United States Department of Agriculture

Weed Risk Assessment for *Thlaspi arvense* L. (Brassicaceae) – Field pennycress

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Left: *Thlaspi arvense* plant (source: Utah State University Archive, Utah State University, Bugwood.org). Top center: Senesced fruits (seed pods) (source: Ohio State Weed Lab Archive, The Ohio State University, Bugwood.org). Bottom center: Plants with seed pods growing in a field of winter wheat (source: Howard F. Schwartz, Colorado State University, Bugwood.org). Right: Fruit [source: Mary Ellen (Mel) Harte, Bugwood.org].

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 weed risk assessment (WRA)—specifically, the PPQ WRA model (Koop et al., 2012)—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, 2011). 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.

	***Thlaspi arvense* L. – Field pennycress**
Species Information	Family: Brassicaceae Synonyms: *Crucifera thlaspi* (Roxb.) E.H.L.Krause, *Lepidium thlaspi* Roxb., *Teruncius arvense* (L.) Lunell, *T. arvensis* (L.) Lunell, *Thlaspi baicalense* DC., *T. collinum* Bieb. M, *T. strictum* Dalla Torre & Sarnth., *Thlaspidea arvensis* (L.) Opiz, *Thlaspidium arvense* (L.) Bubani (The Plant List, 2013; Tropicos.org, 2014). Common names: Field pennycress (CABI, 2014; NRCS, 2014); bastard cress, fanweed, Frenchweed, Mithridate mustard, pennycress, stinkweed, wild garlic (NGRP, 2014b). Preferred common name is field pennycress (CABI, 2014). Botanical description: *Thlaspi arvense* is an erect, annual herb (Holm et al., 1997; NRCS, 2014). It starts out as a rosette of leaves, but then becomes an erect flowering stem (Uva et al., 1997), growing 18 to 80 cm tall (Holm et al., 1997). It produces small white flowers in terminal clusters; the fruit are flat, heart-shaped pods 1 to 2 cm long, each containing 4 to 16 seeds (Royer and Dickinson, 1999). For a full botanical description, see eFloras (2014). Initiation: On August 4, 2014, the Environmental Protection Agency (EPA) contacted Jonathan Jones, USDA Biofuel Team Leader, with questions about the weed status of *T. arvense* (Lie, 2014). We later learned that the EPA wanted to know whether or not this species should be regulated under their Renewable Fuel Standard as a potential invasive species (Lie, 2014). On October 6, the PPQ Weeds Cross-Functional Working Group requested that the PERAL Weed Team conduct a WRA of this species. Foreign distribution: *Thlaspi arvense* is native to and widespread in Europe and Asia (mainly temperate areas) and has naturalized in North America (Canada and the United States), Australia, and New Zealand, as well as parts of Africa (Algeria, Morocco, the Azores, the Madeira Islands, South Africa, the Canary Islands, Tunisia) and South America (Argentina, Brazil, Chile) (GBIF, 2014; Holm et al., 1991; NGRP, 2014b). It was recently introduced to Mexico (Vibrans, 2003), but we do not know if they consider it to be established there. U.S. distribution and status: *Thlaspi arvense* was first detected in the United States (in Detroit, Michigan) in 1701 (Royer and Dickinson, 1999). Since then it has become naturalized in every state in the continental United States (Kartesz, 2013; NRCS, 2014). It is listed as one of the "most widespread invasive plants in North America" (NAISN, 2013). Although we found no evidence that this species is sold commercially in the United States, it may be cultivated privately to some extent [i.e., a person in Washington stated that they have seeds of the plant available for private trade on a gardening forum (Dave's Garden, 2014)]. Also, it is being proposed and developed as a potential oilseed biofuel plant here (ATI, 2010; Dorn et al., 2013; Moser et al., 2009). Several states list it as a noxious weed in seed (Indiana, Kansas, Minnesota, Nebraska, Nevada,

Ohio, South Dakota, Washington) (Kenny, 2015; Nees, 2015; NGRP, 2014a; AMS, 2014), and it is listed in the Invasive Plant Atlas of the United States (Swearingen, 2014). Michigan previously regulated *T. arvense* as a restricted noxious weed but deregulated it in 2015 (Zimmer, 2015).

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

1. *Thlaspi arvense* analysis

Establishment/Spread Potential Beyond its native range in Eurasia, *T. arvense* has established widely throughout the world, including North America, Australasia, and parts of Africa and South America (GBIF, 2014; Holm et al., 1991; NGRP, 2014b; Salisbury, 1961). It was first detected in North America in 1701 (Royer and Dickinson, 1999) and became established throughout Canada and the United States by the 1930s (Best and McIntyre, 1975; Clark, 1923). It is an erect herb that is self-compatible (Best and McIntyre, 1975), has prolific seed production (Holm et al., 1997; Salisbury, 1961), forms a persistent seed bank (Bond et al., 2007; Warwick et al., 2002), and some populations have developed herbicide resistance (Heap et al., 2014; Warwick et al., 2002). Propagules can be dispersed as seed contaminants in trade (Holm et al., 1997; NGRP, 2014b), via agricultural operations (e.g., combines) (Holm et al., 1997), by grazing animals that consume the seed (Pleasant and Schlather, 1994), by wind (Best and McIntyre, 1975; WSSA, 2014) and water (with spring floods) (Clark, 1923), and possibly by birds and externally on animals (Holm et al., 1997; Salisbury, 1961). We had low uncertainty for this risk element.

