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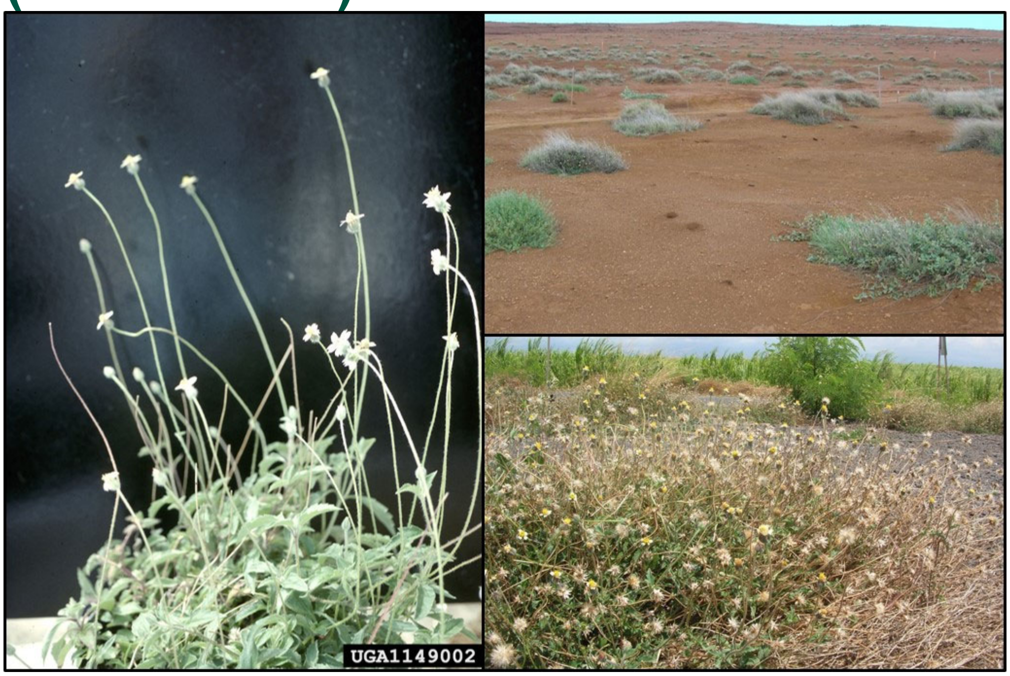
Weed Risk Assessment for *Tridax procumbens* L. (Asteraceae) – Coat buttons



Left: *Tridax procumbens* habit (source: USDA APHIS PPQ, Bugwood.org). Top right: Infestation on the island of Kahoolawe, HI; bottom right: small patch with hundreds of inflorescences (source: Forest and Kim Starr, Starr Environmental, Bugwood.org).

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1. 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 or 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 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 were to 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 *PPQ Weed Risk Assessment Guidelines* (PPQ, 2015), which is available upon request.

We emphasize that our WRA process is designed to estimate the baseline (i.e. unmitigated) risk associated with a plant species. We use evidence from anywhere in the world and 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 (i.e., Federal regulation). Furthermore, risk assessment and risk management are distinctly different phases of pest risk analysis (IPPC, 2016). 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.

2. Plant Information and Background

SPECIES: *Tridax procumbens* L. (NGRP, 2018).

FAMILY: Asteraceae

SYNONYMS: We found no major synonyms, but see The Plant list (2018).

COMMON NAMES: Coat buttons, tridax daisy (NGRP, 2018), railway weed (Graves, 2000), wild-daisy (Stone, 1970), Mexican daisy (Raju, 1999).

BOTANICAL DESCRIPTION: *Tridax procumbens* is a semi-prostrate perennial herb forming many lateral branches that ascend 30 to 50 cm high (Holm et al., 1997) or trail along the ground and root at the nodes (Graves, 2000). Plant stems are covered with coarse, stiff hairs (Ivens, 1967; Reed, 1977). Leaves are simple and opposite, about 3-7 cm long and 1-4 cm wide, with irregularly toothed margins (Holm et al., 1997). Plants produce solitary involucrate flowering heads (i.e., daisy-like) about 1-2 cm across on a peduncle that is about 10-25 cm long (Holm et al., 1997; Ivens, 1967). Ray flowers are few and pale yellow, while disk flowers are yellow to brownish-yellow (Holm et al., 1997). Fruit is a black achene about 2 mm long by 1 mm wide, with a pappus that is 5-6 mm long (Holm et al., 1997). For a full botanical description see Long and Lakela (1976) and Reed (Reed, 1977). *Tridax procumbens* has a chromosome number of 2n = 36 (Galinato et al., 1999; Turner et al., 1961) and is probably of polyploid origin, as several closely related *Tridax* species have a diploid count of 2n = 18 (Turner et al., 1961). In tropical regions this species germinates and flowers throughout the year (Pemadasa, 1976), which makes control difficult.

INITIATION: PPQ had previously developed a WRA for this species in 2000 using an older, narrative-based process (Graves, 2000). We reevaluated it with our current weed evaluation process in order to have a current assessment to support management and policy decisions.

WRA AREA[1]: Entire United States, including territories.

FOREIGN DISTRIBUTION: *Tridax procumbens* is native from Mexico south through Central America (e.g., Belize, Costa Rica, Panama) and to most of South America (Argentina, Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Venezuela) (NGRP, 2018). It is also native to the Galapagos Islands and the Caribbean (e.g., Cuba, Martinique, St. Vincent and the Grenadines) (NGRP, 2018). It has become naturalized in Africa (e.g., South Africa, Kenya, Senegal, Ethiopia, Cape Verde, Zimbabwe), tropical Asia (e.g., India, Vietnam, the Philippines), eastern Asia (e.g., China, Taiwan, Japan), the Pacific (e.g., Fiji, French Polynesia, New Caledonia, Palau), and Australia (Maroyi, 2012; NGRP, 2018; Space et al., 2009). In its native range, it is considered a weed [e.g., Mexico (Villaseñor Ríos and Espinosa García, 1998); Cuba (Acuña Galé, 1974); and Brazil (Moreira and Bragança, 2011)].

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[1] "WRA area" is the area in relation to which the weed risk assessment is conducted [definition modified from that for "PRA area"] (IPPC, 2017).

Tridax procumbens is considered invasive in China (Weber et al., 2008), Palau (Space et al., 2009), and Taiwan (Wu et al., 2004). Seed and shredded plant material that is marketed as *T. procumbens* is available from foreign vendors on eBay (eBay, 2018); however, some of those listings use images of plants that do not resemble *T. procumbens* (Koop pers. obs.).

