fineEUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION
ORGANISATION EUROPEENNE ET MEDITERRANEENNE POUR LA
PROTECTION DES PLANTES

20-25806

# Pest Risk Analysis for

# *Amaranthus palmeri*

*Amaranthus palmeri* in agricultural land Spain (Image courtesy Guillaume Fried, EPPO Global Database)

September 2020

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The risk assessment follows EPPO standard PM 5/5(1) *Decision-Support Scheme for an Express Pest Risk Analysis* (available at http://archives.eppo.int/EPPOStandards/pra.htm), as recommended by the Panel on Phytosanitary Measures. Pest risk management (detailed in appendix 1) was conducted according to the EPPO Decision-support scheme for quarantine pests PM 5/3(5). The risk assessment uses the terminology defined in ISPM 5 *Glossary of Phytosanitary Terms* (available at https://www.ippc.int/index.php).

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**Based on this PRA, *Amaranthus palmeri* was added to the EPPO A2 List. Measures for grains of *Arachis hypogaea, Glycine max, Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*; Seeds of *Glycine max, Gossypium hirsutum, Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*; seed mixtures and native seeds; as well as used agricultural machinery and equipment are recommended.**

# Pest Risk Analysis for *Amaranthus palmeri* S. Watson (Amaranthaceae)

**PRA area:** EPPO region
**Prepared by:** EWG on *Amaranthus palmeri* and *A. tuberculatus*

**Date:** 24-28 February 2020
Further reviewed and amended by EPPO core members and Panel on Invasive Alien Plants.

### Composition of the Expert Working Group (EWG)

| | |
|---|---|
| BRUNDU Giuseppe (Mr) | University of Sassari, Department of Agriculture, Italy |
| CHAPMAN Daniel (Mr) | University of Stirling, United Kingdom |
| FERRELL Jason (Mr) | University of Florida , United States |
| FOLLAK Swen (Mr) | Austrian Agency for Health and Food Safety (AGES), Institute for Sustainable Plant Production, Austria |
| FRIED Guillaume (Mr) | ANSES - Laboratoire de la santé des végétaux, Station de Montpellier, CBGP, France |
| HARTZLER Bob (Mr) | Iowa State University, United States |
| STARFINGER Uwe (Mr) | Julius Kühn Institut (JKI), Federal Research Centre for Cultivated Plants, Institute for National and International Plant Health, Germany |
| PICARD Camille (Mr)<br>TANNER Rob (Mr) | OEPP/EPPO, France<br>hq@eppo.int |

The first draft of the PRA was prepared by the EPPO Secretariat.

Ratings of likelihoods and levels of uncertainties were made during the meeting. These ratings are based on evidence provided in the PRA and on discussions in the group. Each EWG member provided a rating and a level of uncertainty anonymously and proposals were then discussed together in order to reach a final decision.

Following the EWG, the PRA was further reviewed by Ms Suffert (EPPO) and the following core member: MacLeod A.

The PRA, in particular the section on risk management, was reviewed and amended by the EPPO Panel on Invasive Alien Plants on 2020-06. The EPPO Working Party on Phytosanitary Regulations and Council agreed that *Amaranthus palmeri* should be added to the A2 List of pests recommended for regulation as quarantine pests in 2020.

## Contents

**Summary** of the Express Pest Risk Analysis for *Amaranthus palmeri*

**PRA area:** EPPO region in 2020 (Albania, Algeria, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Guernsey, Hungary, Ireland, Israel, Italy, Jersey, Jordan, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, The Republic of North Macedonia, Malta, Moldova, Montenegro, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tunisia, Turkey, Ukraine, United Kingdom, Uzbekistan)

**Describe the endangered area:**

The EWG considered that the endangered area includes agricultural environments in the Mediterranean area, middle east area and central Asian area of the EPPO region. The EWG considered the species distribution modelling conducted as part of this PRA (see Appendix 3) to be a realistic projection of the potential occurrence of *A. palmeri* in the EPPO region.

**Main conclusions**

***Amaranthus palmeri*** **presents a high phytosanitary risk for the endangered area with low uncertainty.**

The likelihood of new introductions to the EPPO region occurring via bird feed is very high with a high uncertainty. The likelihood of new introductions to the EPPO region occurring via grain of peanut *Arachis hypogaea*, soybean (*Glycine max),* sunflower (*Helianthus annuus),* rice (*Oryza sativa),* sorghum (*Sorghum bicolor)* and maize (*Zea mays)* is high with a moderate uncertainty. For seeds of *Glycine max*, *Gossypium hirsutum*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor* and *Zea mays*, the likelihood of new introductions is moderate with moderate uncertainty. Entry into the EPPO region via seed mixtures and single species native seed packets is moderate with a high uncertainty.

Within the EPPO region, the species mostly grows in managed habitats such as ruderal and agricultural environments. *A. palmeri* is capable of invading many summer crops in particular late sowing crops like maize and soybean. The high frequency of maize and soybean in the crop rotation system in many EPPO countries is a factor that may facilitate the establishment of *A. palmeri* once the field has become contaminated. The likelihood of further establishment outdoors is very high with low uncertainty. Establishment in protected conditions is moderate with high uncertainty. Protected conditions such as in nurseries and polytunnels may offer appropriate conditions for the development of the pest. The potential for spread within the EPPO region is very high with a low uncertainty. *A. palmeri* can spread both naturally and via human assisted spread.  Seeds of *A. palmeri* can be moved through agricultural machinery and plant products (e.g. grains, seeds) within the EPPO region.

The impacts of *A. palmeri* in North America are primarily the reduction of crop yields and increased management costs. The EWG considered the potential socio-economic impacts in the EPPO region will be high with a moderate uncertainty.

*A. palmeri* is difficult to manage because it can produce large volumes of seeds and build up a persistant seed bank. This species has already been shown to easily develop resistance to various herbicide mode of actions in North America. The EWG considered that early detection and rapid responses are critical to avoid further spread and impact of *A. palmeri*. The EWG recommended that a weed management strategy should to be developed for the EPPO region as a priority due to the recent increase in the reported spread (Catalonia in Spain).

| | | | |
|---|---|---|---|
| **Phytosanitary risk for the *endangered area*** (*Individual ratings for likelihood of entry and establishment, and for magnitude of spread and impact are provided in the document*) | High X | Moderate ☐ | Low ☐ |
| **Level of uncertainty of assessment** | High ☐ | Moderate ☐ | Low X |

| | | | |
|---|---|---|---|
| (see Section 17 for the justification of the rating. Individual ratings of uncertainty of entry, establishment, spread and impact are provided in the document) | | | 🟧 |

The EWG conducted two PRAs simultaneously on *A. palmeri* and *A. tuberculatus*. Text written in these PRAs have similarities. *Amaranthus palmeri* and *A. tuberculatus* are very similar in their biology and pathways, and both are important weeds in North America. However, these species show differences in terms of competitiveness and area of potential establishment in the EPPO region.