Risk score = 22 Uncertainty index = 0.11

Impact Potential *Thlaspi arvense* has likely been a weed of agriculture for several thousand years (Holm et al., 1997). Today it is a weed of nursery, horticultural, and agricultural crops (Uva et al., 1997). It is an important weed in many crops and countries, especially barley, oats, rape, sunflowers, wheat, forage crops, and oilseed (Holm et al., 1997; Warwick et al., 2002). It can cause serious yield losses of field crops, such as wheat and safflower (Holm et al., 1997; Warwick et al., 2002). The plant is poisonous to livestock (Darbyshire, 2003; Stubbendieck et al., 2003; Warwick et al., 2002), and consumption of its seeds or leaves by cattle causes their milk and flesh to develop an off-flavor (Warwick et al., 2002). Seed contaminants can also lower the quality of wheat and canola (Warwick et al., 2002; WSSA, 2014). Because it is a quarantine or regulated pest for multiple countries or regions of countries (EPPO, 2013; Groves et al., 2005; NGRP, 2014a; Warwick et al., 2002) and can be dispersed as a contaminant, it could impact trade. It may be

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

allelopathic to some extent (Holm et al., 1997) and can strongly compete with plants for water (Best and McIntyre, 1975). Although it has been listed as a weed of natural areas (Groves et al., 2005; Randall, 2007) and gardens and waste areas (Royer and Dickinson, 1999), we found no evidence of it causing impacts in anthropogenic (e.g., cities, suburbs, roadways) or natural systems. We had average uncertainty for this risk element.
Risk score = 3.3 Uncertainty index = 0.14

Geographic Potential *Thlaspi arvense* is already naturalized in every state in the continental United States and occurs in about 75 percent of the counties (Kartesz, 2013; NRCS, 2014). Based on county distribution, it is not very widespread in the southeastern United States (Kartesz, 2013; NRCS, 2014). Using three climatic variables, we estimate that nearly all of the United States is suitable for the establishment of *T. arvense* (Fig. 1). This predicted distribution is based on the species' known distribution in the world and includes point-referenced localities and areas of occurrence. The map for *T. arvense* represents the joint distribution of Plant Hardiness Zones 1-10, areas with 0-100+ inches of annual precipitation, and the following Köppen-Geiger climate classes: steppe, desert, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, humid continental cool summers, subarctic, and tundra.

The area of the United States shown to be climatically suitable (Fig. 1) is likely overestimated since our analysis considered only three climatic variables. Other environmental variables, such as soil and habitat type, may further limit the areas in which this species is likely to establish. Habitats of this plant include cropland, fallow fields, weedy meadows, rangeland, roadsides and railroads, gardens, lawns, nursery plots, waste areas, stream banks, bluffs, thickets, slopes, floodplains, and woods (Cowbrough, 2014; eFloras, 2014; Hilty, 2014; Holm et al., 1997; Warwick et al., 2002). This plant prefers disturbed areas (Hilty, 2014; Holm et al., 1997) and grows well on moist soil (Nawrocki, 2010).

Entry Potential We did not assess the entry potential of *Thlaspi arvense* because it is already present in the United States (Kartesz, 2013; NAISN, 2013; NRCS, 2014).

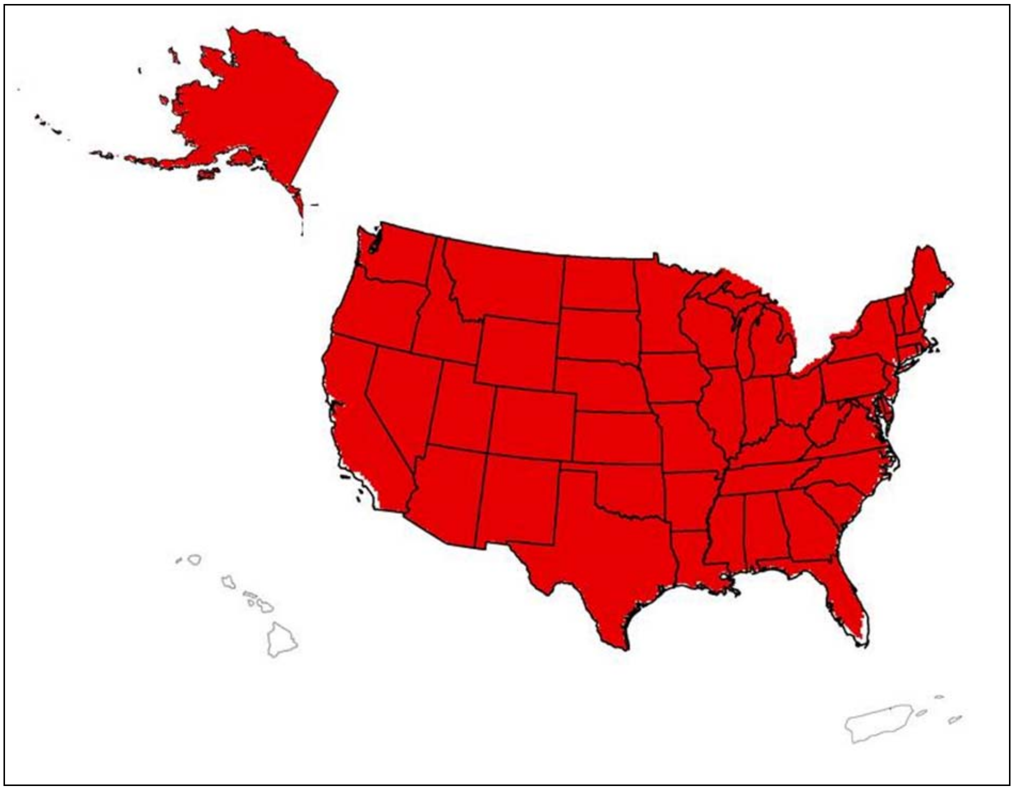

Figure 1. Predicted distribution of *Thlaspi arvense* in the United States. Map insets for Alaska, Hawaii, and Puerto Rico are not to scale.

<u>2. Results</u>

Model Probabilities: P(Major Invader) = 95.4%
P(Minor Invader) = 4.4%
P(Non-Invader) = 0.1%