U.S. DISTRIBUTION AND STATUS: *Tridax procumbens* is native to Puerto Rico and the U.S. Virgin Islands (Acevedo-Rodríguez and Strong, 2012; NGRP, 2018). It has become naturalized through southern and central Florida (Wunderlin and Hansen, 2018), in eight Texas counties (Eason, 2018; Everitt et al., 2007; Graves, 2000; iNaturalist, 2018; Kartesz, 2018; NGRP, 2018; UT, 2018), and in Hawaii (Starr et al., 2008; Wagner et al., 1999). It is also naturalized in the Midway Islands, the Northern Mariana Islands, Guam, and Wake Island (NGRP, 2018; Stone, 1970). It is the most common dicotyledonous plant on Wake Island (cited in Holm et al., 1997) and is considered a weed in its native range in Puerto Rico (Más and Lugo-Torres, 2013). *Tridax procumbens* was listed as a U.S. Federal Noxious Weed (FNW) (7 CFR § 360, 2016) on May 4, 1983, based on the recommendations of the Technical Committee to Evaluate Noxious Weeds (TCENW). The TCENW was composed of representatives from the Agricultural Research Service, the Animal and Plant Health Inspection Service, the Agricultural Marketing Service, and the Weed Science Society of America (Graves, 2000). In the past, PPQ and other agencies have attempted to control or eradicate localized populations of this species (Graves, 2000). We found no evidence that *T. procumbens* is cultivated (e.g., Bailey and Bailey, 1976; Dave's Garden, 2018; Page and Olds, 2001) or sold in the United States (e.g., eBay, 2018; Univ. of Minn., 2018). Figure 1 shows the current U.S. distribution of *T. procumbens.*

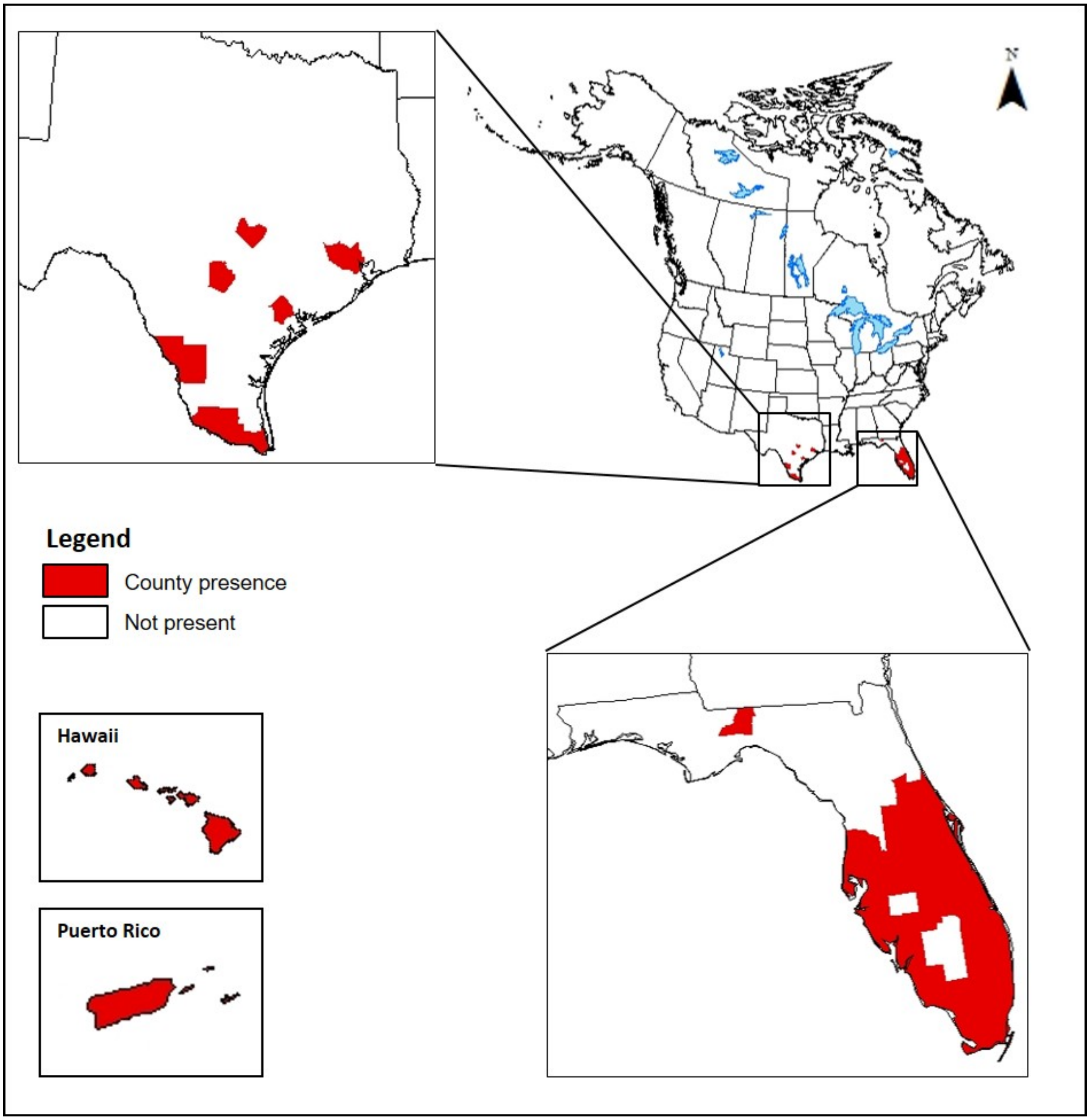

Figure 1. Known naturalized distribution of *Tridax procumbens* in the United States and Canada. The records shown here were obtained primarily from other species-distribution databases (Eason, 2018; Everitt et al., 2007; Graves, 2000; iNaturalist, 2018; Kartesz, 2018; UT, 2018; Wunderlin and Hansen, 2018) and were not independently verified by PERAL. Scales differ for all map insets. See text for a description of this species' distribution on some of the United States Pacific Island Territories.

3. Analysis

ESTABLISHMENT/SPREAD POTENTIAL

Based on its wide naturalized distribution throughout tropical and subtropical regions of the world, *T. procumbens* has already demonstrated a strong ability to establish and spread. *Tridax procumbens* is an annual or short-lived perennial (Everitt et al., 2007; Ivens, 1967) that reproduces by seed (Holm et al., 1997) but can also reproduce vegetatively, as it roots along the nodes of its decumbent stems (Moreira and Bragança, 2011). This species readily forms high-density populations in disturbed areas (Doll et al., 1977; Udoh et al., 2007), is self-compatible (Shivanna, 2014), and produces large quantities of seed, up to 2500 seeds per plant (Pancho, 1964). *Tridax procumbens* is wind-dispersed (Tadulingam and Venkatanarayana, 1955) and is readily spread by people as a hitchhiker on cars (Lonsdale and Lane, 1994), ships and containers (Graves, 2000), and commodities (AQAS, 2018; Smither-Kopperl, 2007). From 1992 to 2018, U.S. port inspectors intercepted this species 4378 times in a variety of commodities and conveyances (AQAS, 2018). *Tridax procumbens* forms a short-lived seed bank (Lutzeyer and Koch, 1992), has developed resistance to glyphosate (Heap, 2018), and may break at the base during manual weeding, allowing plants to re-sprout (Holm et al., 1997). We had low uncertainty for this risk element.

