United States Department of Agriculture

United States Department of Agriculture

Animal and Plant Health Inspection Service

February 14, 2020

Version 3

Weed Risk Assessment for *Amaranthus palmeri* (Amaranthaceae) – Palmer's amaranth

Left: A mature *Amaranthus palmeri* plant (source: *Ross* Recker, University of Wisconsin-Madison, Bugwood.org). Top right: A young *A. palmeri* plant (source: Bruce Ackley, The Ohio State University, Bugwood.org). Bottom right: Infestation of *A. palmeri* in corn (Chahal, 2018).

AGENCY CONTACT

Plant Epidemiology and Risk Analysis Laboratory
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 2760

Executive Summary

The result of the weed risk assessment for *Amaranthus palmeri* is High Risk for the United States. It is an annual C_4 herb and a weed of agricultural systems. Although it is native to the southwestern United States, it is invasive in the eastern part of the country and is present outside its native range in 19 states. *Amaranthus palmeri* is not regulated as a Federal Noxious Weed, but is regulated as a noxious weed in Delaware, Iowa, Minnesota, North Dakota, Ohio, and Pennsylvania. It produces abundant tiny seeds that are easily dispersed. Collectively, populations across its global range, have developed resistance to eight different herbicidal modes of action, with some populations being reported as resistant to two or more of these modes of action. This weed has caused yield losses ranging from 6 to 94 percent in corn, cotton, peanut, sorghum, soybean, and sweet potato, though it can also have allelopathic effects on subsequent crops. Further spread of this species in the United States may impact trade because it is regulated in Australia and Brazil. About 81 percent of the United States is suitable for it to establish. It is most likely to spread to new areas as a contaminant of seed or hay, as a hitchhiker on vehicles or equipment, and through natural dispersal by water or wildlife.

1. Plant Information and Background

SPECIES: *Amaranthus palmeri* S. Watson (Amaranthaceae) (NGRP, 2019)

SYNONYMS: None listed (NGRP, 2019)

COMMON NAMES: Carelessweed, dioecious amaranth, Palmer amaranth, Palmer's amaranth, Palmer's pigweed (Brouillet et al., 2010; Matzrafi et al., 2017; NGRP, 2019; NRCS, 2019).

BOTANICAL DESCRIPTION: *Amaranthus palmeri* is an annual C_4 plant that usually grows 0.5 to 1.5 m tall and occasionally to as much as 3 m (Ward et al., 2013; eFloras, 2019). It is native to the Sonoran desert, where it typically grows near water (Sauer, 1955; Bryson and DeFelice, 2010), but it is also common in disturbed habitats (Sauer, 1955; DiTomaso and Healy, 2007).

INITIATION: This WRA was initiated by the Canadian Food Inspection Agency (CFIA) due to the identification of a pest that may require phytosanitary measures. *Amaranthus palmeri* has been found in a few small areas of southern Ontario and is a major weed in the United States, where it has developed herbicide-resistant biotypes and is spreading in the northeastern states. APHIS-PPQ reviewed the CFIA WRA and placed it into PPQ's format due to interest in this weed's impacts in the United States.

WRA AREA[1]: United States and Territories.

FOREIGN DISTRIBUTION: *Amaranthus palmeri* is native to North America, from the southwestern to south-central United States, and then south through much of Mexico to Oaxaca and Veracruz (NGRP, 2019). Outside of North America, it has naturalized in Australia, Cyprus, India (Maharashtra), Portugal (Madeira Islands), Spain, Sweden (NGRP, 2019), and Romania (Anastasiu et al., 2011). It may also be naturalized in Canada (Ontario) (eFloras, 2019). It has been reported from many other countries, including Argentina, Austria, Belarus, Belgium, Brazil, China, Cuba, Czech Republic, Denmark, Egypt, France, Germany, Greece, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Russia (European part), South Korea, Tunisia, Turkey, Ukraine, and the United Kingdom (EPPO, 2014; Randall, 2017; Kistner and Hatfield, 2018). In many of these countries, however, it is present as a casual alien and may not be fully established. This species is not known to be cultivated (Sauer, 1955; Bailey and Bailey, 1976; IPK Gatersleben, 2019; University of Minnesota, 2019; NGRP, 2019).

U.S. DISTRIBUTION AND STATUS: *Amaranthus palmeri* is native to the southwestern United States and is expanding its range as an invasive plant in the eastern states (eFloras, 2019). It is present in at least 27 states (NRCS, 2017b), including North Dakota, Minnesota, Wisconsin, New York, and Massachusetts (EDDMapS, 2019; eFloras, 2019; Peters et al., 2018; SEINet, 2019; Stockford, 2018). *Amaranthus palmeri* is not regulated as a Federal Noxious Weed (USDA, 2010); however, it is

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

prohibited from agricultural and commercial seed in Ohio, Minnesota, Iowa, Washington, and Wisconsin (AMS, 2018) and is regulated as a noxious weed in Delaware, Iowa, Minnesota, and North Dakota, Ohio, and Pennsylvania (NPB, 2020). Control requires additional effort and expense (Swearingen and Bargeron, 2016), using a variety of cultural and chemical methods (NDSU 2014; Schonbeck 2014; Chahal et al., 2015; VanGessel and Johnson, 2015; USDA-NRCS 2017b)

2. Analysis

ESTABLISHMENT/SPREAD POTENTIAL

Amaranthus palmeri is an annual herbaceous plant that is spreading rapidly beyond its native range in North America as a result of human-mediated seed dispersal and the creation of new habitats through agricultural expansion (Ward et al., 2013). It is wind-pollinated, and a single female plant can produce 80,000 to 600,000 seeds, depending on time of emergence and degree of interspecific competition (Ward et al., 2013; Berger et al., 2016). The seeds remain viable for one to four years (Jha et al., 2008) and are easily dispersed as contaminants of seed, grain, hay, and feed, as well as through agricultural practices and the movement of vehicles and equipment (Legleiter and Johnson, 2013; Ward et al., 2013; Barber et al., 2015; NRCS, 2017a). The seeds may also be dispersed by water, as they are light and can float (NDSU, 2015), and by animals, as they remain viable after passage through the digestive tract (DeVlaming and Proctor, 1968; Costea et al., 2004; NDSU, 2014; NDSU, 2015; Farmer et al., 2017). *Amaranthus palmeri* became resistant to trifluralin in South Carolina in 1989, and since then, some populations have become resistant to one or more modes of action (MOAs) (Ward et al., 2013; Heap, 2019). Across its global range, it has demonstrated resistance to ALS-inhibiting herbicides, dinitroanilines, triazines, glyphosate, and HPPD inhibitors (Ward et al., 2013). Also, *A. palmeri* is somewhat resistant to mowing and cutting as it can regrow and produce viable seed (Sosnoskie et al., 2014). We had low uncertainty for this risk element because the species is well known, and published information is abundant.

Risk score = 28.0 Uncertainty index = 0.07

IMPACT POTENTIAL

Amaranthus palmeri is primarily a weed of production systems and has been described as "one of the most widespread, troublesome, and economically damaging agronomic weeds in the southeastern U.S." (Ward et al., 2013). Studies reviewed by Ward et al. (2013) reported 6 to 94 percent yield losses in corn, cotton, peanut, sorghum, soybean, and sweet potato; the weed also reduces quality in sweet potato (Meyers et al., 2010). Stands of *A. palmeri* incorporated into the soil can have allelopathic effects on subsequent crops such as sorghum, carrot, cabbage, and onion (EPPO, 2014). It may also impact trade, as it is regulated in Australia (Moniodis, 2014; BICON, 2019) and Brazil (WTO, 2018). To a lesser extent, *A. palmeri* is a weed of anthropogenic systems, as it occurs in gardens, landscaped areas, roadsides, waste places, and other disturbed areas (DiTomaso and Healy, 2007), but we found no evidence of targeted control in anthropogenic systems. Its appearance along roadsides is recent and is believed to be due to spread from heavily infested production fields (Bagavathiannan and Norsworthy, 2016). *Amaranthus palmeri* is not reported as an invader of natural areas. When it was found as a contaminant of native seed mixes used in conservation plantings in Illinois, Indiana, Iowa, Minnesota, and Ohio, the main concern was that it would move from the conservation plantings into crop fields (NRCS, 2017a; Haines et al., n.d.). It is not considered likely to persist in established perennial plant communities (NRCS, 2017b). We had low uncertainty for this risk element because the species is well known, and published information is abundant.

Risk score = 2.8 Uncertainty index = 0.07

GEOGRAPHIC POTENTIAL

Based on three climatic variables, we estimate that about 81 percent of the United States is suitable for the establishment of *A. palmeri* (Fig. 1). This predicted distribution is based on its known distribution elsewhere in the world, using evidence from both point-referenced localities and general areas of occurrence. The map for *A. palmeri* represents the joint distribution of Plant Hardiness Zones 4-13, areas with 0 to 80 inches of annual precipitation, and the following Köppen-Geiger climate classes: tropical savanna, steppe, desert, Mediterranean, humid subtropical, marine west coast, humid continental warm summers, and humid continental cool summers.

The area of the United States shown to be climatically suitable (Fig. 1) for species establishment considered 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. *Amaranthus palmeri* is native to the Sonoran desert, where it is usually found near permanent or intermittent sources of water, including river valleys and floodplains, streambanks, and marsh edges (Sauer, 1955; Bryson and DeFelice, 2010; eFloras, 2019). It is more common, however, in disturbed habitats and grows as a weed in crop fields, pastures, orchards, vineyards, gardens, landscaped areas, and waste places, and along irrigation ditches, roadsides, and railroads (Sauer, 1955; DiTomaso and Healy, 2007). It can infest row crops, including corn, cotton, peanut, sorghum, soybean, and sweet potato (Ward et al., 2013; Schonbeck, 2014). Populations are typically found at elevations of 300 to 3,000 ft (eFloras, 2019).