Risk Result = High Risk

Secondary Screening = Not Applicable

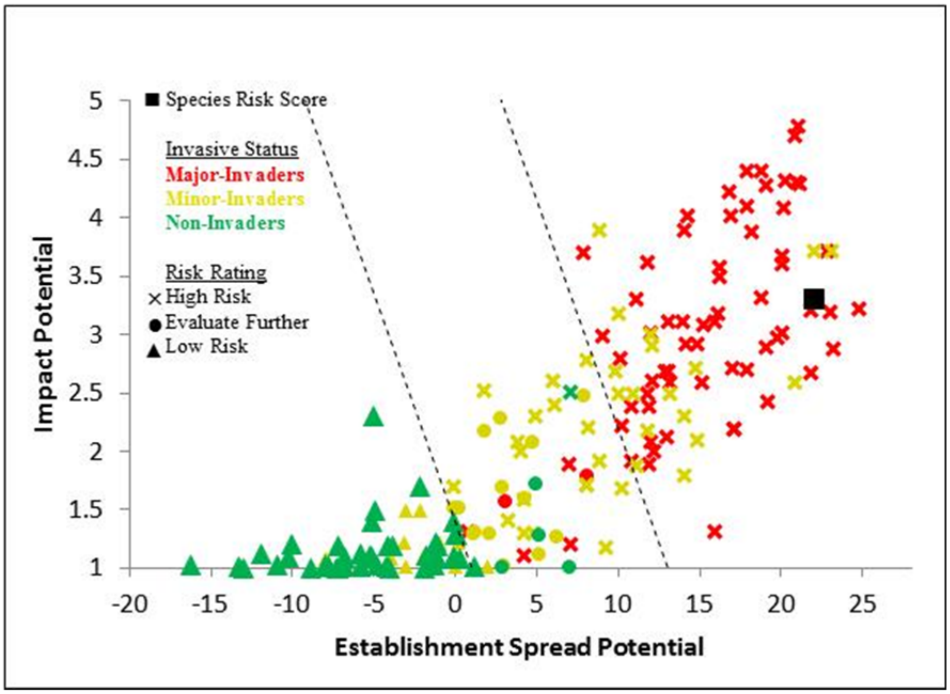

Figure 2. *Thlaspi arvense* risk score (black box) relative to the risk scores of species used to develop and validate the PPQ WRA model (other symbols). See Appendix A for the complete assessment.

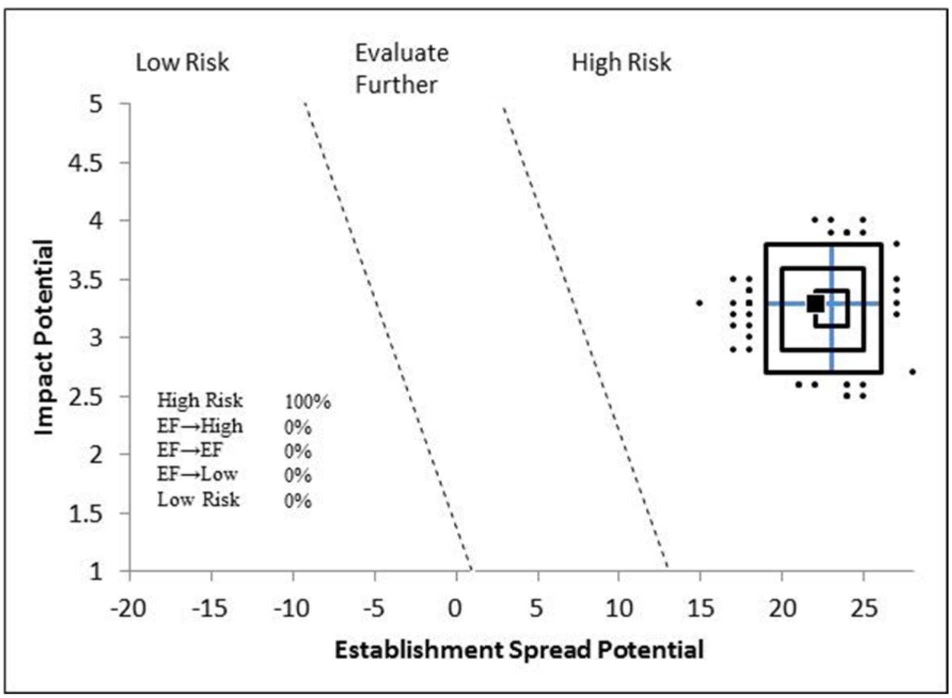

Figure 3. Model simulation results (N=5,000) for uncertainty around the risk score for *Thlaspi arvense*. The blue "+" symbol represents the medians of the simulated outcomes. The smallest box contains 50 percent of the outcomes, the second 95 percent, and the largest 99 percent.

3. Discussion

The result of the weed risk assessment for *Thlaspi arvense* is High Risk (Fig. 2) and is well supported by our uncertainty simulation (Fig. 3). This species tolerates a wide range of environmental conditions. It is an important agricultural weed for multiple crops (e.g., wheat, forage, oilseeds) (Bridges, 1992; Holm et al., 1997; Warwick et al., 2002), and it can harm livestock health and the quality of animal products (Darbyshire, 2003; Stubbendieck et al., 2003; Warwick et al., 2002). *Thlaspi arvense* is usually described as occurring predominantly in or restricted to disturbed habitats (NatureServe, 2014). While it can impact agricultural production systems, we found no evidence of harm in anthropogenic or natural systems.

Other groups have also assessed the risk of this plant. A WRA by the U.S. Forest Service (2014), resulted in a High risk score (= 19, well above the threshold of 6). The U.S. Forest Service model is based on the Australian WRA model (Pheloung et al., 1999) and therefore is similar to our model. On the other hand, the University of Alaska Anchorage's Alaska Natural Heritage Program, using the "Alaska non-native plant invasiveness ranking form," rated *T. arvense* "weakly invasive" (ANHP, 2011; Nawrocki et al., 2010). A NatureServe (2014) assessment rated its overall U.S. Invasive Species Impact Rank as Low/Insignificant because it is often restricted to disturbed areas, but that tool does not evaluate potential impacts to agricultural areas.

Thlaspi arvense is being proposed as a winter biofuel crop (Lie, 2014), and may also have industrial (chemical) uses (e.g., Fan et al., 2013). Furthermore, it is being tested as a rotational/cover crop (Johnson et al., 2015; Phippen and Phippen, 2012; Royo-Esnal et al., 2015). While the weediness of *T. arvense* is firmly established, it is unclear what effect these potentially beneficial uses may have on its prevalence or impacts in other crops.

Although we found no evidence that *T. arvense* has been bred for any particular traits resulting in reduced weed potential, because of its promise as a biofuel plant, it is an "attractive target for rapid domestication," and within the past five years concerted efforts to domesticate this plant have begun (Sedbrook et al., 2014). Those authors proposed that knowledge about other brassicas and "the advent of affordable next generation sequencing... can bring about the rapid domestication and improvement of pennycress." Traits (and possible genes to target) identified as needing domestication include reducing seed dormancy, eliminating glucosinolate in seeds, and reducing pod shatter (Sedbrook et al., 2014). Pod shatter can result in significant harvest loss; 10-15 percent of seeds may be lost during harvest (Sedbrook et al., 2014). Improving all three traits in breeding lines used for biofuel production would decrease the weed risk.