Risk score = 18 Uncertainty index = 0.12

IMPACT POTENTIAL

Tridax procumbens is considered an economically important weed (Reed, 1977). Holm et al. (1997) classify it as a serious or principal weed of cassava, cotton, dry-land crops, jute, wheat, irrigated crops, vegetables, pastures, peanuts, sorghum, soybeans, and sugarcane across numerous tropical countries. It is also considered a weed of waste ground, roadsides, and neglected lawns and gardens in many countries (Ivens, 1967; Kissmann and Groth, 1992; Liogier and Martorell, 2000; Stone, 1970; Zhang and Bojiu, 2000), including the United States (Murphy et al., 1992). It also invades natural areas in Australia (Randall, 2007), Reunion (Soubeyran, 2008), and the United States [Florida (Long and Lakela, 1976)]. *Tridax procumbens* occurs in a variety of crops, sometimes at relatively high frequencies and densities (Bindroo et al., 2013). Although it is reported to have substantial impacts in Brazilian soybean production, experimental evidence indicates it is not very competitive with soybean (Vivian et al., 2013a; Vivian et al., 2013b) or with other weeds (Pemadasa, 1976). *Tridax procumbens* reduces crop yield in Sri Lanka (Pemadasa, 1976). In Texas, it invades areas with buffel grass[2] and chokes it out (Graves, 2000). *Tridax procumbens* is a host to several important crop pests (Holm et al., 1997) and, based on laboratory evidence, is allelopathic (Andriana et al., 2018; Femina et al., 2012; Mecina et al., 2016; Nurul Ain et al., 2016). This species is also reported to interfere with harvesting in rice (Galinato et al., 1999). Plants have been controlled with both mechanical and chemical means in agricultural areas (Ivens, 1967; Petter et al., 2007). In glyphosate-resistant soybean in Brazil, this weed

[2] *Pennisetum ciliare*, an exotic species cultivated in pastures.

is difficult to control with glyphosate and must be treated with other herbicides (Galon et al., 2013), such as 2,4 D (Petter et al., 2007). We had high uncertainty for this risk element due to the limited amount of specific evidence regarding impacts.

Risk score = 2.6 Uncertainty index = 0.22

GEOGRAPHIC POTENTIAL

Based on three climatic variables, we estimate that about 21 percent of the United States is suitable for the establishment of *T. procumbens* (Fig. 2). This predicted distribution is based on the species' known distribution elsewhere in the world and includes point-referenced localities and general areas of occurrence. The map for *T. procumbens* represents the joint distribution of Plant Hardiness Zones 8-13, areas with 0 to 100 or more inches of annual precipitation, and the following Köppen-Geiger climate classes: tropical rainforest, tropical savanna, steppe, desert, humid subtropical, and marine west coast. In this weed risk assessment, we had high uncertainty as to whether this species could survive in Plant Hardiness Zone 8 because for the few areas where we found evidence of it occurring in this Zone (GBIF, 2018), it was either near the border with Zone 9, or it occurred in a narrow band of Zone 8 in a mountainous region near zone 9. Furthermore, this species is generally distributed in tropical and subtropical regions (GBIF, 2018). The map shown in Figure 2 assumes that Zone 8 is suitable for *T. procumbens*; however, if it is not, then only a narrow region along the southern border of the conterminous United States would be climatically suitable for its establishment. For reference, the northernmost county shown in the map inset for Texas in Fig. 1, corresponding to Travis County (Austin, TX), is located at the very southern edge of Zone 8. In one growth chamber study, *T. procumbens* had very low germination rates (about 2 percent) at alternating cycles of 25/15 °C and much higher germination rates (about 70 percent) at alternating cycles of 30/20 °C, suggesting that temperature may be a significant factor limiting its northern range (Chauhan and Johnson, 2008).

The area of the United States shown to be climatically suitable (Fig. 2) for species establishment was estimated considering only three climatic variables. Other variables, such as soil and habitat type, novel climatic conditions, or plant genotypes may alter the areas in which this species is likely to establish. *Tridax procumbens* occurs in tropical and subtropical regions of the world and is frequently found in annual and perennial croplands, roadsides, pastures, fallow land, railroads, riverbanks, meadows, dunes, lawns, coastal areas, mountainous regions, and nurseries (Galinato et al., 1999; Holm et al., 1997; Hsu et al., 2006; Zhang and Bojiu, 2000). In Texas it occurs along sidewalks (Brown et al., 2011) and railroad tracks (Graves, 2000; UT, 2018) and in urban areas, feral fields, and roadsides (Eason, 2018). In Florida, it occurs in disturbed sites, waste areas, and margins of hammocks (Long and Lakela, 1976). In Hawaii, it occurs in dry, disturbed sites, ranging from 0 to 2805 m in elevation (Wagner et al., 1999), and in Guam it is common on limestone (Stone, 1970). *Tridax procumbens* thrives especially in drier areas and where it is sunny or lightly shaded (Galinato et al., 1999).

