS, 1985). A study in the San Marcos River in Texas showed that recreational activities and aquatic plant management were associated with increased loadings of aquatic plant fragments downstream in the river system (Owens et al., 2001).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	? - max	0	This species reproduces easily through fragmentation (Alexander et al., 2008); it is possible it could travel as a contaminant of some other aquatic plant in trade, but we found no specific evidence of this. Species in the *C. beckettii* complex are difficult to distinguish without floral characteristics (Jacono, 2002; Reumer, 1984). Thus they may enter trade accidentally with a different species' name, but we found no specific evidence of this. Because mislabeling of aquatic plants is very common (Keller and Lodge, 2007), we answered this question as unknown, instead of no.
ES-17 (Number of natural dispersal vectors)	1	-2	We did not find any botanical description of *C. beckettii*'s fruit and seed traits. Even a detailed botanical description of the *Cryptocoryne* species of Sri Lanka did not include fruit or seeds (Jacobsen, 1976). The genus *Cryptocoryne* produces compound fruit, and *C. spiralis* produces a "[f]leshy, round, composite, hexalocular syncarpium with about 6 basally attached erect seeds per locule" (Kulkarni et al., 1990). It seems likely that *C. beckettii* produces similar fruit.
ES-17a (Wind dispersal)	n - low		We found no evidence of wind dispersal. Given the fleshy fruit that *Cryptocoryne* species produce, wind dispersal is unlikely.

Question ID	Answer - Uncertainty	Score	Notes (and references)
ES-17b (Water dispersal)	y - negl		Broken basal shoots of *C. beckettii*, *C. undulata*, and *C. wendtii* sink and can be dragged by stream currents, while rhizome fragments float (Jacono, 2002). Though rarely produced, *Cryptocoryne* fruit are dispersed by water (Kasselmann, 2003).
ES-17c (Bird dispersal)	? - max		Unknown.
ES-17d (Animal external dispersal)	n - low		We found no evidence of this kind of dispersal, nor does it seem likely based on plant morphology or biology.
ES-17e (Animal internal dispersal)	? - max		Unknown.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	n - low	-1	*Cryptocoryne* seeds are typically short lived because they will die within a couple of days if they dry out (Jacobsen, 1976).
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - low	1	*Cryptocoryne beckettii* reproduces easily by rhizome fragmentation (Alexander et al., 2008; Jacono, 2002). "Fragments as small as 2 mm can easily break off from the parent plant and grow into a separate plant" (cited in Alexander et al., 2008). Belowground biomass of roots, rhizomes, and stolons is twice that of aboveground tissues (Jacono, 2002). Walking on a population can easily create plant fragments (Jacono, 2002; Owens et al., 2001). In general, recreational and other activities in aquatic plant populations readily produce fragments (Owens et al., 2001). Although we found no direct evidence that mutilation benefits individual plants or populations, the evidence suggests that this species would benefit from fragmentation, as do most other aquatic plants. Also, aroid plants have contractile roots that allow them to straighten themselves after heaving or flooding (cited in Jacono, 2002).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	n - low	0	We found no direct evidence. This species is not listed as having herbicide resistance (Heap, 2015).
ES-21 (Number of cold hardiness zones suitable for its survival)	6	0	
ES-22 (Number of climate types suitable for its survival)	4	2	
ES-23 (Number of precipitation bands suitable for its survival)	9	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	? - max		We found no direct information indicating that this species is allelopathic. *Cryptocoryne crispatula* inhibits the growth of cyanobacteria around it (Wang et al., 2012). Given that *C. beckettii* forms thick mats (Anonymous, 2012; Jacono, 2002), it is possible it may have some allelopathic impacts on nearby species. Consequently, we answered unknown.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence this species is parasitic. Furthermore, it is not a member of plant family known to contain parasitic plants (Heide-Jorgensen, 2008; Walker, 2014).
Impacts to Natural Systems			