In agricultural settings, despite control efforts, *T. arvense* can interfere with crop production (see above) and persist in crop fields (Hume, 1987, 1988). Also, multiple populations in Canada have developed resistance to ALS inhibitor herbicides (Heap et al., 2014; Warwick et al., 2002). Nevertheless, other authors indicate it can be easily controlled with herbicides such as glyphosate and glufosinate (Sedbrook et al., 2014). Tillage, grubbing, digging, or hand pulling before flowering, as well as the use of various herbicides, are said to give excellent control of *T. arvense* (DiTomaso and Kyser, 2013). In Spain, the weed's near disappearance in some regional cereal fields probably resulted from changes in management practices, such as greater use of conservation tillage and spraying glyphosate before sowing (Cirujeda et al., 2011). Many complex factors (e.g., weather, timing, biotypes, crops, years) may contribute to its interference with crops and ease of control. It is unknown how its production on a large scale may contribute to this complexity; therefore, additional study and monitoring seems appropriate if it is to be grown as a crop.

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Appendix A. Weed risk assessment for *Thlaspi arvense* L. (Brassicaceae). 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 (Status/invasiveness outside its native range)	f - negl	5	*Thlaspi arvense* is native to and widespread in Europe and Asia (mainly temperate areas) and has naturalized in North America (Canada and the United States), Australia, New Zealand, as well as parts of Africa (Algeria, Morocco, the Azores, the Madeira Islands, South Africa, the Canary Islands, Tunisia), and South America (Argentina, Brazil, Chile) (GBIF, 2014; Holm et al., 1991; NGRP, 2014b; Salisbury, 1961). Also, it was recently introduced to Mexico (Vibrans, 2003), but it is unclear if it is considered established there or not. It has "widely spread" in temperate regions of the northern hemisphere (Warwick et al., 2002). Randall (2012), citing numerous sources, lists it as a species escaping cultivation and naturalizing. It was first detected in the United States (in Detroit, Michigan) in 1701 (Royer and Dickinson, 1999), and by 1937 it "was distributed throughout the United States from Maine to Florida and westward to California and Washington" (Best and McIntyre, 1975). It was first detected in Canada in 1860 (Claudi et al., 2002) and then was found in every Canadian province by 1923 (Clark, 1923). In 1940 in Kansas, it was described as one of the weeds "spreading from the north to the south" in the state (Gates, 1940). In the United States, it is "common" ("those species that are widely existing, or prevalent") in crops in multiple states (Bridges, 1992). It is now naturalized in every state in the continental United States (Kartesz, 2013; NRCS, 2014) and is one of the "most widespread invasive plants in North America" (NAISN, 2013). Alternate answers for the Monte Carlo simulation were both "e."
ES-2 (Is the species highly domesticated)	n - low	0	While it has been cultivated in various parts of the world for consumption of its leaves (WSSA, 2014) and is being developed as a potential oilseed biofuel plant (ATI, 2010; Dorn et al., 2013; Moser et al., 2009), we found no evidence that it has been bred for any particular traits resulting in reduced weed potential. Other risk assessors have also found no evidence of domestication that reduces invasive traits (U.S. Forest Service, 2014). "There has been little agronomic improvement in pennycress through traditional breeding" (Dorn et al., 2013). However, because of its promise as a biofuel plant, this plant is considered an "attractive target for rapid domestication," and traits (and possible genes to target) that have been identified as needing domestication include reducing seed dormancy, abolishing seed glucosinolate content, and reducing pod shatter (Sedbrook et al., 2014). We answered no with low uncertainty, because even if domestication has occurred (or will soon occur), it would be highly unlikely to affect the species as a whole.
ES-3 (Weedy congeners)	y - high	1	The genus *Thlaspi* contains six species (eFloras, 2014; Mabberley, 2008). Randall (2012) lists species in the genus as agricultural weeds (e.g., *T. alliaceum, T. perfoliatum*), invasive plants (*T. caerulescens, T. perfoliatum*), quarantine weeds (*T. cepaeifolium, T. microphyllum*), and an environmental weed (*T. perfoliatum*)

Question ID	Answer - Uncertainty	Score	Notes (and references)
			somewhere in the world. In Norway, after escaping cultivation in a botanical garden, *T. caerulescens* rapidly expanded its range and is now present in all provinces and is frequent to common in many areas; however, it is noted as not being aggressive or representing a danger to native populations (Elven and Fremstad, 1996). We found no other evidence to indicate that congeners are causing significant direct or indirect impacts. Based on the use of only one reference (i.e., Randall, 2012), we use high uncertainty.
ES-4 (Shade tolerant at some stage of its life cycle)	n - negl	0	In a study in Sweden, it could not develop under conditions of low light (Holm et al., 1997). It requires "full sun" (Hansen, 2014). It "cannot grow in the shade" (PFAF, 2014). It is "shade intolerant" (Nawrocki, 2010).
ES-5 (Climbing or smothering growth form)	n - low	0	The plant is not a vine. It is an erect, annual herb (Holm et al., 1997; NRCS, 2014). It starts out as a rosette of leaves, but the basal leaves do not persist at maturity, and it then becomes an erect flowering stem (Uva et al., 1997), growing 18 to 80 cm tall (Best and McIntyre, 1975; Holm et al., 1997). Although it can form basal rosettes, we found no evidence in the literature of them being described as flat and tightly appressed with overlapping leaves or as covering or smothering other plants.
ES-6 (Forms dense thickets)	? - max	0	Unknown. One author states that it "does not form dense thickets" (Nawrocki et al., 2010). However, according to Best and McIntyre (1975), this species "may grow as isolated plants, in small patches or in pure stands." Also, in Ireland, it sometimes occurs in "dense stands where obviously self-sown" (Reynolds, 2002). A website about its weed importance in Denmark states that a "dense population" may lead to yield loss in crops (Rydahl, 2014). We found no other evidence of this plant forming dense populations. We answered unknown, as we found conflicting evidence, and the evidence for dense populations is not very strong considering the fact that it is a very common weed.
ES-7 (Aquatic)	n - negl	0	Not an aquatic plant; this plant is a terrestrial herb (eFloras, 2014; Holm et al., 1997; NRCS, 2014; O'Flynn et al., 2014).
ES-8 (Grass)	n - negl	0	This plant is not in the family Poaceae (NGRP, 2014b).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	We found no evidence that *T. arvense* fixes nitrogen. It is not a member of one of the plant families known to fix nitrogen (Martin and Dowd, 1990). Also, it is a non-woody plant (Hansen, 2014).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	Reproduces solely by seed (CABI, 2014; Cowbrough, 2014; Hansen, 2014; Holm et al., 1997).
ES-11 (Self-compatible or apomictic)	y - negl	1	The species is "self-compatible and readily autogamous" (Best and McIntyre, 1975). The flowers have both male and female organs, and the plant is self-fertile (PFAF, 2014). It produces high yields of viable seeds via self-pollination (Holm et al., 1997). This plant is mainly autogamous (Bond et al., 2007).
ES-12 (Requires special pollinators)	n - negl	0	Although mainly autogamous (see ES-11) and not requiring specialized pollinators, there is some cross-pollination by insects (Bond et al., 2007; Holm et al., 1997); outcrossing rates have been estimated to range between 3 to 20 percent (Warwick et al., 2002). Multiple genera and species of Lepidoptera, Hymenoptera, and Diptera are reported to be "occasional visitors" on this plant (Best and McIntyre, 1975; Warwick et al., 2002).
ES-13 (Minimum generation time)	b - high	1	*Thlaspi arvense* is an annual (Kartesz, 2013; NRCS, 2014; Stubbendieck et al., 2003). It can be a winter, spring, or summer