***Other recommendations:***

- perform a proper botanical survey in the EPPO region (e.g. during August when the inflorescence is visible). This can be performed for *A. palmeri* and *A. tuberculatus* together. If performed on the endangered area identified for *A. tuberculatus*, this would already cover the *A. palmeri* endangered area.
- take samples to determine herbicide resistance of the established populations.
- develop educational materials to help people identifying this species and promote early detection in new areas.

**EPPO Pest Risk Analysis:**

# *Amaranthus palmeri* S.Watson

## Stage 1. Initiation

**Reason for performing the PRA:**

*Amaranthus palmeri* was first observed in the EPPO region (e.g. Sweden) in the early 1900s and is now recorded as established in a few EPPO countries and transient in several others. In the USA, *A. palmeri* is considered a significant weed in agricultural systems (Ward *et al*., 2013). Despite its invasive pattern in North America, the emergence of *A. palmeri* as a major agronomic weed is relatively recent. Major impacts have been reported in maize, soybean, peanut, sweet potato and the plant has become one of the most economically damaging weed species in the USA. Its high capacity for developing herbicide resistance could complicate control programmes using traditional techniques within the EPPO region, should the species become established. Following relatively recent reports in maize fields in Spain, the species has been added to the EPPO Alert List in 2014. In June 2019, the Panel on Invasive Alien Plants prioritized *A. palmeri* for a pest risk analysis.

**PRA area:**

EPPO region in 2020: (Albania, Algeria, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Guernsey, Hungary, Ireland, Israel, Italy, Jersey, Jordan, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Luxembourg, The Republic of North Macedonia, Malta, Moldova, Montenegro, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tunisia, Turkey, Ukraine, United Kingdom, Uzbekistan).

(see https://www.eppo.int/ABOUT_EPPO/eppo_members)

## Stage 2. Pest risk assessment

### 1. Taxonomy:

Kingdom: *Plantae,* Division: *Magnoliophyta,* Class: *Angiospermae,* Order: *Caryophyllales,* Family: *Amaranthaceae,* Sub-family: Amaranthoideae Genus *Amaranthus*, Species *Amaranthus palmeri* S. Watson, according to S. Watson Proc. Am. Acad. 12: 274 1877 (as Amarantus).

**EPPO code:** AMAPA

**Synonyms:**
*Amaranthus palmeri* var. *glomeratus* Uline & W.L.Bray

Ref: The Plant List (http://www.theplantlist.org/tpl1.1/record/kew-2633009)

**Common name:**

(English) careless weed, dioecious amaranth, Palmer amaranth, (Czech) laskavec Palmerův, (Dutch) tweehuizige amarant, (Finish) rassirevonhäntä, (French) Amarante de Palmer (German) Palmer-Amarant, Palmer-Fuchsscchwanz, (Hebrew) yarbuz palmer, (Italian) Amaranto di Palmer, (Japanese) ô-honaga-aogeitô, (Korean) gin i sak bi reum, (Norwegian) soya-amarant, (Polish) szarłat Palmera, (Russian) щирица Пальмера, (Slovak) láskavec Palmerov, (Swedish) kvarnamarant (EPPO, 2020).

Collectively, the genus *Amaranthus* is known as pigweed.

**Plant type:** Annual herbaceous.

**Related species in the EPPO region:**
The genus *Amaranthus* has a global distribution and comprises approximately 70 species (Iamonico, 2015). Some 40 species are native to the Americas, and the remaining are native to Australia, Africa, Asia and Europe (Costea *et al*., 2001). Examples of native *Amaranthus* species to the EPPO region are listed below. A number of non-native *Amaranthus* species occur in the EPPO region (see below). Here the list is not intended to be exhaustive but gives examples of species.

**Examples of native species in the EPPO region:**

*Amaranthus blitum* subsp. *blitum*, *A. graecizans* subsp. *sylvestris*. *Amaranthus* × *cacciatoi* and *A. hybridus* var. *bouchionii* listed by Iamonico (2015) as 'probably native' to Europe should be considered as neonative species sensu Stace & Crawley (2015).

**Examples of non-native species in the EPPO region:**
*Amaranthus acutilobus*, *A. albus*, *A. blitoides*, *A. caudatus*, *A. crispus*, *A. cruentus*, *A. deflexus*, *A. emarginatus subsp*. *emarginatus* var. *emarginatus*, *A. emarginatus* subsp. *emarginatus* var. *pseudogracilis*, *A. graecizans* subsp. *graecizans*, *A. hybridus*, (excluding *A hybridus* var *bouchionii*) *A. hypochondriacus*, *A. muricatus*, *A. polygonoides*, *A. powellii, A. retroflexus, A. spinosus, A. tamariscinus, A. tuberculatus, A. tricolor, A. viridis* (Iamonico, 2015)

### 2. Pest overview

### 2.1 Introduction
*Amaranthus palmeri* is a $C_4$ summer annual herbaceous species native to North America (Sauer, 1955).

### 2.2 Identification

Appendix 2 includes images of the plant. Further images can be found in EPPO Global Database https://gd.eppo.int/taxon/AMAPA.

The following information on morphology of *A. palmeri* has been taken from the Flora of North America (Mosyakin & Robertson, 1997), Ward *et al*. (2013) and Iamonico (2015).

Stems are erect, branched, usually (0.3-)0.5-1.5(-3) m tall, with many lateral branches often ascending. The central stem is reddish-green. Leaves are long-petiolate; blade obovate or rhombic-obovate to elliptic proximally, sometimes lanceolate distally, 1.5-7 × 1-3.5 cm, base broadly to narrowly cuneate, margins entire, plane, apex subobtuse to acute, usually with terminal mucro. The leaves are green and can have a dark V-shaped chevron on the adaxial surface. Inflorescences are terminal, linear spikes to panicles, usually drooping, occasionally erect, especially when young, with few axillary clusters, uninterrupted or interrupted in proximal part of plant. Bracts: of pistillate flowers with long-excurrent midrib, 4-6 mm, longer than tepals, apex acuminate or mucronulate; of staminate flowers, 4 mm, equaling or longer than outer tepals, apex long-acuminate. Pistillate flowers: tepals 1.7-3.8 mm, apex acuminate, mucronulate; style branches spreading; stigmas 2(-3). Staminate flowers: tepals 5, unequal, 2-4 mm, apex acute; inner tepals with prominent midrib excurrent as rigid spine, apex long-acuminate or mucronulate; stamens 5. Utricles tan colour to brown, occasionally reddish brown, obovoid to subglobose, 1.5-2 mm, shorter than tepals, at maturity walls thin, almost smooth or indistinctly rugose. Seeds are dark reddish brown to brown, 1-1.2 mm diam., shiny. However, a lot of variability is observed within *A. palmeri*. Identification of the species should be supported by molecular methods (Section 2.2.2).