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	n - high	0	We found no evidence of this. Because this species can form dense and extensive mats (Anonymous, 2012; Jacono, 2002), it is possible it could have an impact on stream properties.
Imp-N2 (Changes habitat structure)	? - max		Unknown.
Imp-N3 (Changes species diversity)	y - low	0.2	In Florida, a dense mat of this species and its close relatives excluded other aquatic macrophytes (Jacono, 2002). "In the San Marcos River in Texas, *C. beckettii* has been reported as forming colonies that extend from bank to bank and exclude native plants and animals" (Tu, 2005).
Imp-N4 (Is it likely to affect federal Threatened and Endangered species?)	y - low	0.1	*Cryptocoryne beckettii* is present in the San Marcos River in Texas, which contains several other T&E species, including Texas wild rice (*Zizania texana*; Doyle, 2001). Although there is no evidence that *C. beckettii* is currently displacing Texas wild rice, it prefers similar water depths and flow velocities as that species (Alexander et al., 2008). Furthermore, populations of *C. beckettii* are expanding rapidly (Alexander et al., 2008; Doyle, 2001). The U.S. Fish and Wildlife Service took action to limit the threat that *C. beckettii* poses to the endangered species (Alexander et al., 2008; Kleinsasser, 2013).
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	n - mod	0	Given that *C. beckettii* is restricted to streams and rivers, it seems unlikely that it would have widespread impact on an entire ecoregion.
Imp-N6 [What is the taxon's weed status in natural systems? (a) Taxon not a weed; (b) taxon a weed but no evidence of control; (c) taxon a weed and evidence of control efforts]	c - negl	0.6	*Cryptocoryne beckettii* is an environmental weed (Tu, 2005). Because of this species' threat to Texas wild rice, a Federal Threatened and Endangered species, the U.S. Fish and Wildlife Service used a suction dredge machine to remove 537 m^2 of aerial coverage of *C. beckettii* from the San Marcos River in Texas (Alexander et al., 2008). The machine cost $6250, and the removal and follow-up treatment of regrowth involved 1110 hours of labor (Alexander et al., 2008). Suction-dredging of the river required officials to monitor the geomorphic processes of the river for six years to ensure that management didn't damage the river (Kleinsasser, 2013). "The USFWS has continued monitoring for the plant's occurrence and removing any remnants. The two most recent surveys revealed two occurrences of single water trumpet plants. There have been reports, however, downstream from the Blanco River confluence, which will warrant further monitoring" (Kleinsasser, 2013). Alternate answers for the Monte Carlo simulation were both "b."
Impact to Anthropogenic Systems (cities, suburbs, roadways)			
Imp-A1 (Negatively impacts personal property, human safety, or public infrastructure)	n - mod	0	We found no evidence. Because this species has only recently become naturalized, and because many aquatic weeds have impacts in anthropogenic systems, we used moderate uncertainty for most questions in this risk sub-element.
Imp-A2 (Changes or limits recreational use of an area)	n - low	0	We found no direct evidence. Although free-floating aquatic plants typically have this kind of impact (Pieterse

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
			and Murphy, 1990), *C. beckettii* is a short-statured, rooted plant, and therefore unlikely to have this impact.
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	n - mod	0	We found no evidence.
Imp-A4 [What is the taxon’s weed status in anthropogenic systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	a - mod	0	We found no evidence that this species is considered a weed because of impacts to people or society. Alternate answers for the Monte Carlo simulation were both "b."
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	n - low	0	Because we found no evidence that this species invades ditches, canals, or irrigation channels, or has any kind of impact in productions systems, we used low uncertainty for the questions in this sub-element.
Imp-P2 (Lowers commodity value)	n - low	0	We found no evidence.
Imp-P3 (Is it likely to impact trade?)	n - low	0	We found no evidence that this species is regulated by any country (e.g., APHIS, 2015; EPPO, 2015). Thus it seems unlikely it will impact trade. We found no evidence.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	n - low	0	We found no evidence.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	n - low	0	We found no evidence.
Imp-P6 [What is the taxon’s weed status in production systems? (a) Taxon not a weed; (b) Taxon a weed but no evidence of control; (c) Taxon a weed and evidence of control efforts]	a - low	0	We found no evidence. Alternate answers for the Monte Carlo simulation were both "b."
GEOGRAPHIC POTENTIAL			Because there were no georeferenced points for this species available in GBIF (2015) and only a few other records of its distribution, we based this analysis on the distribution of the genus, which is restricted to southeastern Asia. Below, when the evidence is based on information about *C. beckettii*, we annotate the evidence with (Cb). Also, unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2015).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z2 (Zone 2)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z3 (Zone 3)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z4 (Zone 4)	n - negl	N/A	One point in China, but this is likely an erroneous record given how far north it is located.
Geo-Z5 (Zone 5)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z6 (Zone 6)	n - negl	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z7 (Zone 7)	n - high	N/A	We found no evidence that it occurs in this hardiness zone.
Geo-Z8 (Zone 8)	y - negl	N/A	Invading two Texas counties in the United States (Cb: Kartesz, 2015).