Question ID	Answer - Uncertainty	Score	Notes (and references)
			annual (Sedbrook et al., 2014; Uva et al., 1997). In the United States, it may behave as either a summer or winter annual (Bond et al., 2007). The minimum generative time is one year (U.S. Forest Service, 2014). However, one author states that its short life cycle permits "several generations per year" (Holm et al., 1997). Alternate answers for the Monte Carlo simulation were both "a."
ES-14 (Prolific reproduction)	y - negl	1	*Thlaspi arvense* is a prolific seed producer (Holm et al., 1997). The reported estimates of the number of seeds per plant range from 900 (Hanf, 1983) to 2,000 (Salisbury, 1961), 7,000 (Nawrocki, 2010), 15,000 (Moser et al., 2009), 20,000 (Holm et al., 1997; Salisbury, 1961), and up to 50,000 (AgroAtlas, 2014). In crop production in Canada, its density has been reported to range from 52 to 137 plants per meter square (Warwick et al., 2002). Outside of cultivation, even if two to three plants occurred per square meter and with germination rates of 87 to 99 percent (Best and McIntyre, 1975), it readily meets our threshold of 5,000 viable seeds per square meter for a yes response.
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	Its spread is commonly associated with agricultural operations (Nawrocki et al., 2010). Dispersed locally by grain combines and other machinery, by mud on people's shoes, and by falling from vehicles during transport on farm roads (Holm et al., 1997). It is ranked among weeds that have the greatest seed fall during harvest operations (Holm et al., 1997).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	It is a potential seed contaminant (CABI, 2014; Nawrocki, 2010; NGRP, 2014b). It spreads as a seed contaminant in cereal and flax seed stocks, and in India it is one of the common weed seeds found in wheat for sale (Holm et al., 1997). In Ireland, it was probably reintroduced with grain or animal seed; it has been found there in birdseed and in assemblages of exotic plants introduced with animal feed (Reynolds, 2002). The seeds can ripen before harvest, shatter, and subsequently infest crop seeds (AgroAtlas, 2014). In St. Louis, Missouri, it frequently forms colonies of different sizes on the margins of railroads as well as on the tracks (Mühlenbach, 1979).
ES-17 (Number of natural dispersal vectors)	5	4	Information relevant for ES-17a through ES-17e: The fruit (or seed pods) are flattened and oval to heart-shaped (Nawrocki, 2010) with a broad flat wing (Cowbrough, 2014), measuring 1-2 cm long and 7-20 mm wide (Nawrocki, 2010). The seed-containing section is split into two compartments by a narrow membranous partition, each side containing 3 to 8 seeds; this membranous partition often remains on the plant after the pod breaks apart to release the seeds (Cowbrough, 2014). The seeds are flattened, ovoid, 1-2 mm in length, approximately two-thirds the length in width, reddish-brown to purplish or blackish, and with several rows of concentric ridges on each side (Cowbrough, 2014; Salisbury, 1961).
ES-17a (Wind dispersal)	y - mod		Based on the available evidence, it is unclear to what extent wind contributes to seed dispersal, in particular to long distance spread. Some authors report that the seeds are disseminated via the wind (e.g., Kaul, 1986). The seedpods become detached from the plant and “blow about in the wind” (Hilty, 2014). Whereas some authors indicate that dispersal is mainly by wind (Best and McIntyre, 1975; WSSA, 2014), others suggest that wind disperses the seed only moderate distances (e.g., 1 km) (CABI, 2014; NatureServe, 2014). "Wind occasionally disperses seeds over long distances"; "[t]he wide