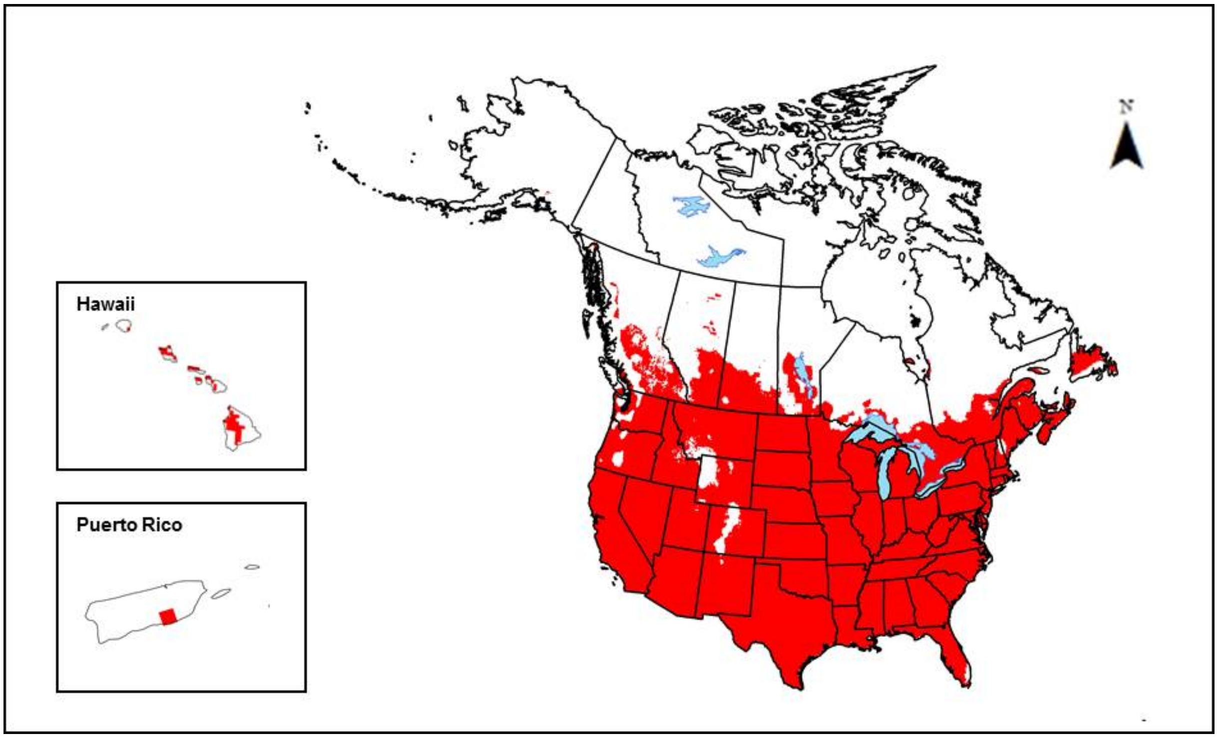

Figure 1. Potential geographic distribution of *Ameranthus palmeri* in the United States and Canada. Map insets for Hawaii and Puerto Rico are not to scale. For additional information on the PPQ climate-matching process, see Magarey et al. (2017).

ENTRY POTENTIAL

Although *A. palmeri* is native to the southwestern United States, we evaluated this risk element to determine how it may spread to other regions. *Amaranthus palmeri* could enter new areas of the United States as a contaminant of seed, grain, hay, or feed or in association with soil, vehicles, or farm equipment (DiTomaso and Healy, 2007; Legleiter and Johnson, 2013; NRCS, 2017a). Less likely pathways of introduction include wool waste (Haines et al., n.d.) and ballast (Rhoads and Block, 2007).The seeds are readily dispersed in water and by animals (NDSU, 2014; NDSU, 2015; NRCS, 2017a). They can also be dispersed short distances by wind (DiTomaso and Healy, 2007), but they have no specific adaptations for wind dispersal.

Risk score = 0.38 Uncertainty index = 0.07

3. Predictive Risk Model Results

Model Probabilities: P(Major Invader) = 98.4%
P(Minor Invader) = 1.5%
P(Non-Invader) = 0.1%
Risk Result = High Risk
Risk Result after Secondary Screening = N/A

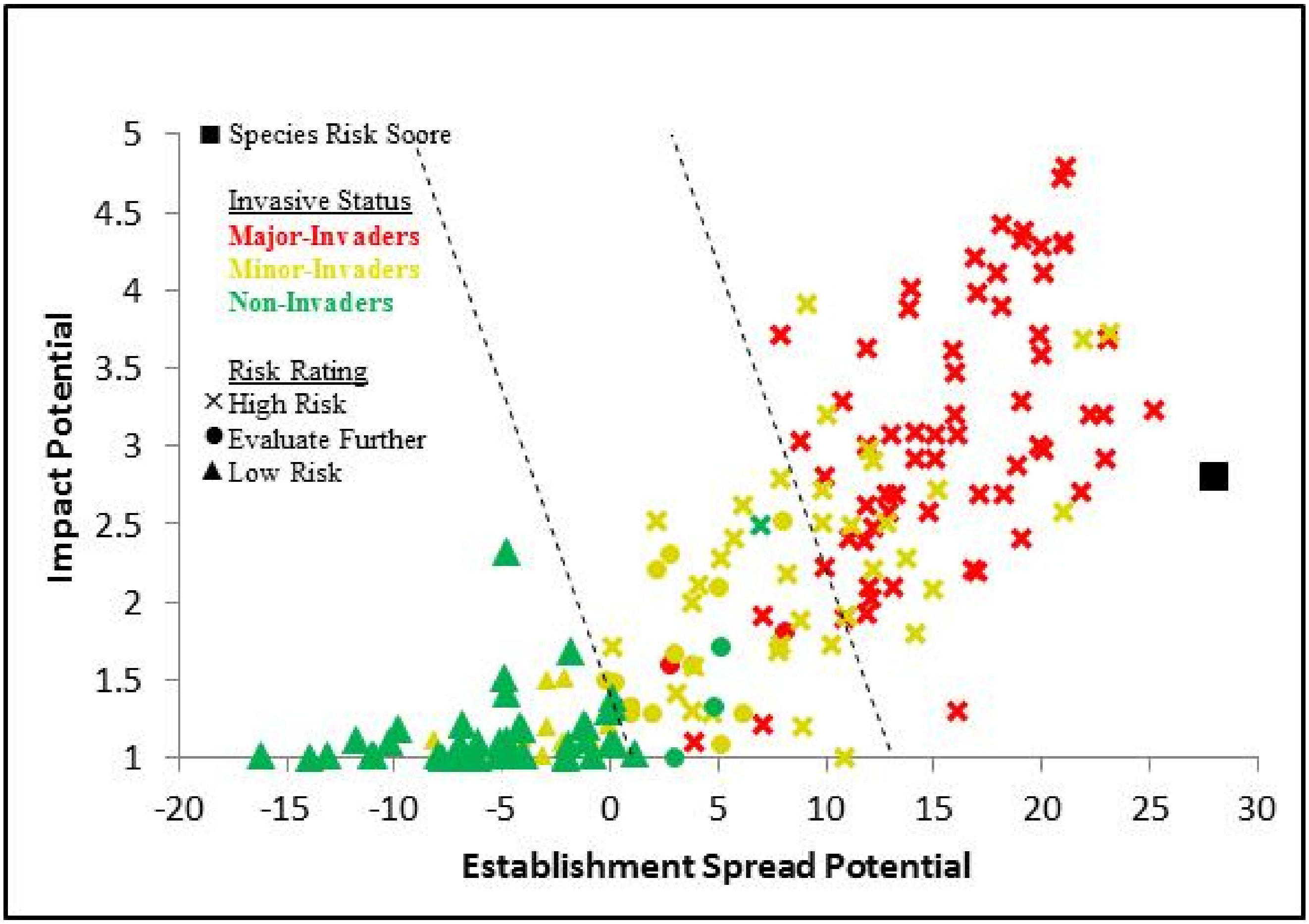

Figure 2. Risk score for *Amaranthus palmeri*. The species risk score (solid black symbol) is plotted relative to the risk scores of the species used to develop and validate the PPQ WRA model (Koop et al., 2012).