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
Geo-Z9 (Zone 9)	y - negl	N/A	Three points in Myanmar and one point in China (GBIF, 2015). Naturalized in the United States in one Florida county (Cb; Kartesz, 2015).
Geo-Z10 (Zone 10)	y - negl	N/A	Two points in Indonesia, and one point each in Myanmar and China.
Geo-Z11 (Zone 11)	y - negl	N/A	Some points in Laos and Thailand. One point in Indonesia and two points in Papua New Guinea.
Geo-Z12 (Zone 12)	y - negl	N/A	Some points in Cambodia, Laos, and Vietnam.
Geo-Z13 (Zone 13)	y - negl	N/A	Indonesia, Malaysia, and Papua New Guinea.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - negl	N/A	Indonesia and Malaysia.
Geo-C2 (Tropical savanna)	y - negl	N/A	Cambodia, Laos, and Thailand.
Geo-C3 (Steppe)	n - low	N/A	We found no evidence that it occurs in this climate class.
Geo-C4 (Desert)	n - negl	N/A	We found no evidence that it occurs in this climate class.
Geo-C5 (Mediterranean)	n - mod	N/A	We found no evidence that it occurs in this climate class.
Geo-C6 (Humid subtropical)	y - negl	N/A	China and Myanmar. In the United States in two counties in Texas and one in Florida (Cb: Kartesz, 2015).
Geo-C7 (Marine west coast)	y - mod	N/A	One point in Myanmar. Regional occurrences in Sri Lanka (Cb: de Graaf and Arends, 1986).
Geo-C8 (Humid cont. warm sum.)	n - low	N/A	We found no evidence that it occurs in this climate class.
Geo-C9 (Humid cont. cool sum.)	n - low	N/A	We found no evidence that it occurs in this climate class.
Geo-C10 (Subarctic)	n - negl	N/A	We found no evidence that it occurs in this climate class.
Geo-C11 (Tundra)	n - negl	N/A	One point in China, but this is likely an erroneous record given how far north it is.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence that it occurs in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	n - negl	N/A	We found no evidence that it occurs in this precipitation band.
Geo-R2 (10-20 inches; 25-51 cm)	n - high	N/A	We found no evidence that it occurs in this precipitation band.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	In the United States in one Texas county (Cb: Kartesz, 2015).
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	In the United States in one Texas county (Cb: Kartesz, 2015).
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	We found no evidence that it occurs in this precipitation band, but because it occurs in drier and wetter areas (Geo-R4 and Geo-R7) and occurs in a spring-fed river in the United States in Texas, we answered yes.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	We found no evidence that it occurs in this precipitation band, but because it occurs in drier and wetter areas (Geo-R4 and Geo-R7) and occurs in a spring-fed river in the United States in Texas, we answered yes.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	In the United States in one Florida county (Cb: Kartesz, 2015). A few points in Thailand. One point in China.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	Three points in Indonesia and a few in Laos.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	A few points in Thailand and Myanmar. One point each in Vietnam and China.
Geo-R10 (90-100 inches; 229-254 cm)	y - negl	N/A	A few points in Indonesia.
Geo-R11 (100+ inches; 254+ cm)	y - negl	N/A	Indonesia and Malaysia.
ENTRY POTENTIAL			

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
Ent-1 (Plant already here)	y - negl	1	*Cryptocoryne beckettii* was first reported for the United States in 1996 from the San Marcos River in Texas (Rosen, 2000). It is now naturalized in two counties in Texas (NRCS, 2015) and one in Florida (Jacono, 2002; Jacono, 2015; Kartesz, 2015).
Ent-2 (Plant proposed for entry, or entry is imminent)	-	N/A	
Ent-3 (Human value & cultivation/trade status)	-	N/A	
Ent-4 (Entry as a contaminant)			
Ent-4a (Plant present in Canada, Mexico, Central America, the Caribbean or China)	-	N/A	
Ent-4b (Contaminant of plant propagative material (except seeds))	-	N/A	
Ent-4c (Contaminant of seeds for planting)	-	N/A	
Ent-4d (Contaminant of ballast water)	-	N/A	
Ent-4e (Contaminant of aquarium plants or other aquarium products)	-	N/A	
Ent-4f (Contaminant of landscape products)	-	N/A	
Ent-4g (Contaminant of containers, packing materials, trade goods, equipment or conveyances)	-	N/A	
Ent-4h (Contaminants of fruit, vegetables, or other products for consumption or processing)	-	N/A	
Ent-4i (Contaminant of some other pathway)	-	N/A	
Ent-5 (Likely to enter through natural dispersal)	-	N/A	