Question ID	Answer - Uncertainty	Score	Notes (and references)
			distribution of field pennycress appears to result more from it being a contaminant in crop seed than from dispersal by wind" (Nawrocki, 2010). Its seed pods have broad wings (Cowbrough, 2014; eFloras, 2014), which may assist with wind dispersal, and there are multiple references to its seed being dispersed by wind (e.g., Hilty, 2014; Kaul, 1986; Best and McIntyre, 1975; WSSA, 2014). However, Cowbrough (2014) states that the membranous partition of the pod often remains on the plant, suggesting that the seeds may often not be dispersed by wind. Given the number of references indicating that wind dispersal is involved, we answered yes; however, we used moderate uncertainty.
ES-17b (Water dispersal)	y - low		Seeds disperse with water greater distances than that with wind (DiTomaso and Healy, 2007). Its seeds are distributed by spring floods (WSSA, 2014). In Canada in 1923, one author observed that it is difficult to control "on account of the distribution of its seeds by spring floods" (Clark, 1923). "The seed has a high specific gravity and in water it sinks upon agitation, but Hope (1927) in Alberta, Canada found significant amounts of the seed moving with the flow in mains and laterals of irrigation systems" (cited in Holm et al., 1997). One study found that ninety percent of seeds floated on still water for 24 hours (cited in Best and McIntyre, 1975).
ES-17c (Bird dispersal)	y - mod		It can disperse locally by "mud on the feet of…birds…" (Holm et al., 1997). Viable seeds have been found in the excreta of pigeons and other birds (Salisbury, 1961). Seeds can be spread by sticking to feathers (cited in Nawrocki, 2010). Mourning doves will occasionally eat the seeds of weedy species in the mustard family (Hilty, 2014). Based on the evidence, it is unclear how often this type of dispersal may occur; therefore, we used moderate uncertainty.
ES-17d (Animal external dispersal)	y - mod		Can disperse locally by "mud on the feet of…animals" (Holm et al., 1997). Over short distances the seed may be spread by being in the soil on the feet or fur of animals (CABI, 2014).
ES-17e (Animal internal dispersal)	y - low		Can disperse locally by animal dung as it is spread in fields (Holm et al., 1997). Seeds of it have been obtained from droppings of cattle and horses (Salisbury, 1961), and they can remain viable after passage through the digestive system of animals (Holm et al., 1997; AgroAtlas, 2014). In one study, up to 98 percent of seeds were able to germinate following rumen digestion (cited in Bond et al., 2007). On a dairy farm in New York, "apparently-viable" seeds of *T. arvense* were found in samples of cow manure, averaging 3,700 seeds per 1,000 kg of manure (Pleasant and Schlather, 1994). On the other hand, because of its bitter-garlic flavor, *T. arvense* is not a preferred food source for mammalian herbivores (Hilty, 2014).
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - negl	1	*Thlaspi arvense* has a persistent seed bank (Warwick et al., 2002). Most of the seed germinate within nine years (Nawrocki, 2010), but they can remain dormant up to 20 or more years (Nawrocki, 2010; Warwick et al., 2002; references cited in CABI, 2014). In a seed viability study, after three years of dormancy, 62 percent of the seeds were still viable, whereas after 30 years, 11 percent were still viable (Salisbury, 1961). After 10 years in the soil, seed can still have 87 percent viability (Bond et al., 2007).
ES-19 (Tolerates/benefits from mutilation, cultivation or	n - low	-1	We found no evidence that the plant tolerates or benefits from mutilation, cultivation, or fire, despite this being a common and widespread economically important agricultural weed. It does not

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
fire)			resprout after removal of aboveground portions (Nawrocki et al., 2010), and "[t]here is no evidence of vegetative reproduction" (Warwick et al., 2002). Recommended measures for "excellent control" of this weed include tillage, digging, or hand pulling before flowering (DiTomaso and Kyser, 2013).
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	y - negl	1	*Thlaspi arvense* is listed in Heap et al. (2014). "A resistant biotype to Group 2 herbicides, which inhibit acetolactate synthase (ALS), has been found at two to five sites in Alberta in 2001" (Warwick et al., 2002).
ES-21 (Number of cold hardiness zones suitable for its survival)	10	1	
ES-22 (Number of climate types suitable for its survival)	9	2	
ES-23 (Number of precipitation bands suitable for its survival)	11	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - high	0.1	In a study on allelopathic effects of seeds, some authors in Romania found that *T. arvense* seeds stimulated the germination and early growth of seeds of certain cultivated crops (e.g., rye, clover), but inhibited the germination of wheat seeds; these authors suggested that the active compounds are released in exudates from the newly-formed roots (Holm et al., 1997). *Thlaspi arvense* contains the glucosinolate sinigrin, which can be hydrolyzed to form compounds that may be involved in allelopathy (Vaughn et al., 2005). Defatted *T. arvense* seedmeal "completely inhibited seedling germination/emergence" of wheat and arugula in a laboratory study, and significantly reduced the dry weight of bioassay plants in field studies (Vaughn et al., 2005). Holm et al. (1997) is not an original source reference, and we were unable to verify the source they cited, and the Vaughn et al. (2005) report was of processed seedmeal, not of naturally occurring plants or seeds. Also, given this species is extremely common as an agricultural weed, we would expect there would be more reports if the species were strongly allelopathic. Given these factors, we answered yes but with high uncertainty.
Imp-G2 (Parasitic)	n - negl	0	We found no evidence this species is parasitic. Furthermore, *Thlaspi arvense* does not belong to a family known to contain parasitic plants (Heide-Jorgensen, 2008; NGRP, 2014b; Nickrent, 2009).
Impacts to Natural Systems			
Imp-N1 (Change ecosystem processes and parameters that affect other species)	n - low	0	We found no evidence of this type of impact. "No evidence of negative impact to natural systems" (U.S. Forest Service, 2014). “Field pennycress is not likely to have ecological impacts in undisturbed areas”; it requires sparsely vegetated soil in disturbed areas or cultivated lands in order to germinate (Nawrocki, 2010). It is widely described as occurring predominantly in or restricted to disturbed habitats (NatureServe, 2014). For instance, in Finland, it is not found growing in the wild (NatureGate, 2014), and in Ireland it is considered established mainly in artificial habitats (e.g., roadsides, disturbed ground, landfill sites, cultivated and formerly cultivated ground) (Reynolds, 2002). NatureServe (2014) ranked its ecological