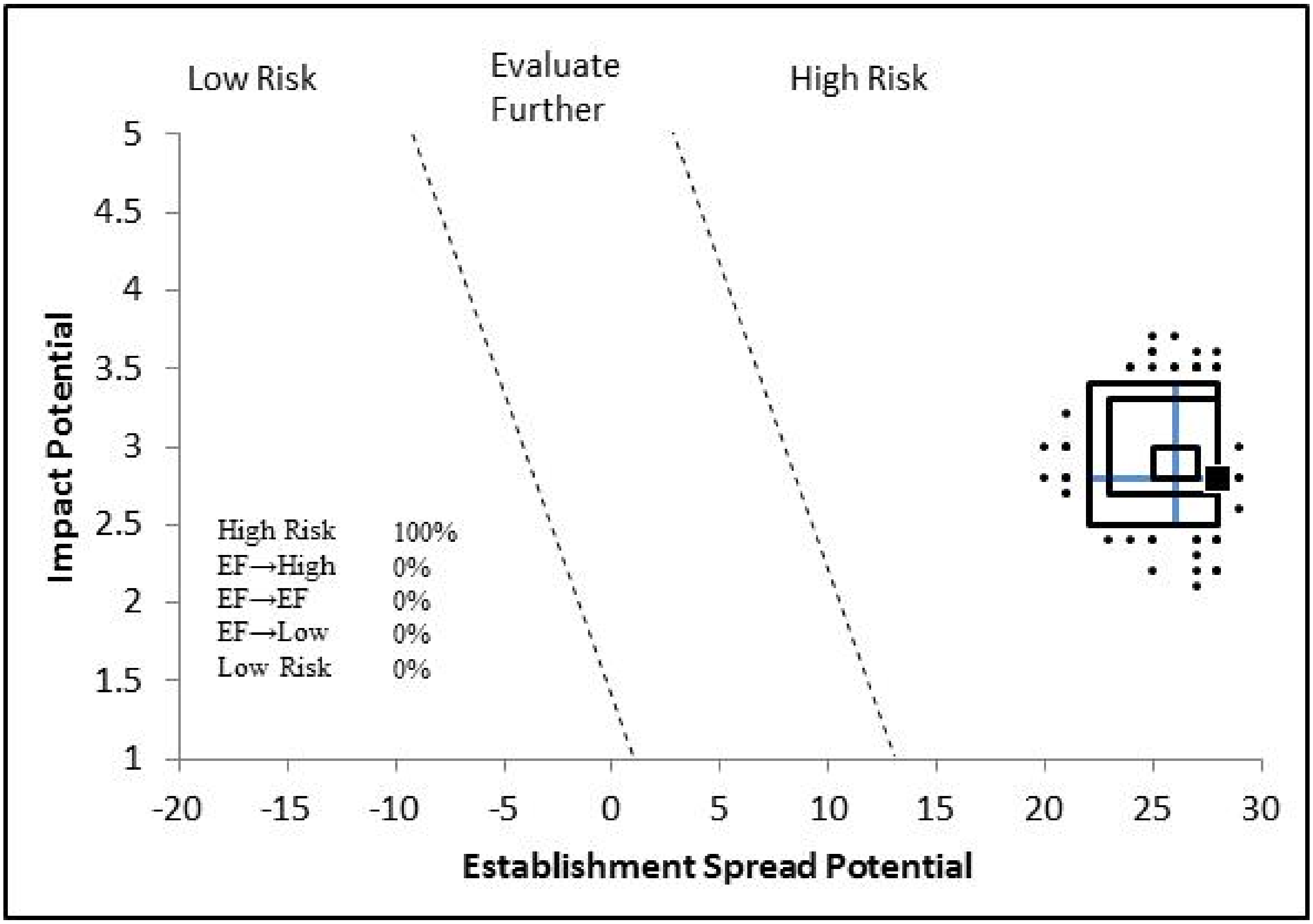

Figure 3. Uncertainty results for *Amaranthus palmeri.* The results from the uncertainty analysis are plotted around the risk score. The smallest black box contains 50 percent of the simulated risk scores, the second 95 percent, and the largest 99 percent. The black vertical and horizontal lines in the middle of the boxes represent the medians of the simulated risk scores (N=5000). For additional information on the uncertainty analysis used, see Caton et al. (2018).

4. Discussion

The result of the weed risk assessment for *Amaranthus palmeri* is High Risk of becoming weedy or invasive outside of its native range in the United States. Notably, the establishment/spread potential for this species was higher than that of any of the test species used to develop the WRA model and its impact potential is comparable to that many test species that were classified as major invaders. *Amaranthus palmeri* is well studied, so a large amount of literature was available to answer the WRA questions. Accordingly, the level of uncertainty for both the establishment/spread and the impact risk elements was low, indicating that the conclusion from the risk assessment is robust. *Amaranthus palmeri* is an annual plant of the Sonoran desert that has spread rapidly in the eastern United States in recent decades and has become a major agricultural weed. It is of great concern to farmers in both the

United States and Canada because it reproduces prolifically by seed, causes significant yield losses, and is very difficult to control.

We estimated 81 percent of the United States is suitable for the establishment of *A. palmeri*. Environmental variables such as soil and habitat type may limit its potential distribution; however, it has adapted to a wide range of disturbed habitats, such as crop fields, pastures, orchards, vineyards, gardens, landscaped areas, irrigation ditches, roadsides, railroads, and waste places (Sauer, 1955; DiTomaso and Healy, 2007). Based on its High Risk score and its geographic potential, *A. palmeri* could cause significant damage to plants and agricultural fields outside of its native range, leading to negative economic, environmental, societal, or export market impacts.

5. Suggested Citation

PPQ. 2020. Weed risk assessment for *Amaranthus palmeri* (Amaranthaceae) – Palmer amaranth, ver. 3. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (PPQ), Raleigh, NC. 27 pp.

6. Literature Cited

AMS. 2018. State Noxious-Weed Seed Requirements Recognized in the Administration of the Federal Seed Act. United States Department of Agriculture, Agricultural Marketing Service, Gastonia, NC. 129 pp.

Anastasiu, P., G. Negrean, C. Samoila, D. Memedemin, and D. Cogalniceanu. 2011. A comparative analysis of alien plant species along the Romanian Black Sea coastal area. The role of harbours. Journal of Coastal Conservation 15(4):595-606.

AOSA/SCST. 2018. Palmer Amaranth. Association of Official Seed Analysts, Society of Commercial Seed Technologists, Wichita, KS. Last accessed 3/5/2019, https://www.analyzeseeds.com/palmer-amaranth/.

Bagavathiannan, M. V., and J. K. Norsworthy. 2016. Multiple-Herbicide Resistance Is Widespread in Roadside Palmer Amaranth Populations. PLoS ONE doi:10.1371/journal.pone.0148748.

Bailey, L. H., and E. Z. Bailey. 1976. Hortus Third: A Concise Dictionary of Plants Cultivated in the United States and Canada. Macmillan, New York. 1,290 pp.

Barber, L. T., K. L. Smith, R. C. Scott, J. K. Norsworthy, and A. M. Vanglider. 2015. Zero Tolerance: A Community-Based Program for Glyphosate-Resistant Palmer Amaranth Management (FSA2177). University of Arkansas, Agriculture and Natural Resources, Little Rock, AR.

Bayer Crop Science. 2019. Crop Compendium. Bayer AG. https://www.cropscience.bayer.com/en/crop-compendium/pests-diseases-weeds/weeds/amaranthus-palmeri.

Berger, S., P. T. Madeira, J. Ferrell, L. Gettys, S. Morichetti, J. J. Cantero, and C. Nuñez. 2016. Palmer Amaranth (*Amaranthus palmeri*) Identification and Documentation of ALS-Resistance in Argentina. Weed Science 64:312-320.

Berger, S. T., J. A. Ferrell, D. L. Rowland, and T. M. Webster. 2015. Palmer Amaranth (*Amaranthus palmeri*) Competition for Water in Cotton. Weed Science 63:928-935.

BICON. 2019. Australian Biosecurity Import Conditions. Australia Department of Agriculture and Water Resources. https://bicon.agriculture.gov.au/BiconWeb4.0.

Brouillet, L., F. Coursol, S. J. Meades, M. Favreau, M. Anions, P. Belisle, and P. Desmet. 2010. *Amaranthus palmeri* S. Watson: VASCAN, the Database of Vascular Plants of Canada. http://data.canadensys.net/vascan/taxon/2504?lang=en.

Bryson, C. T., and M. S. DeFelice (eds.). 2010. Weeds of the midwestern United States and central Canada. University of Georgia Press, Athens, GA. 427 pp.

Burrows, G. E., and R. J. Tyrl. 2013. Toxic Plants of North America. Wiley-Blackwell, Ames, IA. 1383 pp.

Caton, B. P., A. L. Koop, L. Fowler, L. Newton, and L. Kohl. 2018. Quantitative uncertainty analysis for a weed risk assessment model. Risk Analysis:1-16. DOI: 10.1111/risa.12979.

Chahal, P. 2018. RE: request permission to use your photo of Palmer amaranth. Personal communication to K. Castro on November 6, 2018, from P. Chahal (University of Nebraska-Lincoln).

Chahal, P. S., J. S. Aulakh, M. Jugulam, and A. J. Jhala. 2015. Herbicide-Resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) in the United States - Mechanisms of Resistance, Impact, and Management. Pages 1-29 *in* A. Price (ed.). Herbicides: Agronomic Crops and Weed Biology. IntechOpen Limited, London.

CNPS. 2019. Calscape. California Native Plant Society. https://calscape.org/Amaranthus-palmeri-(Palmer's-Amaranth)?srchcr=sc5c795a8f79ac2.

Connick, W. J., J. M. Bradow, M. G. Legendre, S. L. Vail, and R. M. Menges. 1987. Identification of Volatile Allelochemicals from *Amaranthus palmeri* S. Wats. Journal of Chemical Ecology 13(3):463-472.

Cornell University. 2019. Department of Animal Science - Plants Poisonous to Livestock. Cornell College of Agriculture and Life Sciences. http://poisonousplants.ansci.cornell.edu/php/plants.php?action=display.

Costea, M., S. E. Weaver, and F. J. Tardif. 2004. The biology of Canadian weeds. 130. *Amaranthus retroflexus* L., *A. powellii* S. Watson and *A. hybridus* L. Canadian Journal of Plant Science 84:631-668.

Costea, M., S. E. Weaver, and F. J. Tardif. 2005. The Biology of Invasive Alien Plants in Canada. 3. *Amaranthus tuberculatus* (Moq.) Sauer var. *rudis* (Sauer) Costea & Tardif. Canadian Journal of Plant Science 85(2):507-522.

DAO. 1963. *Amaranthus palmeri* S. Wats. Agriculture and Agri-Food Canada, National Collection of Vascular Plants, Ottawa, ON.

Dave's Garden. 2019. *Amaranthus* Species, Careless Weed, Carelessweed, Palmer Amaranth, Palmer's Pigweed. Internet Brands. https://davesgarden.com/guides/pf/go/77160.

Davis, A. S., B. J. Schutte, A. G. Hager, and B. G. Young. 2015. Palmer Amaranth (*Amaranthus palmeri*) Damage Niche in Illinois Soybean Is Seed Limited. Weed Science 63:658-668.

DeVlaming, V., and V. W. Proctor. 1968. Dispersal of aquatic organisms: viability of seeds recovered from the droppings of captive killdeer and mallard ducks. American Journal of Botany 55(1):20-26.

DiTomaso, J. M., and E. A. Healy. 2007. Weeds of California and Other Western States, Vol. 1: Aizoaceae - Fabaceae. University of California, Agriculture and Natural Resources, Oakland, CA. 834 pp.

EDDMapS. 2019. Early Detection & Distribution Mapping System. University of Georgia, Center for Invasive Species and Ecosystem Health. https://www.eddmaps.org/distribution/uscounty.cfm?sub=5090.

eFloras. 2019. Missouri Botanical Garden, Harvard University Herbaria. http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=242415653.

Ehleringer, J. 1983. Ecophysiology of *Amaranthus palmeri*, a Sonoran Desert Summer Annual. Oecologia 57(1/2):107-112.

EPPO. 2014. EPPO Alert List - *Amaranthus palmeri* (Amaranthaceae). European and Mediterranean Plant Protection Organization, Paris. Last accessed 2/26/2019, https://www.eppo.int/ACTIVITIES/plant_quarantine/alert_list_plants/amaranthus_palmeri.