Ward *et al*. (2013) detail that *A. palmeri* is probably an ancient tetraploid due to different chromosome counts which have been reported in the literature (e.g. Gaines *et al*., 2012: 2n = 34; Rayburn *et al*., 2005: 2n = 32).

*Amaranthus palmeri* has a fibrous root system which extends far from a well-developed taproot (Morichetti *et al*., 2012).

The EWG noted that *A. palmeri* has high levels of phenotypic and phenological plasticity that can hinder the identification of the species at the beginning of its development. Mature plants can be more easily identified by its significant inflorescence. Ward *et al.* (2013) notes plasticity in leaf morphology and root/shoot size ratios.

### 2.2.1 Morphological identification

Misidentification between *Amaranthus* species can and has occurred throughout its range due to the morphological variation within species and hybridization between species (Wetzel *et al*., 1999). There are several identification keys that can be used to distinguish between *Amaranthus* species (e.g. Pratt *et al*., 1999; Horak *et al*., 2019), and some of the key characteristics include flower morphology (needing magnification identification due to their small size), leaf shape, presence or absence of hair on the stem, seed head shape and seedling shape (Pratt *et al*., 1999).

Iamonico (2015) provides short descriptions of the *Amaranthus* species found in the EPPO region.

Seeds of *A. palmeri* are not visually distinguishable from those of all other *Amaranthus* species.

### 2.2.2 Molecular identification

Molecular methods are available to identify species within the genus using either plant material or seed.

A PCR test method has been developed to distinguish seven weedy *Amaranthus* species (*A. palmeri*, *A. spinosus, A. retroflexus, A. blitoides, A. viridis, A. tuberculatus* and *A. hybridus*) from plant material based on intron 1 sequences from the 5-enolpyrvylshikimate-3-phosphate synthase gene (Wright *et al*., 2015). Other methods are also described in the literature (e.g. Wetzel *et al*., 1999; Popa *et al*., 2010).

A qPCR assay to distinguish *A. palmeri* seeds from 12 other *Amaranthus* species has been developed and validated in the USA (Murphy *et al*., 2017). The method can detect a single *A. palmeri* seed from a sample of 100 *Amaranthus* seeds.

### 2.3 Hybridization

*Amaranthus palmeri* has been shown through field and greenhouse experiment to be capable of hybridizing with *A. spinosus*, *A. tuberculatus* and *A. hybridus* (Gaines *et al.*, 2012). Hybridization rates varied between greenhouse and field experiments where frequency rates between *A. palmeri* and *A. spinosus* in field studies ranged from <0.01% to 0.4%, and 1.4% in greenhouse crosses. Those hybrids which were grown to adult plants were monoicous and the majority produced viable seed. Hybrids were also formed from field experiments between *A. palmeri* and *A. tuberculatus* (frequency rate < 0.2 %) and *A. palmeri* and *A.*

*hybridius* (frequency rates < 0.01 %). In the same study, Gaines *et al.*, 2012 did not find any evidence of hybridization between *A. palmeri* and *A. powellii* or *A. palmeri* and *A. retroflexus.* Ward *et al.* (2013) suggests that the aforementioned studies highlight that hybridization under field conditions is low and probably rare within the natural environment especially when consideration is given to the lack of overlap in flowering times between congeners. It is important to note, however, that *A. palmeri* has been shown to have developed herbicide resistance to a number of active substances (see section 2.7) and herbicide resistance can be passed on through gene flow (Ward *et al.,* 2013). Hybridization is not a common situation in field conditions.

## 2.4 Life cycle and environmental requirements

*A. palmeri* is a dioecious summer annual species. Spaunhorst *et al.* (2018) highlight that even though *A. palmeri* can vary biologically from different populations, plants exhibit phenotypic plasticity driven by the environment which facilitates their spread and persistence in new areas. The competitive ability of *A. palmeri* may, in part, be attributed to its high photosynthetic rate which has been cited up to 81 µmol/m2/s at 42 $^{o}$C) (Davis, 2015 citing Ehleringer, 1983). However, the EWG note that this rate is high and other publications detail 60 µmol/m2/s (Jha *et al*., 2008) and 30 µmol/m2/s Berger *et al*., 2015). In its native desert habitat, *A. palmeri* grows as a summer annual herb and is adapted to the rigors of intense heat and low unpredictable rainfall. PFAF (2019) detail that *A. palmeri* is a frost sensitive species. It can grow on a wide range of soil types in terms of texture and pH: it grows in light (sandy), medium (loamy) and heavy (clay) soils where it prefers well drained soils, but can also grow and persist in flooded rice (Norsworthy *et al*., 2013). The pH of preferred soils include acid, neutral and alkaline soils. It prefers full sunlight to shade (Ward *et al*., 2013). *A. palmeri* can persist in very high temperatures. Indeed, at 45/40 °C, *A. palmeri* plants only died 25 days after initiation of the heat treatment (Guo & Al-khatib, 2003).

### 2.4.1 Seed germination and emergence of seedlings

Seed germination is initiated with availability of moisture, coupled with temperature and light availability (Jha, 2008). *Amaranthus palmeri* seeds germinate quickly in the soil often within 1 or 2 days. The small size of the seeds necessitates a relatively shallow position within the soil profile for successful germination (Ward, 2013). Steckel *et al*. (2000) highlights that germination can occur between 5 °C and 35 °C with 8 % and 71 % emergence respectively. Guo and Al-khatib (2003) conducted experiments on the effect of temperature on seed germination and did not observe any germination at 15/10$^{o}$C day/night temperatures. Seed germination was at its peak with 35/30$^{o}$C day/night temperature. Jha (2008) conducted seed germination experiments using seed collected in South Carolina and showed germination was related to temperature with a time factor. Seeds collected in November had lower germination rates when exposed to constant temperatures compared to the higher fluctuating temperatures. Seeds which underwent a time period dormancy (exposed to winter temperatures in nylon bags) showed the highest germination rates.

Steinmaus *et al*. (2000) estimate that the minimum temperature required for development (base temperature ($T_b$) of *A. palmeri* is 16.6 $^{o}$C. Seeds were observed to germinate at a minimal temperature above 15°C in the USA, from mid-March to October (November for the unique situation of Florida).

The EWG noted that seed germination is not observed in field conditions in the USA (Florida) before March (J. Ferrell, pers. comm., 2020). Based on experimental studies in greenhouses conditions, the EWG considered that at least a few seeds of *A. palmeri* can germinate at a temperature range of between 2.5 – 42.5 °C. *Amaranthus palmeri* can exhibit a prolonged emergence period throughout the growing season (Davis, 2015), and there can be a number of peak emergence periods throughout the season (Jha, 2008) driven by the timing of rainfalls and moisture periods (e.g. irrigation).