Question ID	Answer - Uncertainty	Score	Notes (and references)
			impact as "low/insignificant", and its overall U.S. Invasive Species Impact Rank (I-Rank) as Low/Insignificant based on it being predominantly found in or restricted to disturbed areas. Although listed as a weed of natural areas by a few sources (see Imp-N6), these sources provide no information on the types or extent of impacts in natural areas. Based on this evidence (plus additional evidence below in this subelement) and because we found no evidence of impacts in natural areas, we used low uncertainty for this question and the others in this subelement.
Imp-N2 (Change community structure)	n - low	0	We found no evidence of this type of impact.
Imp-N3 (Change community composition)	n - low	0	We found no evidence of this type of impact. In Canada's Riding Mountain National Park, *T. arvense* was found only in ruderal (i.e., waste ground) habitats (not natural habitats), was considered to have a low risk of proliferation, and in the absence of soil disturbance was considered to "not threaten native biodiversity" (Otfinowski et al., 2007). It is a poor competitor with grass species such as *Agropyron cristatum, A. trachycaulum*, and *Bromus inermis* (Best and McIntyre, 1975), and when it colonizes abandoned prairie environments, it appears to have insignificant effects on the normal pattern of succession (NatureServe, 2014).
Imp-N4 (Is it likely to affect federal Threatened and Endangered species)	n - low	0	We found no evidence. This plant occurs predominantly in or restricted to disturbed habitats, and we found no evidence of negative impacts in natural areas (see Imp-N1, N2, and N3).
Imp-N5 (Is it likely to affect any globally outstanding ecoregions)	n - low	0	We found no evidence. This plant occurs predominantly in or restricted to disturbed habitats, and we found no evidence of negative impacts in natural areas (see Imp-N1, N2, and N3).
Imp-N6 (Weed status in natural systems)	b - mod	0.2	Listed as "a weed of the natural environment" in Australia (Randall, 2007) and "invasive in natural areas in the U.S." (Swearingen, 2014). In Australia, it is also listed as an "environmental weed" with a score of 2 for natural ecosystems (2 = "Naturalised and known to be a minor problem warranting control at 3 or fewer locations within a State or Territory") (Groves et al., 2005), but this reference does not give any more information on control efforts in natural systems, nor does it cite any sources that we could verify. It is a Declared Noxious Weed and is prohibited from sale in Western Australia, Australia (Groves et al., 2005); however, this source does not indicate if the plant is being regulated because of impacts in natural systems. Alternate answers for the Monte Carlo simulation were "a" and "c."
Impact to Anthropogenic Systems (cities, suburbs, roadways)			
Imp-A1 (Impacts human property, processes, civilization, or safety)	n - low	0	No evidence of this type of impact.
Imp-A2 (Changes or limits recreational use of an area)	n - high	0	It can have a "strong, fetid, onionlike odor" (Callihan et al., 2000). When bruised the leaves release an unpleasant odor, which is responsible for the common name stinkweed used in Canada (Salisbury, 1961). We found no direct evidence for this type of impact; however, because it can produce an unpleasant odor, we answered no with high uncertainty.
Imp-A3 (Outcompetes, replaces, or otherwise affects desirable plants and vegetation)	? - max		We found no direct evidence for this impact. However, considering that this plant occurs in gardens (Lorenzi and Jeffery, 1987; Warwick et al., 2002) and is reported to be a serious weed of gardens (Royer and Dickinson, 1999), that control measures for this weed are

Question ID	**Answer - Uncertainty**	**Score**	**Notes (and references)**
			indicated for "home gardens" (Lorenzi and Jeffery, 1987), and that this plant can have important impacts on crop plants (see Imp-P1), it seems likely that *T. arvense* may have some negative impacts on desirable plants and vegetation in home gardens.
Imp-A4 (Weed status in anthropogenic systems)	c - high	0.4	It is a serious weed of gardens and waste areas (Royer and Dickinson, 1999). The use of 2,4-D, paraquat, or a soil sterilant are recommended control options for this weed occurring in fence rows, waste areas, and industrial sites (Lorenzi and Jeffery, 1987). Control measures for *T. arvense* are indicated for "home gardens" (Lorenzi and Jeffery, 1987). This evidence suggests that people may be controlling this weed in these environments. Based on the use of indirect evidence, we used high uncertainty. 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)	y - negl	0.4	It can cause serious yield losses of field crops, especially in Canadian prairies (Warwick et al., 2002). In Canada, studies have shown that a light infestation can reduce wheat yields by 35 percent and a heavy infestation by 50 percent (Holm et al., 1997). In 1986-1989 studies in Canada, in combination with other weeds, it reduced winter wheat yield by 18-32 percent and safflower yield by up to 73 percent (Warwick et al., 2002). In the United States, it causes crop losses and is listed as "troublesome" (which are "species which despite weed control efforts are inadequately controlled and interfere with crop production and/or yield, crop quality, or harvest efficiency) in oats, wheat, and rye (Bridges, 1992).
Imp-P2 (Lowers commodity value)	y - negl	0.2	Seeds contaminating livestock feed can cause the animals to reject the feed (Westmoreland, 1983). When cattle do consume the seeds or leaves, it causes their milk and meat to develop an off-flavor (Cowbrough, 2014; Hilty, 2014; Holm et al., 1997; Warwick et al., 2002). Grain contaminated with *T. arvense* seed can lead to ruined wheat flour and very sharply reduced price of the grain (WSSA, 2014). Contaminated canola can lead to lowered quality through increased erucic acid levels in the extracted oil and glucosinolate content in the meal (Warwick et al., 2002).
Imp-P3 (Is it likely to impact trade)	y - low	0.2	It is an A1 quarantine pest for Mexico (EPPO, 2013), a declared noxious-weed seed in multiple U.S. states (NGRP, 2014a), a "secondary noxious" plant in the Weed Seeds Order by Agriculture Canada (which limits the number of seeds permitted in commercial seed lots) (Warwick et al., 2002), and a Declared Noxious Weed prohibited from sale in Western Australia, Australia (Groves et al., 2005). Based on this evidence, plus the fact that it can be dispersed in trade as a contaminant (see ES-16), we answered yes.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	y - mod	0.1	*Thlaspi arvense* has an extensive root system that surrounds those of nearby plants, thereby competing for the uptake of water (Holm et al., 1997). In the Prairie Provinces of Canada, "it competes with crops for limited moisture supply, causing significant reductions in yield" (Best and McIntyre, 1975). It "competes keenly with crops for moisture" (WSSA, 2014).
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	y - negl	0.1	It is poisonous to livestock (Darbyshire, 2003; Stubbendieck et al., 2003). While the leaves are usually not toxic to animals, the seeds are rich in oil glucosides and when ground with feed can result in break-down products that are toxic to livestock (Holm et al., 1997). When contaminating hay or other fodder, its seeds or leaves can be toxic to