Farmer, J. A., E. B. Webb, R. A. Pierce II, and K. W. Bradley. 2017. Evaluating the potential for weed seed dispersal based on waterfowl consumption and seed viability. Pest Management Science 73:2592-2603.

Fern, K. 2019. Tropical Plants Database. http://tropical.theferns.info/viewtropical.php?id=Amaranthus+palmeri.

GBIF Secretariat. 2017. *Amaranthus palmeri* S. Watson. GBIF Backbone Taxonomy. https://www.gbif.org/species/5384393.

Haines, A. 2011. Amaranthaceae. Pages 312-329 *in* New England Wild Flower Society's Flora Nova Angliae: A Manual for the Identification of Native and Naturalized Higher Vascular Plants of New England. New England Wild Flower Society, Yale University Press, New Haven, CT.

Haines, L., B. Hartzler, R. Nowierski, S. Ratcliffe, and J. Schroeder. n.d. National Pest Alert: Palmer Amaranth, *Amaranthus palmeri*. United States Department of Agriculture, Regional IPM Centers, Champaign, IL. 2 pp.

Hanson, D. 2018. Minnesota Noxious Weeds. Minnesota Department of Transportation, Saint Paul, MN. 76 pp.

Heap, I. 2019. The International Survey of Herbicide Resistant Weeds. http://www.weedscience.org/Summary/Species.aspx?WeedID=14.

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

Hoffner, A. E., D. L. Jordan, A. Chandi, A. C. York, E. J. Dunphy, and W. J. Everman. 2012. Management of Palmer Amaranth (*Amaranthus palmeri*) in Glufosinate-Resistant Soybean (*Glycine max*) with Sequential Applications of Herbicides. ISRN Agronomy doi:10.5402/2012/131650.

Holm, L. G., J. V. Pancho, J. P. Herberger, and D. L. Plucknett. 1991a. A Geographical Atlas of World Weeds. Krieger Publishing Company, Malabar, FL. 391 pp.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1991b. The World's Worst Weeds: Distribution and Biology. Krieger Publishing Company, Malabar, FL. 609 pp.

IPK Gatersleben. 2019. Mansfeld's World Database of Agricultural and Horticultural Crops. http://mansfeld.ipk-gatersleben.de/apex/f?p=185:7:.

IPPC. 2017. International Standards for Phytosanitary Measures No. 5: Glossary of Phytosanitary Terms. Food and Agriculture Organization of the United Nations, Secretariat of the International Plant Protection Convention (IPPC), Rome, Italy. 34 pp.

Jha, P., J. K. Norsworthy, and J. Garcia. 2014. Depletion of an artificial seed bank of Palmer amaranth (*Amaranthus palmeri*) over four years of burial. American Journal of Plant Sciences 5(11):1599-1606.

Jha, P., J. K. Norsworthy, M. B. Riley, D. G. Bielenberg, and W. Bridges Jr. 2008. Acclimation of Palmer Amaranth (*Amaranthus palmeri*) to Shading. Weed Science 56:729-734.

Kartesz, J. T. 2015. Taxonomic Data Center. Biota of North America Program. http://bonap.net/tdc.

Keeley, P. E., C. H. Carter, and R. J. Thullen. 1987. Influence of Planting Date on Growth of Palmer Amaranth (*Amaranthus palmeri*). Weed Science 35(2):199-204.

Kingsbury, J. M. 1964. Amaranthaceae. Pages 244-245 *in* Poisonous Plants of the United States and Canada. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Kistner, E. J., and J. L. Hatfield. 2018. Potential Geographic Distribution of Palmer Amaranth under Current and Future Cliamtes. Agricultural & Environmental Letters doi:10.2134/ael2017.2112.0044.

KLT. 2017. Palmer Amaranth Headed for Montana. Kaniksu Land Trust, Sandpoint, ID. Last accessed 3/12/2019, https://kaniksulandtrust.org/2017/03/22/palmer-amaranth-headed-montana/.

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

Korres, N. 2018. Comments on control of *Amaranthus palmeri* along roadsides in the United States. Personal communication to K. Castro on November 9, 2018, from N. Korres (Crop, Soil and Environmental Science, University of Arkansas).

Korres, N. E., and J. K. Norsworthy. 2017. Palmer Amaranth (*Amaranthus palmeri*) Demographic and Biological Characteristics in Wide-Row Soybean. Weed Science 65:491-503.

Korres, N. E., J. K. Norsworthy, M. V. Bagavathiannan, and A. Mauromoustakos. 2015. Distribution of Arable Weed Populations along Eastern Arkansas Mississippi Delta Roadsides: Occurrence, Distribution, and Favored Growth Habitats. Weed Technology 29:587-595.

Langcuster, J. 2008. Alabama: The Nightmare Weed That Threatens Southern Row Crops. AgFax. Last accessed 3/4/2019, https://agfax.com/news/2008/10/alnightmareweed1023.htm.

Legleiter, T., and B. Johnson. 2013. Palmer Amaranth Biology, Identification, and Management (WS-51). Purdue Extension, Perdue Weed Science, West Lafayette, IN. 13 pp.

Mabberley, D. J. 2008. Mabberley's Plant-Book. Cambridge University Press, Cambridge, UK. 1021 pp.

Magarey, R., L. Newton, S. C. Hong, Y. Takeuchi, D. Christie, C. S. Jarnevich, L. Kohl, M. Damus, S. I. Higgins, L. Millar, K. Castro, A. West, J. Hastings, G. Cook, J. Kartesz, and A. L. Koop. 2017. Comparison of four modeling tools for the prediction of potential distribution for non-indigenous weeds in the United States. Biological Invasions:1-16: DOI: 10.1007/s10530-10017-11567-10531.

Massinga, R. A., R. S. Currie, M. J. Horak, and J. Boyer Jr. 2001. Interference of Palmer amaranth in corn. Weed Science 49:202-208.

Matzrafi, M., I. Herrmann, C. Nansen, T. Kliper, Y. Zait, T. Ignat, D. Siso, B. Rubin, A. Karnieli, and H. Eizenberg. 2017. Hyperspectral technologies for assessing seed germination and trifloxysulfuron-methyl response in *Amaranthus palmeri* (Palmer amaranth) [abstract]. Frontiers in Plant Science 8:474.

Menges, R. M. 1987a. Allelopathic Effects of Palmer Amaranth (*Amaranthus palmeri*) and Other Plant Residues in Soil. Weed Science 35(3):339-347.

Menges, R. M. 1987b. Weed seed population dynamics during six years of weed management systems in crop rotations on irrigated soil. Weed Science 35(3):328-332.

Meyers, S. L., K. M. Jennings, J. R. Schultheis, and D. W. Monks. 2010. Interference of Palmer Amaranth (*Amaranthus palmeri*) in Sweetpotato. Weed Science 58(3):199-203.

Moniodis, J. 2014. Submission on Import Risk Analysis, September 12, 2014. Western Australia Farmers Federation, Burswood, Australia. 6 pp.

Moore, J. W., D. S. Murray, and R. B. Westerman. 2004. Palmer Amaranth (*Amaranthus palmeri*) Effects on the Harvest and Yield of Grain Sorghum (*Sorghum bicolor*). Weed Technology 18:23-29.

NCSU Extension. 2019. *Amaranthus palmeri*. North Carolina State University Extension, Raleigh, NC. Last accessed 3/1/2019, https://plants.ces.ncsu.edu/plants/all/amaranthus-palmeri/.

NDSU. 2014. Palmer Amaranth - Weed of the Year. North Dakota State University, Weed Science, Fargo, ND. 1 pp.

NDSU. 2015. Palmer Amaranth - Weed of TWO Years - 2014-2015. North Dakota State University, Weed Science, Fargo, ND. 2 pp.

NGRP. 2019. Germplasm Resources Information Network (GRIN). United States National Germplasm System. https://npgsweb.ars-grin.gov/gringlobal/taxonomydetail.aspx?id=101541.

NHIC. 2007. *Amaranthus palmeri* S. Wats. Natural Heritage Information Centre, Peterborough, ON.

Nickrent, D. 2019. Parasitic Plant Classification. Southern Illinois University, Department of Plant Biology, Carbondale, IL. Last accessed 3/4/2019, https://parasiticplants.siu.edu/ListParasites.html.

NPB. 2020. Laws and regulations. The National Plant Board (NPB). Last accessed January 21, 2019, http://nationalplantboard.org/laws-and-regulations/.

NRCS. 2017a. Palmer Amaranth, *Amaranthus palmeri* S. Watson (MT-2017). United States Department of Agriculture, Natural Resources Conservation Service, Bozeman, MT. 2 pp.

NRCS. 2017b. Palmer amaranth/Palmer pigweed (*Amaranthus palmeri*) Eradication in Native Seedlings (Illinois Agronomy Technical Note No. 24). United States Department of Agriculture, Natural Resources Conservation Service, Champaign, IL. 5 pp.

NRCS. 2019. The PLANTS Database. United States Department of Agriculture, Natural Resources Conservation Service. https://plants.sc.egov.usda.gov/core/profile?symbol=AMPA.

Peters, T., B. Jenks, and E. Crawford. 2018. Palmer Amaranth Confirmed in North Dakota (08/30/18). North Dakota State University, Fargo, ND. Last accessed 2/27/2019, https://www.ag.ndsu.edu/cpr/weeds/palmer-amaranth-confirmed-in-north-dakota-08-30-18.

PFAF. 2012. Plants For A Future. https://pfaf.org/user/Plant.aspx?LatinName=Amaranthus+palmeri.

Pichardo, J. M., and H. Vibrans. 2009. Amaranthaceae: *Amaranthus palmeri* S. Wats. Quintonil tropical (sugerido). Malezas de México. http://www.conabio.gob.mx/malezasdemexico/amaranthaceae/amaranthus-palmeri/fichas/ficha.htm.

Place, G., D. Bowman, M. Burton, and T. Rufty. 2008. Root penetration through a high bulk density soil layer: differential response of a crop and weed species. Plant & Soil 307:179-190.

Randall, R. P. 2017. A Global Compendium of Weeds. R.P. Randall, Perth, Australia. 3654 pp.

Rhoads, A. F., and T. A. Block. 2007. Amaranthaceae: Amaranth Family. Pages 470-481 *in* The Plants of Pennsylvania: An Illustrated Manual, Second Edition. University of Pennsylvania Press, Philadelphia, PA.