There seems to be a physical dormancy based on seed coat thickness which is related to how long the seed is staying on the mother plant.

Shading (light quality) of the maternal plant can influence seed germination (Ward *et al*., 2013; Jha, 2008). Additionally, the location of the seed on the mother plant can influence seed germination (Jha, 2008). Jha (2008) showed that plants grown in 87 % shade produced seed with a lower percentage germination compared to plants grown in full sunlight. Seed from the middle and top third of the plant had a higher percentage germination compared to seed from the lower third of the plant.

### 2.4.2 Growth rates

*Amaranthus palmeri* has first a lag phase with a low above ground growth rate with a rapid root extension (J. Ferrell, pers. comm., 2020). Three to four weeks after germination, a rapid growth rate is observed (up to 2 to 3 inches [5.1 to 7.6 cm] per day (Hensleigh, 2017). Maximum growth is achieved during the summer months.

### 2.4.3 Pollen

Pollen is wind-dispersed and male flowers produce copious amounts of pollen (Ward *et al*., 2013). Pollen has been shown to fertilize female plants up to 250 m from the paternal plant (Davis, 2015). However, pollen may be dispersed over much longer distances. Extreme fluctuations in humidity and temperature during pollen dispersal can decrease the viability of pollen (Davis, 2015).

### 2.4.4 Seed production

A number of aspects can influence the number of seeds produced (Ward *et al.*, 2013; Davis, 2015). Spaunhorst *et al*. (2018) showed that above-ground biomass of individual plants was positivity correlated with the number of seeds. Ward *et al*. (2013) (citing Keeley *et al*., 1987) details that female plants in California, which emerge between March and June, can produce between 200 000 and 600 000 seeds when growing without plant competition. Plants that emerge later were observed to produce fewer seeds (< 80000 seeds per plant), but much faster than early season emerging plants (e.g. production of maturated seeds in about 1.5 months) (Spaunhorst, 2018).

### 2.4.5 Seed bank persistence

Seed bank densities have been estimated to be as high as 1.1. billion seeds ha $^{-1}$ (Menges, 1987). The length of time seed occurs in the soil profile can affect its viability. In a burial experiment, Sosnoskie & Culpepper (2011) showed that seed viability decreased with time following burial. When an average was taken over varying depths, seed viability was 60 % after 12 months and 40 % after 24 months. Ward *et al*., (2013) citing Burnside *et al*., 1996), highlights that studies have excavated viable seeds from burial experiments 17 years after burial. In addition to time as a factor of viability, the depth seed occurs in soil is also reported to affect seed viability within the seed bank. Sosnoskie and Culpepper (2011) showed that seeds buried at depths of 1-10 cm lost 30 % of their viability after 6 months and 50 % after a year, reducing to less than or equal to 15 % viability. When buried at 40 cm, seed viability was greater with 78, 61, and 22 % viability at 6, 12 and 36 months respectively (Sosnoskie and Culpepper, 2011). Jha *et al*. (2014) demonstrated that the seedbank in soil will be almost completely depleted in 4 years if no additional seed are allowed to enter.

### 2.4.6 Seed dispersal capacity

Seeds are naturally dispersed by barochory (falling from the parent plant) and hydrochory (dispersal via water). In the case of barochory, dispersal takes place over very limited distances (a few metres around the mother plant). In the case of hydrochory, Norsworthy *et al*. (2014) reports that *A. palmeri* seed can travel as far as 114 m in rainwater. Seeds can be spread through water movement, along rivers and streams and throughout a catchment.

## 2.5 Habitats

*A. palmeri* is an early successional species colonizing disturbed areas. It is found in natural habitats along permanent or intermittent streams, river flood plains, dried river beds and the edge of marshes (Sauer, 1955). The species is also found in artificial habitats in the United States including irrigation ditches, roadsides, railways and dumps (Bagavathiannan & Norsworthy, 2015; Sauer, 1955). The species is mainly found in agricultural habitats within the fields or along the field margins. crops (section 2.6).

See section 7 for further details on habitats in the EPPO region.

## 2.6 Association with crops

As a summer annual species, *A. palmeri* is able to persist and thrive in crops which have a similar agronomic lifecyle to the species. *A. palmeri* has been found in fields of a number of crop types (Table 1). North Central IPM Center (2020) highlights that crops with a different life cyle to *A. palmeri*, i.e. perennial crops and winter grown cover crops present unfavorable environments for the species.

**Table 1. Main crops which *Amaranthus palmeri* is associated with.** Country codes are ISO Country codes (AR: Argentina, IL: Israel, IT: Italy, US: USA, TR: Turkey)

| Crop | Country | Reference |
|---|---|---|
| *Arachis hypogaea* | AR, US | Morichetti *et al*., 2013; Burke *et al*., 2007 |
| *Glycine max* | AR, US, IT | Fabbri & Campagna, 2016; Morichetti *et al*., 2013; Klingaman and Oliver 1994 |
| *Ipomoea batatas* | US | Meyers *et al*., 2010 |
| *Sorghum bicolor* | US | Moore *et al*. 2004 |
| *Citrullus lanatus* | IL, TR, US | Matzrafi *et al*., 2017; Özaslan *et al*., 2017; Bertucci *et al*., 2019 |
| *Zea mays* | IL, US, TR | Massinga *et al*., 2001; Matzrafi *et al*., 2017 |
| *Oryza sativa* | US | Norsworthy *et al*., 2017 |
| *Helianthus annuus* | US | Reddy *et al*., 2015 |
| *Cucumis sativus* | US | McGowen *et al*., 2018 |
| *Gossypium hirsutum* | IL, US, TR | Massinga *et al*., 2001; Matzrafi *et al*., 2019 |

*A. palmeri* may be associated with other summer crops in its area of origin.

China intercepted *A. palmeri* in canola grains (*Brassica napus* subsp. *napus*) from Canada (GACC, 2020). The EWG commented that it can be explained by a secondary contamination. Therefore, canola grains are not considered further in the PRA.

*Amaranthus palmeri* has also repetitively been reported on 12 port sites situated along the Romanian Black Sea). The authors hypothesize that it may have been transported with cereal containers (Anastasiu *et al*., 2011). However, the EWG note that it is unlikely that seed of the species would be a contaminant of cereal crops in North America.

### 2.7 Herbicide resistance

Resistance has been confirmed in populations of the species to eight different herbicide mechanisms of action including: ALS-inhibiting herbicides (e.g. imazethapyr), auxins (e.g. 2,4-D), tubulin inhibitors (e.g. trifluralin), EPSPS (e.g. glyphosate), HPPD inhibitors (e.g. mesotrione), Protoporphyrinogen Oxidase (PPO, e.g. acifluorfen), Photosystem II (PSII, e.g. atrazine) and VLCFA (e.g. metolachlor) (Heap, 2020; USDA, 2019a). Resistance has been shown in the USA (cotton, soybean, maize, sorghum, alfalfa, peanut), Argentina (soybean), Brazil (cotton, maize, soybean) and Israel (maize, cotton, watermelon) (Heap, 2020).