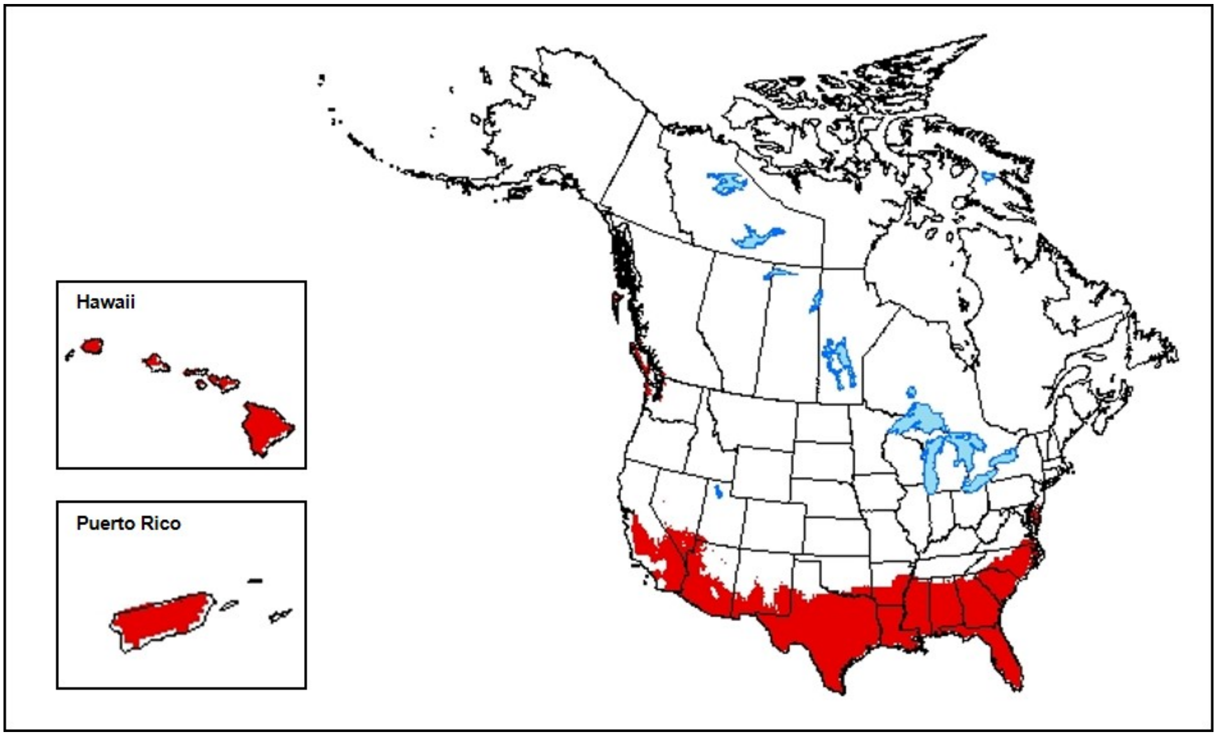

Figure 2. Potential geographic distribution of *Tridax procumbens* in the United States and Canada. Map insets for Hawaii and Puerto Rico are not to scale.

ENTRY POTENTIAL

Tridax procumbens is already present in the United States, where it is native to Puerto Rico and the U.S. Virgin Islands (Acevedo-Rodríguez and Strong, 2012) and has become naturalized in Florida (Wunderlin and Hansen, 2018), Texas (Eason, 2018), Hawaii (Wagner et al., 1999), the Midway Islands, the Northern Mariana Islands, Guam, and Wake Island (NGRP, 2018; Stone, 1970). Based on our analysis, we determined that this species has a relatively high likelihood of entering other areas of the United States. On a scale of 0 to 1, where 1 represents the maximum likelihood of entry, *T. procumbens* scored 0.86. Our evaluation resulted in a high score because of abundant evidence that it is readily dispersed by people (Lonsdale and Lane, 1994; Maroyi, 2012) as a contaminant and hitchhiker in trade (AQAS, 2018; Graves, 2000; Smither-Kopperl, 2007). Although we did not find specific evidence that it is cultivated, the species is used in some cultures (Prajapati, 2017; Raju, 1999; Tiwari et al., 2005; App. A), and seeds are available from foreign vendors on eBay (2018).

Risk score = 0.86 Uncertainty index = 0.33

4. Predictive Risk Model Results

Model Probabilities: P(Major Invader) = 84.2%
P(Minor Invader) = 15.3%
P(Non-Invader) = 0.6%

Risk Result = High Risk

Secondary Screening = Not Applicable

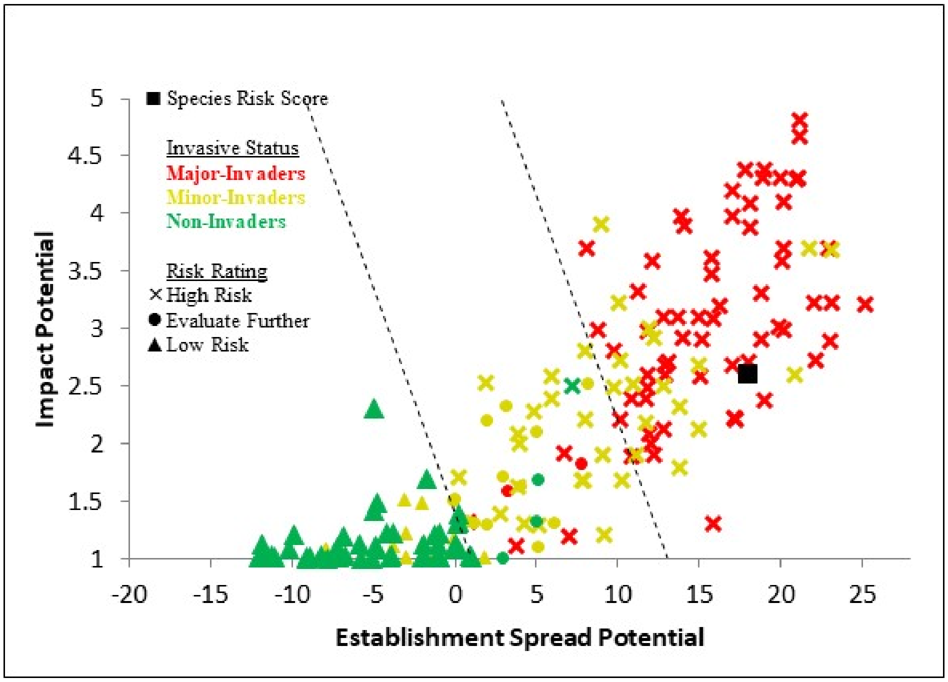

Figure 3. *Tridax procumbens* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

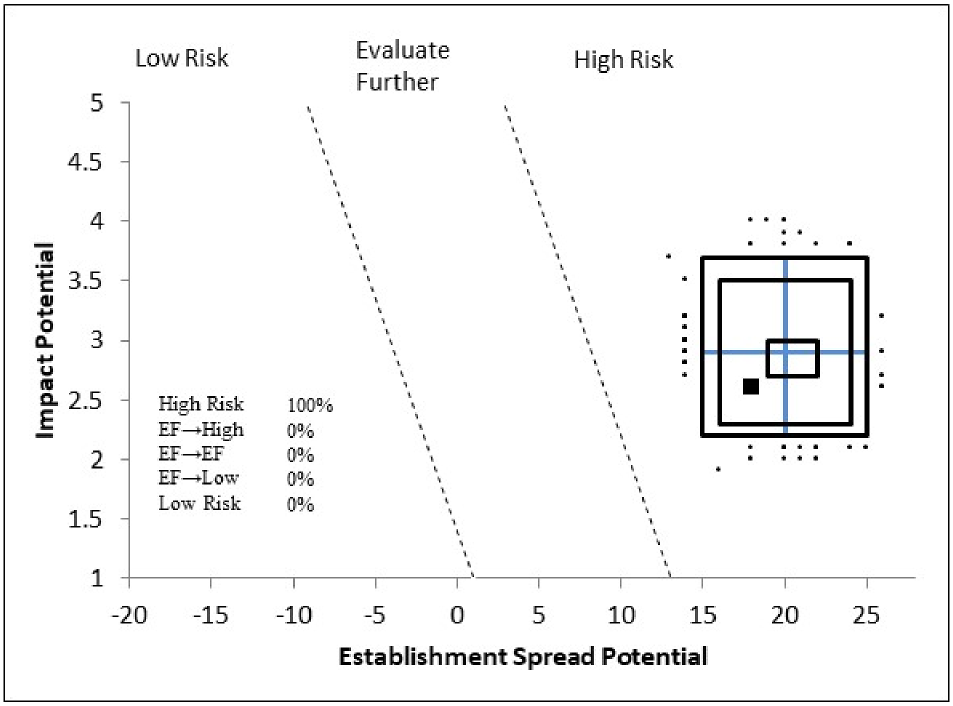

Figure 4. Model simulation results (N=5,000) for uncertainty around the risk score for *Tridax procumbens*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