Ribeiro, D. N., Z. Pan, S. O. Duke, V. K. Nandula, B. S. Baldwin, D. R. Shaw, and F. E. Dayan. 2014. Involvement of faculative apomixis in inheritance of EPSPS gene amplification in glyphosate-resistant *Amaranthus palmeri*. Planta 239:199-212.

Ricketts, T. H., E. Dinerstein, D. M. Olson, C. J. Loucks, W. Eichbaum, D. Della-Sala, K. Kavanagh, P. Hedae, P. T. Hurley, K. M. Carney, R. Abell, and S. Walters. 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, DC.

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

Sauer, J. 1955. Revision of the Dioecious Amaranths. Madrono 13(1):5-46.

Sauer, J. D. 1972. The Dioecious amaranths: a new species name and major range extensions. Madrono 21(6):426-434.

Schonbeck, M. 2014. Palmer Amaranth (*Amaranthus palmeri*). eXtension, Kansas City, MO. Last accessed 2/28/2019, https://articles.extension.org/pages/65209/palmer-amaranth-amaranthus-palmeri.

Scoggan, H. J. 1979. The Flora of Canada, Part 4 - Dicotyledoneae (Losaceae to Compositae). National Museums of Canada, Ottawa, ON. 612 pp.

SEINet. 2019. SEINet Portal Network. http://swbiodiversity.org/seinet/taxa/index.php?taxon=Amaranthus+palmeri&formsubmit=Search+Terms.

Sosnoskie, L. M., A. S. Culpepper, and T. M. Webster. 2011. Palmer amaranth seed mortality in response to burial depth and time. Beltwide Cotton Conference, Atlanta, GA. January 4-7, 2011.

Sosnoskie, L. M., T. M. Webster, and A. S. Culpepper. 2013. Glyphosate Resistance Does Not Affect Palmer Amranth (*Amaranthus palmeri*) Seedbank Longevity. Weed Science 61:283-288.

Sosnoskie, L. M., T. M. Webster, T. L. Grey, and A. S. Culpepper. 2014. Severed stems of *Amaranthus palmeri* are capable of regrowth and seed production in *Gossypium hirsutum*. Annals of Applied Biology 165:147-154.

Spaunhorst, D. J. 2016. The biology and management of Palmer amaranth (*Amaranthus palmeri* S. Wats) in Indiana. Dissertation, Purdue University, West Lafayette, IN.

Steckel, L. E. 2007. The Dioecious *Amaranthus* spp.: Here to Stay. Weed Technology 21(2):567-570.

Stephenson, K. 2019. Palmer's Amaranth, *Amaranthus palmeri*. Edible Wild Food. Last accessed 3/1/2019, https://www.ediblewildfood.com/palmers-amaranth.aspx.

Stockford, A. 2018. Is palmer amaranth waiting in the wings? Manitoba Co-operator, Winnipeg, MB. Last accessed 2/27/2019, https://www.manitobacooperator.ca/news-opinion/news/palmer-amaranth-edging-closer-to-manitoba/#_ga=2.107460490.901450922.1538509867-295743578.1494619532.

Swearingen, J., and C. Bargeron. 2016. Invasive Plant Atlas of the United States. University of Georgia, Center for Invasive Species and Ecosystem Health. https://www.invasive.org/browse/subinfo.cfm?sub=5090.

University of Arizona. 2016. A Northern Arizona Homeowner's Guide to Identifying and Managing Invasive Plants: Palmer Amaranth. University of Arizona Cooperative Extension, Flagstaff, AZ. Last accessed 3/1/2019, https://www.nazinvasiveplants.org/palmers-amaranth/.

University of Minnesota. 2019. Plant Information Online. https://plantinfo.umn.edu/node/1397950.

USDA. 2010. Federal Noxious Weed List. United States Department of Agriculture, Washington, DC. 5 pp.

VanGessel, M., and Q. Johnson. 2015. Palmer Amaranth Control in Crop Land (Weed Facts WF-21). University of Delaware, Cooperative Extension, Newark, DE. 12 pp.

Villaseñor Rios, J. L., and F. J. E. García. 1998. Catálogo de Malezas de México. Universidad Nacional Autónoma de México, Consejo Nacional Consultivo Fitosanitario y Fondo de Cultura Económica, Mexico City. 448 pp.

Walker, R. 2012. Parasitic Plants Database. Rick Walker. http://www.omnisterra.com/bot/pp_home.cgi.

Ward, S. M., T. M. Webster, and L. E. Steckel. 2013. Palmer Amaranth (*Amaranthus palmeri*): A Review. Weed Technology 27(1):12-27.

Whitson, T. D., L. C. Burrill, S. A. Dewey, D. W. Cudney, B. E. Nelson, R. D. Lee, and R. Parker. 2000. Weeds of the West. Western Society of Weed Science, Newark, CA. 626 pp.

WTO. 2018. Sanitary and Phytosanitary Information Management System. World Trade Organization. http://spsims.wto.org/en/RegularNotifications/View/140521?FromAllNotifications=True.

Appendix A. Weed risk assessment for *Amaranthus palmeri* S. Watson (Amaranthaceae)

The following table includes 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 in which 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	*Amaranthus palmeri* is native to North America, from the southwestern United States and south through much of Mexico to Oaxaca and Veracruz (NGRP, 2019). It has naturalized beyond its native range in various locations, particularly the eastern United States and possibly Canada (Ontario) (eFloras, 2019). Outside of North America, it has naturalized in Spain, Sweden, Australia, Cyprus, India (Maharashtra), Portugal (Madeira Islands) (NGRP, 2019), and Romania (Anastasiu et al., 2011). *Amaranthus palmeri* "is a successful invasive species, which is evident from its expansion both in eastern North America and overseas" (eFloras, 2019). This species has expanded beyond its native range as a result of human activity and land disturbance (Ward et al., 2013). Sauer (1972) notes that "it has been expanding its range on various borders since 1900". Davis et al. (2015) state that "its range is expanding northward" in the United States, and it spreads rapidly (eFloras, 2019). The alternate answers were both "e."
ES-2 (Is the species highly domesticated)	n - negl	0	The leaves and seeds of *A. palmeri* are edible and have been consumed by several Native American tribes (Sauer, 1955; Steckel, 2007; Stephenson, 2019; Ward et al., 2013; Fern, 2019; CNPS, 2019; NCSU Extension, 2019), likely collected from the wild. *Amaranthus palmeri* is not known to be cultivated for any purpose (e.g., Sauer, 1955; Bailey and Bailey, 1976; IPK Gatersleben, 2019; University of Minnesota, 2019; NGRP, 2019). We found no evidence that *A. palmeri* has been bred for traits resulting in reduced weed potential.
ES-3 (Significant weedy congeners)	y - negl	1	The genus *Amaranthus* includes about 70 to 75 species (Steckel, 2007; Mabberley, 2008). Holm et al. (1991a) list 36 species as weeds, and 14 of these are considered "serious" or "principal" weeds in at least one country. *Amaranthus hybridus* and *A. spinosus* are included among the world's worst weeds (Holm et al., 1991b). "Pigweeds that are problem weeds in the United States include redroot

Question ID	Answer - Uncertainty	Score	Notes (and references)
			pigweed (*A. retroflexus*), smooth pigweed (*A. hybridus*), Powell amaranth (*A. powelii*), spiny amaranth (*A. spinosus*), tumble pigweed (*A. albus*), prostrate pigweed (*A. blitoides*) and common waterhemp (*A. rudis* [=*A. tuberculatus*])." (NRCS, 2017a). Pigweeds are common agricultural weeds that grow quickly and aggressively and compete with crops (NRCS, 2017a).
ES-4 (Shade tolerant at some stage of its life cycle)	y - high	1	A study by Jha et al. (2008) demonstrated that *A. palmeri* can acclimate both photosynthetically and morphologically to up to 87 percent shading "and is likely to compete with crops in light-limited environments". *Amaranthus palmeri* compensated for reduced photosynthetic rates in shade by increasing the leaf area to permit greater harvest of the available light. It also decreased its rates of leaf and main-stem branch production. Finally, the leaves produced in shaded conditions were thinner, allowing plants to reduce their light compensation point and dark respiration rate per unit leaf area (Jha et al., 2008). Although *A. palmeri* can adapt to somewhat shaded conditions, it prefers open sunny places (DiTomaso and Healy, 2007; Jha et al., 2008). Several sources describe *A. palmeri* as requiring full sun (PFAF, 2012; Bayer Crop Science, 2019; NCSU Extension, 2019) or as shade intolerant (Hanson, 2018). Schnobeck (2014) describes pigweeds in general as shade intolerant, with substantially reduced growth and reproduction under heavy crop canopies. He notes that rapid stem elongation allows them to escape shading in many cropping situations. Considering 87 percent shade to be full shade, we answered "yes" based on quantitative data from Jha et al. (2008). We raised the uncertainty to "high," however, due to apparent conflict with other sources and because this species clearly prefers high light environments.
ES-5 (Plant a vine or scrambling plant, or forms tightly appressed basal rosettes)	n - negl	0	*Amaranthus palmeri* is neither a vine nor an herb with a basal rosette. It has one erect central stem, is (0.3-) 0.5-1.5 (-3) m tall, and produces many lateral branches (Whitson et al., 2000; eFloras, 2019).
ES-6 (Forms dense thickets, patches, or populations)	y - negl	2	The University of Arizona (2016) refers to "dense populations" of this plant. In Arizona, natural *A. palmeri* stands can attain dry weights of almost 500 g/m^2 within four weeks of emergence (Ehleringer, 1983), "which approaches the biomass of a mature winter annual cover crop" (Schonbeck, 2014). In a study by Korres and Norsworthy (2017), *A. palmeri* was seeded in soybean plots and allowed to self-thin. A wide range of densities was observed, which declined over time. The highest densities at 20