**3. Is the pest a vector?** **Yes** ☐ **No** X

Seeds and grains of *A. palmeri* are not known to be a vector.

**4. Is a vector needed for pest entry or spread?** **Yes** ☐ **No** X

### 5. Regulatory status of the pest

In the USA *A. palmeri* is not regulated at the federal level though, *A. palmeri* is considered a noxious weed in the states of Delaware, Minnesota and Ohio (Hensleigh & Pokorny, 2017) and subject to seed restrictions in the following states (USDA, 2019b):

- Indiana (Restricted[1])
- Iowa (Prohibited, primary[2])
- Minnesota (Prohibited[3])
- North Dakota (Prohibited)
- Ohio (Prohibited)

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[1] It is unlawful for any person to distribute agricultural seeds if the seed consists of or contains restricted noxious-weed seeds in excess of 0.25 percent, or if it contains more than 2.5 percent of all weed seeds. If less than 0.25 percent of such weed seeds by weight are present, the number per pound must be declared on the labelling

[2] Prohibits the sale of agricultural seed if it contains any primary noxious-weed seeds

[3] Minnesota law prohibits the sale of agricultural seed containing any prohibited noxious-weed seeds. *Genetic testing of any Amaranthus contaminant must be conducted to determine if Palmer amaranth is present.

- South Dakota (Prohibited)
- Tennessee (Prohibited)
- Washington (Prohibited)
- Wisconsin (Prohibited)

In Canada, *A. palmeri* is not regulated at the federal level but it is regulated as a noxious weed in the province of Manitoba (Canadian Food Inspection Agency, 2018).

Brazil: *A. palmeri* is regulated for several host seeds and grains from various locations which are required to be free from the pest demonstrated by either the production in a pest-free area, a phytosanitary inspection at the place of production, or laboratory testing (WTO, 2018: WTO notification G/SPS/N/BRA/1369).

Australia: *A. palmeri* is a quarantine species which is prohibited from entry (Pheloung *et al*., 2014; Moniodis, 2014; BICON, 2019; cited in USDA, 2019a).

In the EPPO region the species is regulated in the following countries:

- Morocco (Quarantine pest, 2018) (EPPO, 2020; ONSSA, 2018)
- Spain (ORDRE ARP/172/2019, de 10 de setembre , per la qual es declara l'existència de la mala herba *Amaranthus palmeri* i es qualifica d'utilitat pública la lluita contra aquesta)

### 5.1 **Existing PRAs**

A Weed Risk Assessment has been conducted by the Canadian Food Inspection Agency (2018) with Canada as the PRA area. Pathways assessed in the PRA include natural dispersal and unintentional introduction (contaminant of seed and grain, contaminant of hay and feed, soil, vehicles and farm equipment). Contaminant of wool waste and ballast water were identified as less likely unintentional pathways. In the PRA, the species is scored as a high risk for the PRA area.

A Weed Risk Assessment has been conducted by USDA (USDA, 2019a) with the USA as the PRA area. The PRA identified the same pathways as the Canadian risk assessment. In the PRA, the species is scored as a high risk for the PRA area.

A Weed Risk Assessment has been conducted on *A. palmeri* for Florida (USA) using the Australia/New Zealand Weed Risk Assessment adapted for Florida (HEAR, 2020). The species scored a total of 11 points resulting in the species being rejected (prohibited from import) due to its negative effects (a score above 6 equals rejection).

A weed risk assessment has also been conducted in China (Han *et al.*, 2013). The genus *Amaranthus* is regulated in China.

## 6. Distribution

*Amaranthus palmeri* is native to North America (Mosyakin & Robertson, 1997). The species is recorded as being weedy in many states of the USA. The species has been introduced into Africa, Asia, the EPPO region and South America (Table 2).

In North America, *A. palmeri* has been historically reported as native to the Sonoran Desert (covering a large part of Southwestern United States and Northwest Mexico) (Sauer 1955). In North America, the species has expanded from its native range to occupy many states across the USA but is most common and problematic in the southern tier states (Louisiana, Arkansas, Mississippi, Alabama, Florida, Georgia, North and South Carolina).

Canadian Food Inspection Agency (2018) detail that the species is considered to be present but highlights the 'significant uncertainty' regarding the current status. It is unknown if populations of *A. palmeri* currently occur in Ontario in areas where it was previously reported.

**Table 2. Global distribution of *Amaranthus palmeri***

| **Region** | **Distribution** | **Status** | **References and comments** |
|---|---|---|---|
| **North America** | | | |
| *Canada* | Ontario | Introduced | Mosyakin & Robertson (1987). Present only in some areas, restricted to southern Ontario (Canadian Food Inspection Agency, 2018). |
| *Mexico* | | Native | Mosyakin & Robertson (1997), Hensleigh (2017) |
| *United States of America* | Alabama | Introduced | Chahal *et al* (2015); common and problematic |
| | Arizona | Native | Mosyakin & Robertson (1997); weedy |
| | Arkansas | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | California | Native | Mosyakin & Robertson (1997) |
| | Colorado | Introduced | Mosyakin & Robertson (1997) |
| | Florida | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | Georgia | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | Illinois | Introduced | Mosyakin & Robertson (1997) |
| | Indiana | Introduced | Mosyakin & Robertson (1997); Legleiter & Johnson, 2013 |
| | Iowa | Introduced | Mosyakin & Robertson (1997) |
| | Kansas | Introduced | Mosyakin & Robertson (1997) |
| | Kentucky | Introduced | Mosyakin & Robertson (1997) |
| | Louisiana | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | Maryland | Introduced | Mosyakin & Robertson (1997) |
| | Massachusetts | Introduced | Mosyakin & Robertson (1997) |
| | Michigan | Introduced | Mosyakin & Robertson (1997) |
| | Minnesota | Introduced | Hensleigh (2017) |
| | Mississippi | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | Missouri | Introduced | Mosyakin & Robertson (1997) |
| | Nebraska | Introduced | Mosyakin & Robertson (1997) |
| | Nevada | Native | Mosyakin & Robertson (1997) |
| | New Jersey | Introduced | Mosyakin & Robertson (1997) |
| | New Mexico | Native | Mosyakin & Robertson (1997) |
| | New York | Introduced | Mosyakin & Robertson (1997) |
| | North Carolina | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | North Dakota | Introduced | Mosyakin & Robertson (1997) |
| | Ohio | Introduced | Mosyakin & Robertson (1997) |
| | Oklahoma | Introduced | Mosyakin & Robertson (1997) |