5. Summary and Discussion

The result of the weed risk assessment for *Tridax procumbens* is High Risk (Fig. 3). Despite a high level of uncertainty associated with its impacts, an uncertainty analysis indicates that our conclusion of High Risk is robust (Fig. 4). *Tridax procumbens* is an annual or short-lived perennial aster that has already demonstrated a strong ability to establish and spread. It is readily spread by people as a hitchhiker on cars, ships and containers, and commodities. Seeds are small, about 2 mm long by 1 mm wide, and have a pappus that likely helps seeds attach to some surfaces such as burlap bags. This species is widely considered a weed of agriculture and anthropogenic areas, and even of natural areas to some extent. It is reported to have substantial impacts in Brazilian soybean production and to reduce crop yield in Sri Lanka. It also interferes with harvest in rice and raises production costs due to increased costs of control. *Tridax procumbens* is allelopathic. Plants are controlled with both mechanical and chemical means in agricultural areas, but the species has developed resistance to glyphosate in Australia and is reported to be tolerant to it in Brazil.

Tridax procumbens is currently regulated as a Federal Noxious Weed (FNW) by APHIS. This species is already naturalized in multiple regions in the United States, and its FNW status has caused some trade concerns because APHIS has a zero-tolerance policy towards FNWs intercepted on commodities entering the United States.

PPQ officials have wondered whether this species has reached the limit of its potential distribution in the United States. Our current analysis of this species' potential geographic distribution in the United States was not entirely conclusive due to uncertainty about whether it can survive in Plant Hardiness Zone 8. We found evidence that this species occurs in some locations in Zone 8 around the world (App. A), but those locations are usually close to the border of Zone 9, or in mountainous regions where mapping uncertainty is higher due to rapid elevation changes. Our prediction of *T. procumben*'s potential distribution in the United States assumes that Zone 8 is suitable and suggests that it may still be able to spread farther north in the United States; however, it may not be very weedy in those regions as cold temperatures may limit its ability to establish, spread, and cause harm.

6. Acknowledgements

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SUGGESTED CITATION

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DOCUMENT HISTORY

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Appendix A. Weed risk assessment for *Tridax procumbens* L. (Asteraceae)

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 - negl	5	*Tridax procumbens* is native to Mexico, Central America, South America, and the Caribbean (NGRP, 2018). It has become naturalized in Africa (e.g., South Africa, Kenya, Senegal, Ethiopia, Cape Verde, Zimbabwe), tropical Asia (e.g., India, Vietnam, the Philippines), eastern Asia (e.g., China, Taiwan, Japan), the Pacific (e.g., Fiji, French Polynesia, New Caledonia, Palau), and Australia (Maroyi, 2012; NGRP, 2018; Space et al., 2009). It is considered invasive in China (Weber et al., 2008), Palau (Space et al., 2009), and Taiwan (Wu et al., 2004). When introduced to other tropical regions, this species has spread quickly (Holm et al., 1997; Ivens, 1967). It was recognized as invasive in the early 1960s when it was spreading through tropical regions of the world (Baker, 1965). It spread rapidly along roads in Zambia in the 1950s, and in the 1980s, it became more common in arable lands (Vernon, 1983). In Sri Lanka, *T. procumbens* rapidly colonizes agricultural areas (Pemadasa, 1976). Alternate answers for the uncertainty simulation were both "e."
ES-2 (Is the species highly domesticated)	n - negl	0	*Tridax procumbens* is a wild species, and we found no evidence that it has been cultivated or bred in any fashion to reduce its weed potential.
ES-3 (Significant weedy congeners)	n - negl	0	*Tridax* is a genus of about 26 South American species (Mabberley, 2008). Of all the species, *T. procumbens* is the only one that has become globally important as a weed (Holm et al., 1997). A few other species have been reported as weeds, but these are likely only minor weeds, given the limited number of supporting references reported in Randall (2017).
ES-4 (Shade tolerant at some stage of its life cycle)	n - mod	0	*Tridax procumbens* tolerates diffuse light but prefers sunny areas (Kissmann and Groth, 1992). It "is sensitive to shade, as plant height, dry weight and leaf area index decline as the level of shade increases. However, this species is less affected by shade than many others and thus crop competition may not effectively suppress its growth" (cited in Holm et al., 1997). Fresh seeds require light to germinate, but after two months of burial, about half of the seeds can germinate in darkness (Holm et al., 1997). Another study found that the highest germination rates (76 percent) for *T. procumbens* corresponded to seeds planted at the soil surface (Chauhan and Johnson, 2008). Based on this

Question ID	Answer - Uncertainty	Score	Notes (and references)
			evidence, and because this species generally occurs in open habitats (Holm et al., 1997), we answered no with moderate uncertainty.
ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes)	n - low	0	*Tridax procumbens* is a semi-prostrate, decumbent herb forming many lateral branches that ascend 30 to 50 cm high (Holm et al., 1997; Long and Lakela, 1976). It is neither a vine nor an herb with a tight, basal rosette of leaves.
ES-6 (Forms dense thickets, patches, or populations)	y - low	2	In Nigerian fields that were fallow for two years, it occurred at densities as high as 584 plants per m^2 (Udoh et al., 2007). In Colombia, it was reported to occur in cassava at densities of 24 to 34 plants per m^2 (Doll et al., 1977).
ES-7 (Aquatic)	n - negl	0	This species is not an aquatic plant; it is a terrestrial herb (Holm et al., 1997).
ES-8 (Grass)	n - negl	0	This species is not a grass; it is an aster (NGRP, 2018).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	We found no evidence that this species fixes nitrogen. Furthermore, it is neither woody nor in a plant family typically associated with nitrogen-fixation (Martin and Dowd, 1990; Santi et al., 2013).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	This species reproduces through seed (Holm et al., 1997; Kissmann and Groth, 1992; Moreira and Bragança, 2011; Raju, 1999).
ES-11 (Self-compatible or apomictic)	y - negl	1	An experiment that compared seed set in open and bagged flowers showed that seed set was comparable, indicating that plants can self-pollinate (Shivanna, 2014). This species can be either cross- or self-pollinated, and florets reach the same stage of development via either form of pollination at equivalent times (Holm et al., 1997).
ES-12 (Requires specialist pollinators)	n - negl	0	This species is pollinated by thrips and is visited by butterflies, beetles, and bees (Holm et al., 1997). In Brazil, it is visited by European honeybees (Moreira and Bragança, 2011). In a pollen study of honey from *Apis dorsata* bees in West Bengal, pollen corresponding to *T. procumbens* was the most frequent (Layek and Karmakar, 2018). Also, see evidence under ES-11.
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 - mod	1	This species is an annual (Everitt et al., 2007; Maroyi, 2012) or short-lived perennial (Ivens, 1967; Zhang and Bojiu, 2000). It flowers and germinates throughout the year (Pemadasa, 1976). Plants flower about five to eight weeks after emergence, and seeds mature within three weeks (cited in Holm et al., 1997). It produces seeds for most of the year (Kissmann and Groth, 1992). This species is very invasive because of its "rapid and abundant seed production" (Baker, 1965). Together, this evidence indicates that *T. procumbens* has a minimum generation of a year; however, because it is not clear if there can be multiple generations in one year, our alternate answers for the uncertainty simulation were both "a."
ES-14 (Prolific seed producer)	y - low	1	Baker (1965) considers this species to have "abundant seed production". Plants flower about five to eight weeks after emergence, and seeds mature within three weeks (cited in Holm et al., 1997). In Sri Lanka, there are flowering plants