Question ID	Answer - Uncertainty	Score	Notes (and references)
			days after planting exceeded 900 plants/m^2, and at 75 days were as high as 125 plants/m^2. Since yield losses can occur at 1-10 plants/m^2 (EPPO, 2014), these densities are considered to be high. In North Carolina, Hoffner et al. (2012) conducted a study on *A. palmeri* management in soybean in an area with a high density of *A. palmeri* was compared to other weed species. The photo of *A. palmeri* in corn on the title page also shows a dense population of this species.
ES-7 (Aquatic)	n - negl	0	*Amaranthus palmeri* is a terrestrial species, native to desert regions of the southwestern United States and northern Mexico (NRCS, 2017a). In the USDA-NRCS PLANTS Database (NRCS, 2019), it is designated as a facultative upland species, which means it usually occurs in non-wetlands but may occur in wetlands.
ES-8 (Grass)	n - negl	0	*Amaranthus palmeri* is not a grass. It is an herb of the Amaranthaceae family (NGRP, 2019; NRCS, 2019).
ES-9 (Nitrogen-fixing woody plant)	n - negl	0	*Amaranthus palmeri* is a forb in the Amaranthaceae (NGRP, 2019; NRCS, 2019), which is not one of the families known to contain nitrogen-fixing species (Santi et al., 2013). It is not a woody plant (eFloras, 2019).
ES-10 (Does it produce viable seeds or spores)	y - negl	1	*Amaranthus palmeri* produces viable seeds (DiTomaso and Healy, 2007; Ward et al., 2013; EPPO, 2014). It has a higher germination rate than many other *Amaranthus* spp. (Steckel, 2007).
ES-11 (Self-compatible or apomictic)	y - low	1	*Amaranthus palmeri* has separate male and female plants, so it is an outcrosser (Steckel, 2007; Ward et al., 2013). Ribeiro et al. (2014), however, confirmed that asexual reproduction (apomixis) also occurs in isolated female plants of this species.
ES-12 (Requires specialist pollinators)	n - negl	0	*Amaranthus palmeri* is wind-pollinated (Ward et al., 2013; EPPO, 2014). Flowers are inconspicuous (DiTomaso and Healy, 2007).
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]	a - high	2	The species is a short-lived summer annual forb in its native desert habitat (Ehleringer, 1983; EPPO, 2014; Pichardo and Vibrans, 2009; Ward et al., 2013). It rapidly germinates and completes its life cycle in response to available moisture (Ehleringer, 1983). "[T]he ability of 9- to 12-week-old Palmer's amaranth to produce seed that germinates soon after collection indicates that at least two generations of this weed might be produced in the same year" (Keeley et al., 1987). Although two generations of *A. palmeri* may be produced per year in California (Keeley et al., 1987), "multiple generations in a single season are not common in Oklahoma" (Moore et al., 2004). Based on the evidence, two generations per year may be

Question ID	Answer - Uncertainty	Score	Notes (and references)
			possible under some conditions, although one generation per year appears to be the norm. Alternate answers were both "b".
ES-14 (Prolific seed producer)	y - negl	1	Seed production has exceeded 100,000 seeds/m^2 in soybean, corn, and peanut (Ward et al., 2013, based on multiple sources). Each female plant produces up to 600,000 seeds, with at least 50 percent viability between May and October (Keeley et al., 1987; Jha et al., 2008). It is often described as a "prolific seed producer" (Ward et al., 2013; EPPO, 2014; NRCS, 2017a).
ES-15 (Propagules likely to be dispersed unintentionally by people)	y - negl	1	Seeds of *A. palmeri* are 1-2 mm in diameter and spread "through agricultural management practices such as plowing, mowing, harvesting, and spreading compost, manure or gin trash" (Ward et al., 2013, and references within). Seeds are readily moved into clean fields by equipment such as combines into clean fields (Barber et al., 2015; Legleiter and Johnson, 2013).
ES-16 (Propagules likely to disperse in trade as contaminants or hitchhikers)	y - negl	2	*Amaranthus palmeri* "was recently found as a contaminant in conservation plantings in Illinois, Indiana, Iowa, Minnesota and Ohio. It was a contaminant in Conservation Reserve Program (CRP) seed mixes but honey bee pollinator, wildlife and cover crop plantings may also have been contaminated" (NRCS, 2017a). It is a grain, seed, and feed contaminant (DiTomaso and Healy, 2007; Legleiter and Johnson, 2013) and also spreads through contaminated hay (NRCS, 2017a). "[R]ecorded in Andalucía at the port of Sevilla and in Palos de la Frontera (province of Huelva) in the vicinity of industrial premises where seeds and plant products are processed" (EPPO, 2014).
ES-17 (Number of natural dispersal vectors)	4	4	Propagule traits for questions ES-17a through ES-17e. *Amaranthus palmeri* produces dry, thin-walled, single-seeded fruits (utricles) that are about 1.5-2 mm long (Ward et al., 2013; eFloras, 2019). The seeds are smooth, shiny, round or disc-shaped, and 1-2 mm in diameter (Sauer, 1955; Ward et al., 2013; eFloras, 2019). They are predominantly dispersed by gravity (Ward et al., 2013).
ES-17a (Wind dispersal)	n - mod		"[T]he seeds lack specialized dispersal mechanisms, including for wind dispersal" (Ward et al., 2013). Although seeds may be dispersed short distances by wind (DiTomaso and Healy, 2007) and, in one case, a hurricane was believed to have introduced the species into a noninfested area (Menges, 1987b), wind is unlikely to contribute significantly to the dispersal of *A. palmeri* under normal circumstances. Costea et al. (2004), in discussing three other weedy *Amaranthus* spp. (not *A. palmeri*), note that seeds may be dispersed

Question ID	Answer - Uncertainty	Score	Notes (and references)
			when dried inflorescences blow over frozen snow in winter. We answered no with moderate uncertainty because this question aims to identify species with special traits to facilitate wind dispersal.
ES-17b (Water dispersal)	y - negl		"Palmer amaranth seed is small, light, and floats in water which makes water movement a primary source of spread" (NDSU, 2015). The seed can be spread "by irrigation and other water flow" (Ward et al., 2013). Seeds disperse greater distances on water (DiTomaso and Healy, 2007). *Amaranthus palmeri* grows along streambanks and marsh edges and in river floodplains and irrigation ditches (Sauer, 1955). Costea et al. (2004) note that for congeners *A. hybridus*, *A. retroflexus*, and *A. powellii*, the mature pericarp has two or three layers, "between which are large intercellular spaces filled with air, which permit the fruits to float". Costea et al. (2005) also note that *A. tuberculatus* "fruits and seeds float, and plants prefer the proximity of water".
ES-17c (Bird dispersal)	y - negl		The seed can be dispersed by birds (Ward et al., 2013; NDSU, 2015). In a study by DeVlaming and Proctor (1968), over 60 percent of *A. palmeri* seeds retained viability after passing through intestinal tracts of captive killdeer (*Charadrius vociferus*) and mallard ducks (*Anas platyrhynchos*). As part of the same study, 71 killdeer were shot in the field, and seed of *Amaranthus* and *Polygonum* constituted the bulk of the seed recovered. A study by Farmer et al. (2017) also confirmed that seeds of *A. palmeri* can remain viable after passage through digestive tracts of ducks and geese and can potentially be dispersed over long distances.
ES-17d (Animal external dispersal)	y - high		Haines (2011) notes wool waste as a means of dispersal, suggesting that external dispersal by animals can occur. Multiple other references refer to seed dispersal of *A. palmeri* by animals (DiTomaso and Healy, 2007; Legleiter and Johnson, 2013; Ward et al., 2013; Chahal et al., 2015), but it is not clear whether the references are suggesting external or internal dispersal. The seeds are tiny and round or disc-shaped, so they could get caught up in mud on animal fur and hooves or feet, but they have no special adaptations for attaching to animals.
ES-17e (Animal internal dispersal)	y - negl		*Amaranthus palmeri* was introduced into Missouri through the spread of manure from dairy cows that were fed cotton by-products as a feed supplement (NDSU, 2014; 2015)."Researchers believe Palmer amaranth was introduced to northern Indiana in dairy or beef manure from animals that were fed cotton seed hulls or other feed stocks that came

Question ID	Answer - Uncertainty	Score	Notes (and references)
			from the South that were contaminated with Palmer seed" (Legleiter and Johnson, 2013). We also found evidence of the small seeds of other *Amaranthus* spp. being dispersed after ingestion by animals, including mice, rabbits, sheep, and cattle (Costea et al., 2004).
ES-18 (Evidence that a persistent (>1yr) propagule bank (seed bank) is formed)	y - negl	1	In a seed burial study, seed viability averaged about 60 percent after one year and below 40 percent after two years (Sosnoskie et al., 2011). After three years, seed viability ranged from 9 percent at 1-cm depth to 22 percent at 40-cm depth (Sosnoskie et al., 2013). In an artificial seed bank study by Jha et al. (2014), seeds were buried up to 10 cm deep, and a 0.01 to 0.03 percent remained viable in the soil four years after burial.
ES-19 (Tolerates/benefits from mutilation, cultivation or fire)	y - negl	1	Sosnoskie et al. (2014) demonstrated that "severely pruned *A. palmeri* plants can resume growth, reach reproductive maturity and produce viable seed". The authors cut the main stems of *A. palmeri* plants growing in cotton fields to 15, 3, and zero cm above the soil level. As the severity of pruning increased, mortality rate increased (35 percent at 15 cm, 64 percent at 3 cm, and 95 percent at zero cm), and final plant height and seed production decreased, though some plants did produce seed at all cutting heights. According to Langcuster (2008), root and shoot removal, rather than chopping, is necessary for control, "otherwise weeds return with a vengeance as new plants sprout from the roots". "Pulled plants can re-root and produce seed" (NDSU, 2014; 2015). "Repeated mowing or cutting are not effective at controlling Palmer amaranth infestations" (Hanson, 2018). We answered "yes" because *A. palmeri* can evidently tolerate a significant degree of mutilation from cutting and mowing, though it does not appear to benefit from it.
ES-20 (Is resistant to some herbicides or has the potential to become resistant)	y - negl	1	*Amaranthus palmeri* "shows a remarkable facility for evolving herbicide resistance." Collectively, populations across its global range, have developed resistance to eight different herbicide modes of action (MOAs): ALS-inhibiting herbicides, dinitroanilines, triazines, glyphosate, and HPPD inhibitors. Furthermore, some populations have been reported as resistant to two or more of these MOAs" (Ward et al., 2013, and references cited within). The first reported instance of herbicide resistance was in 1989, when *A. palmeri* plants resistant to trifluralin were detected in soybean and cotton fields in South Carolina (Heap, 2019). Since then, resistance to one or more MOAs has been