| | | | |
|---|---|---|---|
| | Pennsylvania | Introduced | Mosyakin & Robertson (1997) |
| | South Carolina | Introduced | Mosyakin & Robertson (1997); common and problematic |
| | South Dakota, | Introduced | Hensleigh (2017) |
| | Tennessee | Introduced | Mosyakin & Robertson (1997) |
| | Texas | Native | Mosyakin & Robertson (1997) |
| | Utah | Introduced | Mosyakin & Robertson (1997) |
| | Virginia | Introduced | Mosyakin & Robertson (1997) |
| | West Virginia | Introduced | Mosyakin & Robertson (1997) |
| | Wisconsin | Introduced | Mosyakin & Robertson (1997) |
| **South America** | Argentina | Introduced | Córdoba province and also in San Luis and La Pampa provinces (Morichetti *et al.*, 2013) (Berger et al., 2016) |
| | Brazil | Introduced | Gazziero & Adegas 2016; Küpper *et al*. 2017 |
| | Uruguay | Introduced | Belgeri et al. (2017) |
| **Africa** | Egypt | Introduced | (Iamonico & Mokni, 2017) |
| | South Africa | Introduced | Douglas area (Northern Cape) recently identified (2017) (CropLife, 2019) |
| **Asia** | China | Introduced | Zhenyu (2003) Xiang-Qin *et al.*, (2017) |
| | India | Introduced | Kistner and Hatfield (2018); Patil (1998) |
| | Japan | Introduced | Transient (Kistner and Hatfield, 2018) |
| | Republic of Korea | Introduced | Chang *et al*., 2014 (details: introduced) |
| **EPPO region** | Austria | Introduced | Transient (NOBANIS, 2019) |
| | Belgium | Introduced | Transient (Robbrecht & Jongepier, 1986) |
| | Cyprus | Introduced | Established invasive (Hadjikyriakou *et al*., 2004) |
| | Czech Republic | Introduced | Two records (Transient populations) (PLADIAS, 2019) |
| | Denmark | Introduced | Transient (NOBANIS, 2019) |
| | France | Introduced | Absent. Pest no longer present. Transient species in 19th century (INPM, 2020). |
| | Germany | Introduced | Transient (Schmitz, 2002) |
| | Greece | Introduced | Established: population present for several years (Greuter and Raus, 2006), Arianoutsou et al. (2010) records as naturalised. |
| | Israel | Introduced | Established Greuter and Raus, 2006; Flora of Israel Online (2019) |
| | Italy | Introduced | Established (Iamonico, 2015) |
| | Latvia | Introduced | Transient (NOBANIS, 2019); cemetery of Daugavpils, gathered on 06.08.2013 |
| | Lithuania | Introduced | Transient (NOBANIS, 2019) |
| | Luxembourg | Introduced | Transient (Kistner & Hatfield, 2018) |
| | Netherlands | Introduced | Transient. Reported twice, last time in 2002 (NDFF & FLORON, 2019) |
| | Norway | Introduced | Transient (NOBANIS, 2019) |
| | Portugal | Introduced | (Madeira Island) Hansen and Sunding, 1993) |
| | Romania | Introduced | Established (Anastasiu *et al*., 2011; Memedemin *et al*., 2016) |
| | Russia | Introduced | Transient (NOBANIS, 2019); Far East, Moscow region, high Volga, Udmurtiya |
| | Spain | Introduced | Naturalised in three regions: Catalonia, Aragon and Extremadura (Recasens & Conesa, 2011; Recasens *et al.*, 2017; Verloove & Gullon, 2008; M.D. Osuna Ruiz, pers. com., 2020) |
| | Sweden | Introduced | Casual (Jonsell, 2001; Kistner & Hatfield, 2018) Established/rare found in Skane (NOBANIS, 2019) |

| | | | |
|---|---|---|---|
| | Tunisia | Introduced | Transient (Nadhour, North of Tunisia) (Iamonico & Mokni, 2017) |
| | Turkey | Introduced | Established: Corn and cotton field (first ID'ed 2016) (Őzaslan *et al*., 2017) |
| | Ukraine | Introduced | Transient Kiev, Odessa, Donetsk |
| | United Kingdom | Introduced | Transient (Preston *et al*, 2002); infrequent (Stace, 2019) |
| **Oceania** | Australia | Introduced | Doubtful record. Reported as present by Mosyakin & Robertson (1997), USDA (2019a) |

*The transient status may not reflect the initial wording of the referred publication and is used following the IPPC definition (transience: Presence of a pest that is not expected to lead to establishment (ISPM 5, 2019)).

**Specific details about the distribution in selected EPPO countries (where available).** Additional information is provided in Section 7.

Austria: *A. palmeri* was found in 1951/1952 and 1958 in ruderal habitats in the city of Graz in southern Austria (Melzer 1958; Melzer, 1959). The species is rare and currently reported as not established (Fischer *et al*., 2008, NOBANIS 2019).

Belgium: The Manual of the Alien Plants of Belgium (2020) detail that *A. palmeri* is ‘a rather regular but always ephemeral alien, nearly always associated with grain importation. First seen in 1952 and 1957 as a wool alien in the Vesdre valley’. Since 1992, the species has been seen around the vicinity of grain mills in port areas of Antwerpen and Gent.

Czech Republic: Considered as casual (transient) by Pyšek et al. (2012). Recorded as present in two locations in the north of the Czech Republic (PLADIAS, 2019). First reported in the wild in 1908.

Denmark: First reported in 1959. Not regarded as invasive (NOBANIS, 2019).

Germany: The species was reported as transient from 5-6 of the Federal States (Buttler *et al*. 2018). It is not found in meaningful quantities in agricultural fields (H.-P. Söchting, pers. comm., 2020). Investigations were able to identify a single plant in the riverbank pioneer vegetation on a sandbank near Dormagen-Zons. This is the knowledge of the author to find the only evidence of *Amaranthus palmeri* in a natural habitat in DE, i.e. largely outside of anthropogenically influenced Location factors. Nevertheless, this occurrence was just like all other evidence in Europe only of an ephemeral nature. In this case this is certainly less due to the climatic factors that impede the spread of *A. palmeri*, but rather the fact that the species belongs to the dioecious subgenus *Acnida* (L.)Aellen ex K.R. Robertson. The two specimens found by the author on the Lower Rhine were male plants, which without the appropriate female plant would not have the had the opportunity to reproduce and spread.

Greece: Greuter and Raus (2006) highlight that a population near Sparta (Peloponnes) is ‘fully established, stable on the same spot for several years’.

Israel: *A. palmeri is* found throughout the country in agricultural fields. It is found in all regions north from the Negev desert (D. Cafri, pers. comm., 2019; Danin & Fragman-Sapir, 2019).

Italy: Iamonico (2015) details that the species was discovered in Northern Italy where it is an established (locally) alien species (in the two regions of Piedmont and Emilia Romagna).