Question ID	Answer - Uncertainty	Score	Notes (and references)
			animals (Warwick et al., 2002). Acute poisoning in cattle can lead to abortion, colic, peeling skin, massive submucosal edema of the walls of forestomachs, and death (Warwick et al., 2002). Livestock feeding on large amounts of ground seeds may develop “chronic enteritis, haemorrhagic diarrheoa, colic, abortion, nephritis and haematuria, apathy and paralysis of heart and respiration” (Best and McIntyre, 1975). The "contamination of hay and forage grain feed and associated toxic effects...has remained a serious problem, particularly for farmers in western Canada" (Warwick et al., 2002).
Imp-P6 (Weed status in production systems)	c - negl	0.6	There is evidence it has been a weed of agriculture for several thousand years, and today is a problem in 30 crops in 45 countries (Holm et al., 1997). It is a weed of nursery crops, horticultural, and agricultural crops (Uva et al., 1997). A “serious weed” of barley, oats, rape, sunflowers, and wheat in Canada; of barley and wheat in Korea; and of pastures and winter wheat in the United States (Holm et al., 1997). A "principal weed" of other crops (e.g., asparagus, beets, beans, onions, peas, root crops, cereals, horticultural crops, lucerne, maize, potatoes, oil seed rape) (Holm et al., 1997). An "important weed” of grain, oilseed, and forage crops in Canada, especially in the prairies (Warwick et al., 2002). There have been "continuous control efforts" against this weed (Holm et al., 1997). Control measures used against and recommended for this weed include grubbing, digging, and hand pulling before flowering, as well as chemical control (e.g., 2,4-D, glyphosate) (Clark, 1923; DiTomaso and Kyser, 2013; Sedbrook et al., 2014; Warwick et al., 2002). Alternate answers for the Monte Carlo simulation were both "b."
GEOGRAPHIC POTENTIAL			Unless otherwise indicated, the following evidence represents geographically referenced points obtained from the Global Biodiversity Information Facility (GBIF, 2014).
Plant hardiness zones			
Geo-Z1 (Zone 1)	y - low	N/A	Canada and the United States (AK).
Geo-Z2 (Zone 2)	y - negl	N/A	Canada and the United States (AK).
Geo-Z3 (Zone 3)	y - negl	N/A	Canada, Finland, and the United States (CO). A few points in India.
Geo-Z4 (Zone 4)	y - negl	N/A	Finland, India, Norway, and the United States (CO).
Geo-Z5 (Zone 5)	y - negl	N/A	Norway and Sweden. Also the United States (SD) (NRCS, 2014).
Geo-Z6 (Zone 6)	y - negl	N/A	Norway and Sweden. Also the United States (KS).
Geo-Z7 (Zone 7)	y - negl	N/A	Austria, Germany, Spain, and the United States (OR).
Geo-Z8 (Zone 8)	y - negl	N/A	Belgium, France, and Spain. Also the United States (NC) (NRCS, 2014).
Geo-Z9 (Zone 9)	y - negl	N/A	Spain, the Netherlands, and the United Kingdom. Also the United States (FL) (NRCS, 2014).
Geo-Z10 (Zone 10)	y - low	N/A	The United Kingdom and the United States (AZ, CA). A few points in Pakistan. Also in the United States (FL) (NRCS, 2014).
Geo-Z11 (Zone 11)	n - high	N/A	There was one point in Honduras and one in Guatemala, but these are likely spurious or misidentifications.
Geo-Z12 (Zone 12)	n - high	N/A	We found no evidence that this species occurs in this zone. The two points from Zone 11 were near the edge of this zone.
Geo-Z13 (Zone 13)	n - high	N/A	We found no evidence that this species occurs in this zone.
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	n - high	N/A	Reported to occur in the United States in West Palm Beach, Florida (NRCS, 2014), but this county includes both tropical rainforest and humid tropical. Because we found no other evidence it occurs in

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			tropical rainforests we answered no.
Geo-C2 (Tropical savanna)	n - high	N/A	One point in Honduras, but this is likely spurious or a misidentification.
Geo-C3 (Steppe)	y - negl	N/A	Afghanistan and Spain. It often occurs in forest-steppe zones (AgroAtlas, 2014).
Geo-C4 (Desert)	y - mod	N/A	A few points in Afghanistan. *Thlaspi arvense* occurs in semi-desert zones more rarely than some other zones (AgroAtlas, 2014).
Geo-C5 (Mediterranean)	y - low	N/A	Australia, Portugal, and Spain.
Geo-C6 (Humid subtropical)	y - negl	N/A	A few points in India, Nepal, and Pakistan. Also in the United States (FL, GA, NC) (NRCS, 2014).
Geo-C7 (Marine west coast)	y - negl	N/A	France, Germany, and the United Kingdom.
Geo-C8 (Humid cont. warm sum.)	y - negl	N/A	The United States (KS, MO).
Geo-C9 (Humid cont. cool sum.)	y - negl	N/A	Canada, China, Germany, Norway, and Sweden.
Geo-C10 (Subarctic)	y - negl	N/A	Canada, China, Finland, Norway, and Sweden. It has been found in arctic Norway and Svalbard, at approximately 78°N (Nawrocki et al., 2010).
Geo-C11 (Tundra)	y - negl	N/A	Norway, and a few points in Austria, Iceland, and Switzerland.
Geo-C12 (Icecap)	n - low	N/A	We found no evidence.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - high	N/A	A few points in Afghanistan, and a few in the United States either inside this band or right on the edge.
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	Afghanistan, Spain, India, and the United States.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Germany, Spain, and Sweden.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Belgium, France, Germany, and the United Kingdom.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	France, Ireland, and the United Kingdom.
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	Germany, Ireland, and the United Kingdom.
Geo-R7 (60-70 inches; 152-178 cm)	y - negl	N/A	Ireland, Norway, and the United Kingdom.
Geo-R8 (70-80 inches; 178-203 cm)	y - negl	N/A	Germany, Norway, and a few points in the United Kingdom.
Geo-R9 (80-90 inches; 203-229 cm)	y - negl	N/A	Norway and two points in the United Kingdom.
Geo-R10 (90-100 inches; 229-254 cm)	y - mod	N/A	Canada, Norway, and one point on the edge in the United Kingdom.
Geo-R11 (100+ inches; 254+ cm)	y - high	N/A	A few points in Norway, two points in Canada, and one point in the United States.
ENTRY POTENTIAL			
Ent-1 (Plant already here)	y - negl	1	*Thlaspi arvense* was first detected in the United States (in Detroit, Michigan) in 1701 (Royer and Dickinson, 1999), and since that time it has become naturalized in every state in the continental United States (Kartesz, 2013; NRCS, 2014). It is listed as one of the "most widespread invasive plants in North America" (NAISN, 2013).
Ent-2 (Plant proposed for entry, or entry is	-	N/A	

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imminent)			
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	