Question ID	Answer - Uncertainty	Score	Notes (and references)
			reported in 28 U.S. states, as well as in Israel, Brazil, and Argentina (Heap, 2019).
ES-21 (Number of cold hardiness zones suitable for its survival)	10	1	
ES-22 (Number of climate types suitable for its survival)	8	2	
ES-23 (Number of precipitation bands suitable for its survival)	8	1	
IMPACT POTENTIAL			
General Impacts			
Imp-G1 (Allelopathic)	y - negl	0.1	"Experiments indicate that incorporation of a heavy stand of *A. palmeri* into the soil just before planting can hinder seedling growth in carrot, onion, cabbage and sorghum" (EPPO, 2014). In a study by Menges (1987a), soil-incorporated *A. palmeri* residues inhibited carrot growth by 49 percent and onion growth by 68 percent. Connick et al. (1987) identified the allelopathic volatiles associated with *A. palmeri* seedheads, stems, and roots. The allelopathic vapors strongly inhibited germination of carrot, onion, tomato, and even *A. palmeri* seeds. We answered "yes" due to evidence of allelopathic effects of *A. palmeri* in the field.
Imp-G2 (Parasitic)	n - negl	0	*Amaranthus palmeri* is not parasitic. It is in the Amaranthaceae, which is not a plant family known to contain parasitic plants (Heide-Jorgensen, 2008; Nickrent, 2019; Walker, 2012).
Impacts to Natural Systems			
Imp-N1 (Changes ecosystem processes and parameters that affect other species)	n - low	0	We found no evidence. The species is well-known, so uncertainty is low.
Imp-N2 (Changes habitat structure)	n - low	0	We found no evidence. The species is well-known, so uncertainty is low.
Imp-N3 (Changes species diversity)	n - high	0	One source from its native range (Arizona) states: "[d]ense populations reduce plant diversity, which is important to wildlife and pollinators" (University of Arizona, 2016). We found no other sources to support this claim, however, despite *A. palmeri* being a well-known species. It is known to be invasive in natural areas, so we answered no but raised the uncertainty to high due to apparently conflicting information.
Imp-N4 (Is it likely to affect federal Threatened and Endangered species?)	n - low	0	Although *A. palmeri* is native to the Sonoran desert and grows in river valleys (Bryson and DeFelice, 2010) and along streambanks (eFloras, 2019), it primarily invades agricultural and disturbed habitats, similar to those of other weedy *Amaranthus* spp. (Bryson and DeFelice, 2010).

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Since *A. palmeri* is not known to be problematic in natural areas, it is unlikely to affect Federally threatened or endangered species, which are more likely to be restricted to undisturbed systems.
Imp-N5 (Is it likely to affect any globally outstanding ecoregions?)	n - low	0	*Amaranthus palmeri* is not known to invade natural systems and is therefore unlikely to affect any globally outstanding ecoregions as per Ricketts et al. (1999).
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]	a - low	0	In 2016, *A. palmeri* was found as a contaminant in native seed mixes used in conservation plantings for pollinators or other wildlife in Illinois, Indiana, Iowa, Minnesota, and Ohio. Managers of conservation plantings have been encouraged to scout fields and eradicate plants if detected (NRCS, 2017a; Haines et al., n.d.). Despite this recent concern, *A. palmeri* has no record of causing impacts in natural areas. According to Haines et al. (n.d.), "[t]he primary concern with Palmer amaranth is that it will move from conservation plantings into crop fields". It is not considered likely to persist in well-established perennial plant communities (NRCS, 2017b). Alternate answers were "b" 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. The species is well-known, so the uncertainty is low.
Imp-A2 (Changes or limits recreational use of an area)	n - low	0	We found no evidence. The species is well-known, so the uncertainty is low.
Imp-A3 (Affects desirable and ornamental plants, and vegetation)	n - low	0	We found no evidence. The species is well-known, so the uncertainty is low.
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	Habitats of *A. palmeri* include gardens, landscaped areas, roadsides, waste places, and other disturbed sites (DiTomaso and Healy, 2007). Its presence along roadsides is a recent phenomenon and is believed to be a result of spread from heavily infested production fields (Bagavathiannan and Norsworthy, 2016). *Amaranthus palmeri* was the most common species recorded in a 2012 survey of eastern Arkansas-Mississippi Delta roadside weed populations (Korres et al., 2015). The authors highlight the need for an effective management plan to control these weeds along roadsides. A study by Bagavathiannan and Norsworthy (2016) from the same area revealed that multiple-herbicide resistance is prevalent among these populations. They state that "[g]rowers should be vigilant of Palmer amaranth infestation in roadsides adjacent to their fields and implement appropriate control measures". Barber et al. (2015) note the need to

Question ID	Answer - Uncertainty	Score	Notes (and references)
			work with "with state agencies like highway departments to see how they too can help reduce the seedbank on rights of way". Kistner and Hatfield (2018) urge growers to actively search for *A. palmeri* and eliminate it prior to seed set. Although roadside maintenance varies from state to state, no state has an *A. palmeri* control program along roadsides other than the typical maintenance to control vegetation (Korres, 2018) We answered "b" with moderate uncertainty because although *A. palmeri* is considered to be a weed along roadsides and several authors suggest it should be controlled, evidence of targeted control along roadsides is lacking. Alternate answers were both "c".
Impact to Production Systems (agriculture, nurseries, forest plantations, orchards, etc.)			
Imp-P1 (Reduces crop/product yield)	y - negl	0.4	*Amaranthus palmeri* "causes significant yield reductions in all agronomic row crops, especially when it emerges before or with the crop" (Schonbeck, 2014). Studies reviewed by Ward et al. (2013) reported 6 to 94 percent yield losses in corn, cotton, peanut, sorghum, soybean, and sweet potato. For example, yield losses of 65 percent have been reported in cotton (Berger et al., 2015). In a study by Massinga et al. (2001) in Kansas, *A. palmeri* that emerged at the same time as corn reduced corn yields 11 to 91 percent at densities of 0.5 to 8 plants per meter of row. Numerous additional reports of yield losses due to *A. palmeri* interference are available in the literature.
Imp-P2 (Lowers commodity value)	y - low	0.2	"Palmer amaranth density significantly influenced sweetpotato yield and quality" (Meyers et al., 2010). Through competition, *A. palmeri* reduces the weight of individual sweet potatoes, which affects the marketable grade they are placed in (Meyers et al., 2010) and therefore their price. In addition, growers are advised to request seed mixes for conservation plantings that do not contain *A. palmeri* and not to purchase seed containing "*Amaranthus* spp." unless a genetic test has confirmed that the species is not *A. palmeri* (Haines et al., n.d.). Discouraging purchase of native seed mixes containing *A. palmeri* could lower their value.
Imp-P3 (Is it likely to impact trade?)	y - negl	0.2	*Amaranthus palmeri* is prohibited entry into Australia (Moniodis, 2014; BICON, 2019). In March of 2018, Brazil posted a WTO notification to require that imported seed or grain commodities from several origins be free of *A. palmeri* (WTO, 2018). It is a noxious weed in Delaware, Ohio, and Minnesota (NRCS, 2017a). "Inaccurate identification of *Amaranthus* sp. on a Report of

Question ID	Answer - Uncertainty	Score	Notes (and references)
			Analysis may cause stop[ped] sales and further action by regulatory officials" (AOSA/SCST, 2018, referring to sales in the United States). Because *A. palmeri* is regulated, and because it can move as a contaminant of grain, seed, and other commodities (see evidence under ES-16), it is likely to impact trade either by causing shipments to be rejected at ports of entry or by increasing delays or costs associated with trade.
Imp-P4 (Reduces the quality or availability of irrigation, or strongly competes with plants for water)	y - high	0.1	In a study by Berger et al. (2015), *A. palmeri* plants in drought conditions negatively influenced soil moisture to a depth of 1 m and cotton stomatal conductance within a lateral distance of 1.8 m. Under adequate moisture conditions, *A. palmeri* removed more than twice as much water per day as cotton, though the soil moisture was quickly recharged. In a study by Place et al. (2008), *A. palmeri* and *Senna obustifolia* (sicklepod) roots were found to penetrate compacted soil more effectively and to take up nitrogen more efficiently than soybean, suggesting that its roots allow it to be more competitive for water and nitrogen than soybean in the southeastern United States. The root system of *A. palmeri* has both deep and shallow components, allowing it to access water reserves and also intercept sporadic rainfall (Berger et al., 2015). Although we found no direct evidence that *A. palmeri* affects crop yield due to its impact on water availability, because it is a strong competitor for water and at least temporarily affected cotton stomatal conductance, we answered yes with high uncertainty.
Imp-P5 (Toxic to animals, including livestock/range animals and poultry)	y - low	0.1	Although the leaves and seeds of *Amaranthus* can be consumed by people, they may be toxic to livestock, especially ruminants, due to the presence of nitrates (Burrows and Tyrl, 2013). *Amaranthus palmeri* has been "incriminated in cases of livestock loss" (Kingsbury, 1964). According to Pichardo and Vibrans (2009), *A. palmeri* can sometimes be used as forage but can cause harm when the nitrate content is high. Nitrate poisoning may be lethal or sublethal, depending on the concentration in the plant. At sublethal levels, abortion, depression of lactation, digestive disturbances, myocardial degeneration, and renal disease may occur (Kingsbury, 1964; Bryson and DeFelice, 2010). Pigs tend to develop only symptoms of sublethal poisoning, whereas deaths are usually limited to ruminants, especially cattle (Burrows and Tyrl, 2013). Poisoning may occur when livestock graze in pastures with an abundance of *Amaranthus*, and some animals seem to seek it out to eat (Burrows