Latvia: *A. palmeri* is in herbarium of Daugavpils University from cemetary of Daugavpils, gathered on 2013-08-06. NOBANIS (2019) also detail that the species was first reported in 1983 but give no further information.

Lithuania: NOBANIS (2019) detail that the species was introduced in 1989 but do not provide any further information.

Norway: NOBANIS (2019) detail that the species was first introduced and reported in 1965.

Spain: *A. palmeri* was found for the first time in the provinces of Lleida (Menàrguens and Lleida) and Huesca (Binéfar) in North-Eastern Spain in 2007 (Recasens & Conesa, 2011; Recasens *et al*., 2018). The population in Menàrguens dispersed among crop fields (maize) and adjacent field margins (Recasens *et al*., 2013). The species had previously been recorded 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 (Recasens & Conesa, 2011). Verloove & Gullon (2008) also record the species as present on a canal bank (Canal de Seros) and highlight that it is naturalising in the NE of Spain.

In August 2018 a maize field infested by *A. palmeri* was found in another zone located 40 km from the first spot (Josep Maria Llenes Espigares, pers. comm., 2020). In 2018 a total amount of 144 fields were surveyed in the area of the main infestation corresponding to 403 ha. Out of these, 34 fields corresponding to 78 ha had *Amaranthus palmeri* with various level of density. Out of these 34 plots only 16 fields had a generalized infestation within their fields (Alicia Cirujeda Ranzenberger, pers. comm., 2020). In 2019, a second prospection campaign was made to evaluate palmer amaranth infestation and a big information campaign to farmers and field technicians was made in order to find out new zones with palmer amaranth presence. The same year a regulation (ORDRE ARP/172/2019, de 10 de setembre) has been published with the purpose of minimizing the spread of the plant. The same year, *A. palmeri* has also been found in Extremadura (Western Spain) in a limited area close to Merida (Badajoz, Spain) in maize fields (Maria Dolores Osuna Ruiz, pers. comm., 2020).

In Aragón, in 2019, 1467 fields were surveyed and 118 were positive for the presence of *A. palmeri* in different degrees of infestation (pers comm. A. Mari Leon, 2020).

Sweden: NOBANIS (2019) detail that the species was first introduced and reported in 1925. They detail that it was found in Skåne.

Turkey: a newly occurring species in the South Eastern Anatolia region (SEA) in 2016 (Őzaslan *et al*., 2017). The species was found in the Mardin province (Derik district/Atlı town), in crop fields close to the roadside from Kızıltepe to Viranşehir. In addition, Raab-Straube & Raus (2016) reported records of *A. palmeri* from field margins and roadsides in different regions of Turkey in 2014 and 2015 (e.g. provinces İzmir, Adana, Osmaniye). The latter authors consider the species as established.

Tunisia: Iamonico and Mokni (2017) detail '18–20 individuals were found all referring to a single scattered population, which occupies an area of about 3–4 ha' where the habitat is ruderal on roadsides and public gardens.

UK: According to Clement and Foster (1994), *A palmeri* is a transient species estimated to be present in 5-14 locations. For example, *A. palmeri* has been found at railway station where wool shoddy had been unloaded (Alton) and in the cargo area of the Avonmouth Docks (Brenan, 1961). However, the species is not mentioned in the Online Atlas of the British and Irish flora (BRC, 2019).

It should be noted that there are uncertainties about the exact distribution of *A. palmeri s* in the EPPO region due to the transient nature of the species in the region.

## 7. Habitats at risk and their distribution in the PRA area (habitat classification based on EUNIS habitat types)

| **Habitats** | **Presence** | **Status of habitat** | **Is the pest present in the habitat in the PRA area (Yes/No)** | **Comments (e.g. *major/minor habitats* in the PRA area)** | ***Reference*** |
|---|---|---|---|---|---|
| C: Inland surface waters | Banks of major waterways, littoral zone of inland surface waterbodies | Protected in part | Yes | Major | Sauer (1955); Schmitz (2002); Verloove & Gullón (2008) |
| E: Grasslands and lands dominated by forbs, mosses or lichens* | Ruderal environments: road networks (J4-2), rail networks (J4-3), hard surface areas of ports (J4.5) | Protected in part | Yes | Major | Iamonico (2015) Iamonico & Mokni (2017); Recasens & Conesa (2011); Schmitz (2002) |
| F: Heathland, scrub and tundra | Mediterranean shrublands, shrub-steppes and semi-steppe shrublands | Protected in part | Yes | Localised | Flora of Israel, (2019) |
| I: Regularly or recently cultivated agricultural, horticultural and domestic habitats | Cultivated fields, bare tilled, fallow or recently abandoned arable land (I1-5), | None | Yes | Major | Recasens & Conesa (2011) ; Matzrafi et al. (2017) |
| X: Habitat complexes | Gardens of city and town centres (X22 – X25), Pavements and recreation areas (J4.5), Construction parts of cemeteries (J4.7). | None | Yes | Major | Iamonico (2015); Iamonico & Mokni (2017) |

* 'ruderal or pioneer communities invading artificial habitats' are included in E5.1 Anthropogenic Herbaceous Formations (EUNIS Habitat).

Habitat in its native range is described in section 2.5.

Suitable habitats occur for the establishment of *A. palmeri* in the PRA area. The habitats detailed in the table above are widespread within the EPPO region.

Within the EPPO region, the species has been recorded growing along roadsides and cultivated and uncultivated land along roads. It has been reported as growing along canals and rivers in north east Spain (Verloove & Gullon, 2008) and northern Italy (Verloove & Ardenghi, 2015). Addtionally, the species is recorded growing in public gardens, rail networks and areas around ports and industrial premises. Greuter and Raus (2006) detail that the species is found along roads in olive orchards in Greece. In addition, Raab-Straube & Raus (2015) observed *A. palmeri* in a road embankment with ruderal vegetation in Northern Italy (Province of Ravenna). The species is also recorded as growing in agricultural habitats in Spain (Recasens

& Conesa, 2011). Recent evidence from Aragón (Spain) from 2019 details that it mainly grows on the edge of the field or in the first lines of the crops (pers comm. A. Mari Leon, 2020). More than 80% of positive fields were cultivated with maize though itw as also found in orchards, alfalfa, cereal fallow and wasteland. In Italy, *A. palmeri* has been recorded in *Glycine max* fields (Fabbri & Campagna, 2016) as well as in many agricultural fields in Israel (Matzrafi *et al.*, 2017) mainly in summer crops (e.g. irrigated cotton fields) (J-M Dufour, pers. comm., 2020). In Turkey, the species is reported growing in crop fields close to the roadside e.g. corn fields (Raab-Straube & Raus, 2016).