Question ID	Answer - Uncertainty	Score	Notes (and references)
			all year (Pemadasa, 1976). Single plants produce 500 to 2500 seeds (Holm et al., 1997; Pancho, 1964). Seed viability and germination rates range between 44 and 70 percent (Chauhan and Johnson, 2008; Holm et al., 1997). A small infestation in Texas consisted of about six blooming plants per m^2 (Graves, 2000). Another estimate of plant density reported 24 to 34 plants per m^2 (Doll et al., 1977). Assuming that a single plant produces 500 seeds and that half of those seeds are viable, it would take about 20 plants per m^2 to meet our threshold of 5000 seeds for prolific reproduction. Given the evidence reported here and the fact that plants bloom yearlong, it seems likely that *T. procumbens* meets our criteria for a yes response to this question.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - low	1	In a study examining hitchhiking weed seeds on cars driving into a national park in Australia, this species was found on 9.2 percent of the cars (33 of 304; Lonsdale and Lane, 1994). This species was unintentionally introduced into Zimbabwe (Maroyi, 2012).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	At the Port of Puget Sound in Washington during a one-year period, *T. procumbens* was one of the most frequently intercepted Federal Noxious Weeds; it was found associated with a variety of cargo types, including pottery from Vietnam (Smither-Kopperl, 2007). From 1992 to 2018, U.S. port inspectors have intercepted this species 4378 times in a variety of commodities and conveyances (AQAS, 2018). Populations of *T. procumbens* in Laredo and Brownsville, TX likely became established from infested railroad cars carrying coffee from Mexico (Graves, 2000). This species also disperses as a contaminant of sesame seeds and birdseed (Graves, 2000).
ES-17 (Number of natural dispersal vectors)	1	-2	Seed and propagule traits for questions ES-17a through ES-17e: Fruit is a brown to black achene about 2 mm long by 1 mm wide at its apex, with a pappus that is 5-6 mm long (Holm et al., 1997). "The fruits are shortly hairy and crowned with long, stiff, straw-coloured bristles" (Ivens, 1967).
ES-17a (Wind dispersal)	y - low		Seeds are wind-dispersed (Tadulingam and Venkatanarayana, 1955). The relative weight of the pappus to the achene is different between seeds produced by ray flowers and those from disc flowers, suggesting that different dispersal patterns may be operating (Holm et al., 1997).
ES-17b (Water dispersal)	n - high		We found no evidence of this type of dispersal.
ES-17c (Bird dispersal)	? - max		Plant stems are covered with coarse, stiff hairs (Ivens, 1967; Reed, 1977), and the pappus of the achenes is stiff and bristly (Ivens, 1967). Although we found no evidence of this kind of dispersal, it seems likely that achenes may stick to bird feathers, particularly since they stick to coffee sacks (Graves, 2000). Consequently, we answered unknown.
ES-17d (Animal external dispersal)	? - max		We found no direct evidence of this type of dispersal. Based on the same evidence and reasoning described in ES-17c, we think it is possible that seeds may disperse on animal fur.

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Consequently, we answered unknown with maximum uncertainty.
ES-17e (Animal internal dispersal)	n - mod		We found no evidence of this type of dispersal.
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - mod	1	About seven percent of seeds stored in soil for two years were viable (Lutzeyer and Koch, 1992). One source noted that seeds have a high degree of dormancy (97 percent), but later, drying and rewetting the seeds broke seed dormancy, resulting in 45 percent germination (Galinato et al., 1999). This study, however, did not comment on the potential longevity of seeds in the soil seed bank.
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - mod	1	During hand-pulling, plant stems readily break at the base, allowing plants to resprout (Holm et al., 1997). Stems can root along the nodes (Moreira and Bragança, 2011).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	y - low	1	*Tridax procumbens* has developed resistance to glyphosate in Western Australia (Heap, 2018). In Brazil, preliminary evidence suggests that *T. procumbens* may be tolerant to glyphosate, as this herbicide was not effectively translocated to all plant parts from the leaves (Galon et al., 2013).
ES-21 (Number of cold hardiness zones suitable for its survival)	6	0	
ES-22 (Number of climate types suitable for its survival)	6	2	
ES-23 (Number of precipitation bands suitable for its survival)	11	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - high	0.1	Several laboratory studies of extracts from *T. procumbens* have found that it has a negative effect on the germination and growth of test seedlings, leading some authors to conclude that the species may be useful in controlling weeds in agriculture (Andriana et al., 2018; Femina et al., 2012; Mecina et al., 2016; Nurul Ain et al., 2016). Based on this evidence we answered yes. In spite of the number of primary articles supporting an allelopathic effect, however, we used high uncertainty because we did not find any data to indicate whether *T. procumbens* has an allelopathic effect under field conditions.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence that this species is parasitic. It is not a member of a plant family that is known to contain parasitic species (Heide-Jorgensen, 2008; Nickrent, 2009).
Impacts to Natural Systems			
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	n - mod	0	*Tridax procumbens* appears to be primarily an agricultural weed; however, because it is considered invasive in natural areas (Baker, 1965; Long and Lakela, 1976; Randall, 2007; Soubeyran, 2008), it is possible it may have some unreported impacts in natural systems, increasing our level of uncertainty in this risk element. We found no evidence that it changes ecosystems properties. Because this impact seems unlikely, we used moderate uncertainty.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Imp-N2 (Changes habitat structure)	n - high	0	We found no evidence.
Imp-N3 (Changes species diversity)	? - max		We found no direct evidence that this species affects species diversity in natural systems. In forest systems in Nepal, it occurs at relatively low densities, frequencies, and coverage rates (Tiwari et al., 2005). In agricultural habitats, however, it can occur at high densities (see evidence under ES-6), so it is possible that in some natural systems that are open and routinely disturbed, such as rangelands, it may have some impacts [but see Pemadasa (1976) who reports it is not very competitive because of its prostrate habit]. Without additional information, we answered this question as unknown.
Imp-N4 (Is it likely to affect federal Threatened and Endangered species?)	n - high	0	We found no evidence.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	n - mod	0	We found no evidence, and this impact seems unlikely.
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]	b - mod	0.2	*Tridax procumbens* is considered an invasive weed of natural areas in Australia (Randall, 2007) and Reunion (Soubeyran, 2008). It is also invasive in closed grasslands (Baker, 1965). In southern Florida, this species is established around the edges of islands of tropical hardwood trees (called hammocks), which are natural areas (Long and Lakela, 1976). Based on this evidence, we answered "b" with moderate uncertainty. Alternate answers for the uncertainty simulation were "a" and "c."
Impact to Anthropogenic Systems (e.g., cities, suburbs, roadways)			
Imp-A1 (Negatively impacts personal property, human safety, or public infrastructure)	n - low	0	We found no evidence. Considering that this species is well-known as a disturbance weed and that this impact seems unlikely for a terrestrial, herbaceous plant, we answered no with low uncertainty.
Imp-A2 (Changes or limits recreational use of an area)	n - low	0	We found no evidence of this impact. Because it seems unlikely that a short-statured herbaceous plant would affect recreation, we used low uncertainty.
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	n - high	0	This species is considered a weed of turf grass in the United States (Murphy et al., 1992) and may become a nuisance in home gardens (Dave's Garden, 2018). We found no specific evidence of impacts to turf grass or other plants. Because information about weediness is considered under Imp-A4, we answered this question as no, but with high uncertainty.
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]	b - mod	0.1	This species is a weed of waste ground in Puerto Rico (Liogier and Martorell, 2000), Guam (Stone, 1970), Brazil (Kissmann and Groth, 1992), and eastern Africa (Ivens, 1967). It is also very common in neglected lawns and gardens in eastern Africa (Ivens, 1967). It is a weed of turf grass in the United States (Murphy et al., 1992) and of roadsides in China (Zhang and Bojiu, 2000). It is also a weed of urban areas (Kissmann and Groth, 1992). We answered "b" with both alternate answers set to "c," as it