Question ID	Answer - Uncertainty	Score	Notes (and references)
			and Tyrl, 2013). The Cornell University (2019) list of plants poisonous to livestock also includes the genus *Amaranthus* with nitrate as the primary poison.
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	*Amaranthus palmeri* is "one of the most widespread, troublesome, and economically damaging agronomic weeds in the southeastern U.S." (Ward et al., 2013). It is "a major agricultural weed in the southern Great Plains" (Schonbeck, 2014). In 2009, it ranked as the most troublesome weed of cotton in nine of ten U.S. states surveyed and was also one of the most troublesome weeds of corn and soybean (Ward et al., 2013). In addition to cultivated fields, it infests pastures, orchards, and vineyards in the United States (DiTomaso and Healy, 2007). It is a weed of 28 crops in Mexico (Villaseñor Rios and García, 1998). Its resistance to herbicides makes it very difficult to control, so producers spend additional time and money managing it (Swearingen and Bargeron, 2016). Numerous authors provide information on methods of control of *A. palmeri*, which can include hand-pulling, mowing, tillage, flaming, crop rotation, and use of cover crops and chemical control (NDSU, 2014; 2015; Schonbeck, 2014; Chahal et al., 2015; VanGessel and Johnson, 2015; NRCS, 2017b). 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 GBIF Secretariat, 2017).
Plant hardiness zones			
Geo-Z1 (Zone 1)	n - negl	N/A	No evidence.
Geo-Z2 (Zone 2)	n - negl	N/A	No evidence.
Geo-Z3 (Zone 3)	n - low	N/A	No evidence.
Geo-Z4 (Zone 4)	y - high	N/A	Minnesota (4 counties) (EDDMapS, 2019); Colorado (several points) (SEINet, 2019); and McIntosh County, ND (Peters et al., 2018). It is not clear if *A. palmeri* has fully established in this zone, and some of the records are fairly recent. A specimen from Colorado includes a remark that states "[a]dventive and naturalized in vacant ground". Note that the SEINet (2019) map database shows a point record of *A. palmeri* in Montana. However, when the underlying herbarium specimen record is examined, it describes a specimen taken from New Mexico and lists some associated plant species that only occur in the southwestern United States. We therefore excluded this point from consideration.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-Z5 (Zone 5)	y - mod	N/A	Wyoming, Wisconsin (EDDMapS, 2019), northern Illinois (NGRP, 2019; NRCS, 2019), Nebraska (NRCS, 2019), New York, and South Dakota (Kartesz 2015).
Geo-Z6 (Zone 6)	y - negl	N/A	Germany and Kansas. Also in Colorado, Missouri (SEINet 2018), Massachusetts (Kartesz 2015; USDA-ARS 2018), and southern Ontario (Scoggan 1979; DAO, 1963, NHIC, 2007).
Geo-Z7 (Zone 7)	y - negl	N/A	New Mexico, Oklahoma, Arkansas, Missouri, and Germany.
Geo-Z8 (Zone 8)	y - negl	N/A	Texas, New Mexico, Japan, Sweden, Germany, the Netherlands, Denmark, and Belgium.
Geo-Z9 (Zone 9)	y - negl	N/A	Arizona, California, and Japan.
Geo-Z10 (Zone 10)	y - negl	N/A	Mexico and Israel.
Geo-Z11 (Zone 11)	y - negl	N/A	California, Mexico, and Israel.
Geo-Z12 (Zone 12)	y - negl	N/A	Mexico (near Pacific Coast, many points) and Israel.
Geo-Z13 (Zone 13)	y - mod	N/A	Mexico (near Pacific Coast, few points).
Köppen -Geiger climate classes			
Geo-C1 (Tropical rainforest)	n - low	N/A	No evidence.
Geo-C2 (Tropical savanna)	y - negl	N/A	Mexico (many points).
Geo-C3 (Steppe)	y - negl	N/A	Arizona, New Mexico, Mexico (many points), and Israel.
Geo-C4 (Desert)	y - negl	N/A	Arizona, California, and Mexico (many points). A common C_4 summer annual of the Sonoran Desert (Ehleringer, 1983).
Geo-C5 (Mediterranean)	y - negl	N/A	California and Israel (many points).
Geo-C6 (Humid subtropical)	y - negl	N/A	Texas, Alabama, South Carolina, and Japan (many points).
Geo-C7 (Marine west coast)	y - low	N/A	Mexico (2 points), Germany, the Netherlands, and Belgium (many points).
Geo-C8 (Humid cont. warm sum.)	y - low	N/A	Kansas (6 points), Missouri (1 point). Also in Nebraska, Illinois, Ohio, Pennsylvania (NRCS, 2019), Wisconsin (EDDMapS, 2019) and Niagara Falls, Ontario (NHIC, 2007).
Geo-C9 (Humid cont. cool sum.)	y - mod	N/A	Germany, Denmark, and Sweden (few points in each country). Also in Minnesota (2 counties), Wisconsin (1 county) (EDDMapS, 2019), Massachusetts (2 counties) (Kartesz, 2015), and St. Thomas and Field, Ontario (Scoggan, 1979). Naturalized in Sulina, Romania (Anastasiu et al., 2011).
Geo-C10 (Subarctic)	n - low	N/A	No evidence.
Geo-C11 (Tundra)	n - low	N/A	No evidence.
Geo-C12 (Icecap)	n - low	N/A	No evidence.
10-inch precipitation bands			
Geo-R1 (0-10 inches; 0-25 cm)	y - negl	N/A	California, Arizona, New Mexico, Mexico (especially Baja California Sur), and Israel.

Question ID	Answer - Uncertainty	Score	Notes (and references)
Geo-R2 (10-20 inches; 25-51 cm)	y - negl	N/A	California, Arizona, New Mexico, Mexico, and Israel.
Geo-R3 (20-30 inches; 51-76 cm)	y - negl	N/A	Arizona, Kansas, Mexico, and Israel.
Geo-R4 (30-40 inches; 76-102 cm)	y - negl	N/A	Texas, Kansas, Mexico, Germany, the Netherlands, Belgium, and Sweden.
Geo-R5 (40-50 inches; 102-127 cm)	y - negl	N/A	A few points each in Mexico, Denmark, and Germany; 1 point in Japan; and 2 points in South Carolina. Also in Illinois (Kartesz, 2015).
Geo-R6 (50-60 inches; 127-152 cm)	y - negl	N/A	Germany (1 point), Mexico, Louisiana, and South Carolina (few points in each). Also in Mississippi and Georgia (SEINet, 2019).
Geo-R7 (60-70 inches; 152-178 cm)	y - mod	N/A	Japan (2 points), France (1 point), Mexico (1 point), and Alabama (3 points). Also in Mississippi (few points) (SEINet, 2019).
Geo-R8 (70-80 inches; 178-203 cm)	y - high	N/A	Japan (8 points). Several references in Randall (2017) indicate that *A. palmeri* has naturalized in Japan, though Kistner and Hatfield (2018) describe it as only ephemeral there.
Geo-R9 (80-90 inches; 203-229 cm)	n - high	N/A	Japan (4 points), Germany (1 point near edge with 70-80 inches).
Geo-R10 (90-100 inches; 229-254 cm)	n - mod	N/A	Japan (1 point).
Geo-R11 (100+ inches; 254+ cm)	n - mod	N/A	Japan (2 points).
ENTRY POTENTIAL			
Ent-1 (Plant already here)	n - negl	0	This species is found in the southwestern and south-central states and is spreading in the eastern states (eFloras, 2019). Although it is native to parts of the United States, we set this answer to no to evaluate the likelihood that additional material would enter new areas.
Ent-2 (Plant proposed for entry, or entry is imminent)	n - negl	0	*Amaranthus palmeri* has not been proposed for import into the United States.
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]	a - low	0	Although the leaves and seeds have been consumed by several Native American tribes (Ward et al., 2013), *A. palmeri* is largely considered a weed and is not known to be cultivated for any purpose (e.g., Sauer, 1955; Bailey and Bailey, 1976; IPK Gatersleben, 2019; Dave's Garden, 2019; University of Minnesota, 2019; NGRP, 2019).
Ent-4 (Entry as a contaminant)			
Ent-4a (Plant present in the U.S., Mexico, EU or China)	y - negl		It is native to the United States and Mexico (NGRP, 2019).

Question ID	Answer - Uncertainty	Score	Notes (and references)
Ent-4b (Contaminant of plant propagative material (except seeds))	? - max		Seeds are small and numerous and could potentially contaminate propagative plant material in close proximity; however, we found no evidence.
Ent-4c (Contaminant of seeds for planting)	y - negl	0.08	*Amaranthus palmeri* was found as a contaminant in Conservation Reserve Program seed mixes (NRCS, 2017a). Seeds disperse as seed contaminants (DiTomaso and Healy, 2007).
Ent-4d (Contaminant of ballast water)	y - mod	0.06	*Amaranthus palmeri* is described as a rare species of waste ground and ballast in Pennsylvania (Rhoads and Block, 2007).
Ent-4e (Contaminant of aquarium plants or other aquarium products)	n - low	0	We found no evidence, but it is unlikely. The species is well-known and not aquatic.
Ent-4f (Contaminant of landscape products)	y - mod	0.04	Seeds disperse in soil (DiTomaso and Healy, 2007).
Ent-4g (Contaminant of containers, packing materials, trade goods, equipment or conveyances)	y - negl	0.04	*Amaranthus palmeri* is spreading in association with combines and other mobile farm equipment (Legleiter and Johnson, 2013; Barber et al., 2015; Spaunhorst, 2016; KLT, 2017; NRCS, 2017a).
Ent-4h (Contaminants of fruit, vegetables, or other products for consumption or processing)	y - negl	0.02	It is transported by people through grain (Legleiter and Johnson, 2013) and likely entered Belgium as a grain contaminant (EPPO, 2014). It also disperses in association with wool waste (Haines, 2011).
Ent-4i (Contaminant of some other pathway)	e - negl	0.08	It is spreading through contaminated hay and feed (KLT, 2017; NRCS, 2017a; DiTomaso and Healy, 2007; Legleiter and Johnson, 2013) and was introduced in Michigan through the spread of manure from dairy cows that were fed cotton by-products as a feed supplement (NDSU, 2014; NDSU, 2015). We answered "e" because hay and feed are used in agricultural environments where *A. palmeri* could easily establish.
Ent-5 (Likely to enter through natural dispersal)	y - mod	0.06	Populations of *A. palmeri* are spreading in the northeastern and prairie states (Peters et al., 2018; SEINet, 2019). This may occur through a combination of both unintentional human dispersal and natural dispersal by wildlife and water. The recent occurrence of *A. palmeri* in North Dakota is thought to be attributable to migratory birds (Peters et al., 2018).