Question ID	Answer - Uncertainty	Score	Notes (and references)
			may be subject to control in some of these habitats, particularly lawns.
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	y - mod	0.4	*Tridax procumbens* occurs in a variety of crops, sometimes at relatively high frequencies and densities (Bindroo et al., 2013). It is reported to have substantial impacts in Brazilian soybean production (Vivian et al., 2013a) and to reduce crop yield in Sri Lanka (Pemadasa, 1976). In a competition experiment where soybean was grown with *T. procumbens* in a replacement series, however, Vivian et al. (2013b) found that the weed was not very competitive with soybean. In Texas, *T. procumbens* invades areas with buffel grass (a pasture species) and chokes it out (Graves, 2000). It is also a host to several important crop pests (Holm et al., 1997). Based on this evidence, we answered yes, but used moderate uncertainty because specific evidence of impacts was lacking.
Imp-P2 (Lowers commodity value)	y - low	0.2	"*T. procumbens* is often found in maturing rice plants because it can continue to germinate following weed control with herbicides or hand weeding. Such late infestations have little effect on crop yield but interfere with harvesting, add to the weed seed bank, and harbor rodents" (Galinato et al., 1999). In Brazil, to effectively control *T. procumbens*, producers must mix glyphosate with other types of herbicides, which raises production costs (Galon et al., 2013).
Imp-P3 (Is it likely to impact trade?)	n - mod	0	We found ample evidence that *T. procumbens* moves along trade pathways (see evidence under ES-16). Because we found no evidence that it is regulated by a foreign country (APHIS, 2018; queried on June 8, 2018), however, we answered this question as no with moderate uncertainty.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	n - mod	0	We found no evidence.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	n - mod	0	We found no evidence that this species is toxic to animals (e.g., Bruneton, 1999; Burrows and Tyrl, 2013).
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]	c - negl	0.6	*Tridax procumbens* is considered a serious or principal weed of cassava, cotton, dry-land crops, jute, wheat, irrigated crops, vegetables, pastures, peanuts, sorghum, soybeans, and sugarcane across numerous tropical countries (Holm et al., 1997). It is also a serious weed of pastures in Australia and a common weed in pastures and pineapple in Hawaii (Holm et al., 1997; Liogier and Martorell, 2000). It is a weed of orchards in Brazil (Moreira and Bragança, 2011), and of upland rice in India (Raju, 1999) and southeast Asia (Galinato et al., 1999). *Tridax procumbens* is an important weed of cotton and maize that requires control in Africa (Chikoye et al., 2005; Ipou Ipou et al., 2011) and Brazil (Freitas et al., 2006). Unlike other aster weeds, this species

Question ID	Answer - Uncertainty	Score	Notes (and references)
			can be relatively easily controlled through cultivation (Ivens, 1967). Plants are controlled with both mechanical and chemical means in agricultural areas (Ivens, 1967). *Tridax procumbens* has recently become an important weed in Brazil, where it has a very high occurrence in annual crop fields, orchards, and coffee plantations (Galon et al., 2013). In glyphosate-resistant soybean in Brazil, this weed is difficult to control with glyphosate and must be treated with other herbicides (Galon et al., 2013), such as 2,4 D (Petter et al., 2007). One Brazilian study examined which combinations of herbicides are effective in controlling this species and other weeds in soybean (Petter et al., 2007). Alternate answers for the uncertainty simulation were both "b."
GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2018).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - negl	N/A	We found no evidence that this species occurs in this Zone.
Geo-Z2 (Zone 2)	n - negl	N/A	We found no evidence that this species occurs in this Zone.
Geo-Z3 (Zone 3)	n - negl	N/A	We found no evidence that this species occurs in this Zone.
Geo-Z4 (Zone 4)	n - negl	N/A	We found no evidence that this species occurs in this Zone.
Geo-Z5 (Zone 5)	n - negl	N/A	We found no evidence that this species occurs in this Zone.
Geo-Z6 (Zone 6)	n - negl	N/A	We found no evidence that this species occurs in this Zone.
Geo-Z7 (Zone 7)	n - high	N/A	Two points in Mexico and two points in mountainous regions of Argentina. We answered no as this is primarily a tropical species, and these occurrences may simply be due to seasonal transients.
Geo-Z8 (Zone 8)	y - high	N/A	Some points in Mexico in a very narrow band of this Zone. One point in the United States (Texas) that is on the edge of Zone 9. One point in South Africa. Three points in mountainous regions of Argentina. Based on the number of points, we answered yes; however, we have high uncertainty as to whether this species can grow throughout this Zone.
Geo-Z9 (Zone 9)	y - negl	N/A	Few points in Brazil and Mexico. Many points in the United States (Florida, and two in Texas) and some in Australia.
Geo-Z10 (Zone 10)	y - negl	N/A	Brazil, Mexico, South Africa, and the United States (southern Texas).
Geo-Z11 (Zone 11)	y - negl	N/A	Australia, Benin, Brazil, United States (Florida), and Mexico.
Geo-Z12 (Zone 12)	y - negl	N/A	Australia, Benin, Brazil, Mexico, and Nicaragua.
Geo-Z13 (Zone 13)	y - negl	N/A	Australia, Brazil, Costa Rica, and Panama.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	y - negl	N/A	Brazil, Costa Rica, Guatemala, and Mexico.
Geo-C2 (Tropical savanna)	y - negl	N/A	Australia, Brazil, Costa Rica, and Mexico.
Geo-C3 (Steppe)	y - negl	N/A	Australia, Brazil, and Mexico.
Geo-C4 (Desert)	y - high	N/A	A few points in Australia and Mexico. Three points in Madagascar.
Geo-C5 (Mediterranean)	n - high	N/A	We found no evidence that this species occurs in this climate class.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-C6 (Humid subtropical)	y - negl	N/A	Argentina, Brazil, South Africa, Taiwan, and the United States.
Geo-C7 (Marine west coast)	y - low	N/A	Brazil. Four points in Bolivia, one point in Argentina, two points each in India and Nepal, and a few points each in China and Guatemala.
Geo-C8 (Humid cont. warm sum.)	n - negl	N/A	We found no evidence that this species occurs in this climate class.
Geo-C9 (Humid cont. cool sum.)	n - negl	N/A	We found no evidence that this species occurs in this climate class.
Geo-C10 (Subarctic)	n - negl	N/A	We found no evidence that this species occurs in this climate class.
Geo-C11 (Tundra)	n - negl	N/A	We found no evidence that this species occurs in this climate class.
Geo-C12 (Icecap)	n - negl	N/A	We found no evidence that this species occurs in this climate class.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - high	N/A	About 15 points in Brazil. One point on edge of this band in Australia, one point in South Africa, and three points in Senegal. Based on the number of points and countries we answered yes with high uncertainty, but these occurrences may be in certain microhabitats not representative of the broader region.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Australia, Brazil, and Mexico.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Australia, Brazil, Mexico, and the United States (Texas).
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Australia, Brazil, and Mexico.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	Australia and Brazil.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	Australia, Brazil, Central America, Cuba, Mexico, and the United States (Florida).
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	Brazil, Central America, United States (Florida), and Mexico.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	Brazil, Central America, United States (Florida), and Mexico.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	Brazil, Central America, United States (Florida), and Mexico.
Geo-R10 (90-100 inches; 229-254 cm)	y - negl	N/A	Brazil, Central America, and Mexico.
Geo-R11 (100+ inches; 254+ cm)	y - negl	N/A	Brazil, Central America, the Dominican Republic, and Mexico.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	n - negl	0	*Tridax procumbens* is already present in the United States, where it is native to Puerto Rico and the U.S. Virgin Islands (Acevedo-Rodríguez and Strong, 2012; NGRP, 2018) and is naturalized in Florida (Wunderlin and Hansen, 2018), Texas (Eason, 2018; Everitt et al., 2007; Graves, 2000; iNaturalist, 2018; Kartesz, 2018; NGRP, 2018; UT, 2018), and Hawaii (Starr et al., 2008; Wagner et al., 1999). It is also naturalized in the Midway Islands, the Northern Mariana Islands, Guam, and Wake Island (NGRP, 2018; Stone, 1970). To evaluate

Question ID	Answer - Uncertainty	Score	Notes (and references)
			the likelihood for additional spread, however, we set this answer to no.
Ent-2 (Plant proposed for entry, or entry is imminent)	n - low	0	This species is not being proposed for import.
Ent-3 [Human value & cultivation/trade status: (a) Neither cultivated or positively valued; (b) Not cultivated, but positively valued or potentially beneficial; (c) Cultivated, but no evidence of trade or resale; (d) Commercially cultivated or other evidence of trade or resale]	d - high	0.5	In India, the leaves of *T. procumbens* are used to treat various ailments, and the leaf juices are used as a poison to catch fish (Raju, 1999). In Nepal, leaf extracts are used as an antiseptic to treat cuts (Tiwari et al., 2005). This species is also being evaluated for its pharmaceutical potential (Prajapati, 2017). *Tridax procumbens* was introduced into Nigeria as an ornamental (Holm et al., 1997). Seed and shredded plant material that is marketed as *T. procumbens* is available from foreign vendors on eBay (eBay, 2018); however, some of those listings use images of plants that are not consistent with *T. procumbens* (Koop pers. obs.). Nevertheless, we answered "d" because seeds are sold online.
Ent-4 (Entry as a contaminant)			
Ent-4a (Plant present in Canada, Mexico, Central America, the Caribbean or China)	y - negl		*Tridax procumbens* is native from Mexico south through central America (e.g., Belize, Costa Rica, Panama), and into South America. It is also native to the Galapagos Islands, and the Caribbean (e.g., Cuba, Martinique, St. Vincent and the Grenadines) (NGRP, 2018).
Ent-4b (Contaminant of plant propagative material (except seeds))	y - high	0.08	This species has been intercepted a few dozen times on permit cargo of propagative material entering the U.S. (AQAS, 2018).
Ent-4c (Contaminant of seeds for planting)	y - high	0.08	This species has been intercepted a few times by U.S. inspectors on seed for planting (AQAS, 2018).
Ent-4d (Contaminant of ballast water)	n - mod	0	We found no evidence.
Ent-4e (Contaminant of aquarium plants or other aquarium products)	n - mod	0	We found no evidence.
Ent-4f (Contaminant of landscape products)	? - max		We found no specific evidence, but given its ability to enter as a general hitchhiker, this pathway seems likely.
Ent-4g (Contaminant of containers, packing materials, trade goods, equipment or conveyances)	y - negl	0.04	Populations of *T. procumbens* in Laredo and Brownsville, TX likely became established from infested railroad cars carrying coffee from Mexico (Graves, 2000).
Ent-4h (Contaminants of fruit, vegetables, or other products for consumption or processing)	y - negl	0.02	U.S. inspectors have intercepted this species many times on material for consumption and in cargo and personal baggage (AQAS, 2018). It also disperses as a contaminant of sesame seeds (Graves, 2000).
Ent-4i (Contaminant of some other pathway)	e - negl	0.08	At the Port of Puget Sound in Washington during a one-year period, *T. procumbens* was one of the most frequently intercepted Federal Noxious Weeds; it was found associated with a variety of cargo types, including pottery (Smither-Kopperl, 2007). It also disperses as a contaminant of birdseed (Graves, 2000). Based on these frequent and diverse forms of interceptions, we used "e" as it carries the highest score of the possible answer choices.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Ent-5 (Likely to enter through natural dispersal)	y - mod	0.06	This species is native to Mexico (NGRP, 2018), and seeds are wind-dispersed (see evidence under ES-17). It seems likely that if populations are present near the United States-Mexico border, they will be able to disperse naturally into the United States.