In Israel, the species is also reported to be present in the following habitats: Mediterranean woodlands and shrublands, deserts, shrub-steppes and semi-steppe shrublands (Flora of Israel, 2019).

Within the EPPO region, most habitats of high conservation value are unsuitable, particularly in western and northern Europe. However, this may not be the case for semi-arid habitats in the Mediterranean region, where the species has been shown to establish (e.g. Greece and Israel) in ecological conditions quite similar to its native primary habitats.

## 8. Pathways for entry

Seeds and grain (as commodities) should be understood in this PRA as defined in ISPM 5 (IPPC, 2019):

- Seeds: seeds (in the botanical sense) for planting [FAO, 1990; revised ICPM, 2001; CPM, 2016]
- Grain: Seeds (in the botanical sense) for processing or consumption, but not for planting [FAO, 1990; revised ICPM, 2001; CPM, 2016].

Seeds of *A. palmeri* have already been shown to move along certain pathways. The species has been intercepted as a contaminant of seeds (J. Ferrell, pers. comm., 2020; USDA, 2013) and grains (Progressive Farmer, 2020; Oseland *et al* 2017).

The following pathways for entry of *A. palmeri* are discussed in this PRA. Pathways in bold are studied in section 8.1; other pathways were considered as a very low likelihood of entry and are detailed in section 8.2.

- **Grain for animal feed mixtures, human consumption and processing purposes**
- **Seed**
- **Seed mixtures and native seeds**
- **Used agricultural machinery and equipment**
- **Natural spread**
- Cotton ginning by-product
- Hay
- Manure
- Travellers and their equipment
- Intentional importation of *A. palmeri*
- Soil and other growing media (on its own or associated with plants for planting other than seeds)
- Wool products
- Sweet potato

### 8.1 Pathways studied

All the pathways are considered from areas where the pest has been reported to be present, into the EPPO region. Examples of prohibition or inspection are given only for some EPPO countries (in this express PRA the regulations of all EPPO countries was not fully analysed). Similarly, the current phytosanitary requirements of EPPO countries in place on the different pathways are not detailed in this PRA (although some were taken into account when looking at management options). EPPO countries would have to check whether their current requirements are appropriate to help preventing the introduction of the pest.

| **Pathway** | **Grain (for animal feed mixtures, human consumption and processing purposes)** |
|---|---|
| **Coverage (short description why it is considered a pathway)** | Seeds of *A. palmeri* maybe a contaminant in unprocessed grains imported for (1) animal feed mixture (e.g. bird seeds, grains for feeding livestock) and (2) human consumption. Grains for processing purposes are included in this pathway because it is considered that, when imported as grains, even though the process could be partially or totally destructive, storage and transportation conditions may allow further spread of *A. palmeri*. Commodities can be transferred to a processing facility and then separated for the different uses. Grains prepared for final human consumption and packaged in individual containers are not considered a pathway.<br>This pathway covers all summer grains industrially harvested in the area of origin and in which *A. palmeri* was reported (see section 2.6). This is limited to ***Arachis hypogaea, Glycine max, Helianthus annuus, Oryza sativa, Sorghum bicolor*** **and** ***Zea mays*****.**<br>Additional summer industrially harvested crops may need to be considered in the future if there is evidence that *A. palmeri* is associated with these crops. |
| **Pathway prohibited in the PRA area?** | No.<br>However, some EPPO countries impose import requirements on the purity of the grain for animal feed. *Ambrosia* spp. have been added to the list of harmful botanical impurities that are included in Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed. Feed material and compound feed containing unground grains and seeds should contain a maximum of 50 mg of seeds of *Ambrosia* spp. per kg (relative to a feed with a moisture content of 12 %). Exceptions apply to millet (grains of *Panicum miliaceum*) and sorghum (grains of *Sorghum bicolor*) that are not directly fed to animals and which may contain a maximum of 200 mg of seeds of *Ambrosia* spp. per kg (relative to a feed with a moisture content of 12 %). |
| **Pathway subject to a plant health inspection at import?** | No<br>The EWG was not aware of plant health regulations imposing inspection at import in the EPPO region on these commodities. |
| **Pest already intercepted?** | Both Canadian Food Inspection Agency (2018) and USDA (2019a) highlight the movement of *A. palmeri* seed as a contaminant of grain. Apart from these PRAs on the pest, other authors also highlight the movement of *A. palmeri* seed as a contaminant of grain in the USA (Legleiter & Johnson, 2013). It is thought that the spread of |

| Pathway | Grain (for animal feed mixtures, human consumption and processing purposes) |
|---|---|
|  | *A. palmeri* infestation into Indiana, Michigan, and Wisconsin may have started when local beef and dairy cattle were fed with grains from amaranth-infested fields in the southern United States (MacDonald, 2017).<br>Pheloung *et al*. (2014) lists *A. palmeri* as a weed species associated with maize imported from the USA which are not recorded as present in Australia.<br>*A. palmeri* entered Belgium as a contaminant of grain (Verloove, 2006). In Belgium, the species is '*nearly always associated with grain importation. From 1992 onwards seen most years in the vicinity of grain mills in port areas of Antwerpen and Gent, often in abundance (Robbrecht & Jongepier 1986, Verloove & Vandenberghe 1993)*' (Manual of the Alien Plants of Belgium, 2019).<br>In Spain and Romania, indirect evidence suggests the species may have entered via this pathway. The species has been recorded in Andalucía at the port of Sevilla and in Palos de la Frontera (province of Huelva) in the vicinity of industrial premises where grains and plant products are processed. In NE Spain, the infestation started in an animal fodder factory where probably some *A. palmeri* seeds fell out of a maize or soybean truck (Alicia Cirujeda Ranzenberger, pers. comm., 2020). In 2017 the animal fodder factory has been visited by weed scientists who found out at that moment several plants growing in their installations and already some plants had crossed the road and grew along the road in field boundaries.<br>*Amaranthus palmeri* has been identified from bird seed bought from retail outlets (Progressive Farmer, 2020). Oseland *et al* (2017) sourced birdseed from nine different companies, seven sources of wildlife food plot seed mixes from six companies, five sources of pollinator seed mixes from five companies, and four sources of CRP seed mixes from two companies. Results show that *Amaranthus* species were present in all 12 bags of birdseed examined and specifically *A. palmeri* was found in three out of 17 bird seed mixes (Splendid Blend, Birdsnack and Economy Wild Bird Feed). Oseland *et al*. (2020) examined 98 separate commercially available bird feed mixes from North America. *A. palmeri* was present in 27 of the 98 mixes.<br>*Amaranthus* spp. have also been found as contaminants of grain used for pet food in commercial mixes from different origins in Sardinia (Italy) (Cossu *et al*., 2019). |
| **Most likely stages associated with the pathway** | Seeds of *A. palmeri* are the most likely stage of the pest to be associated with the pathway. Seeds may become associated with seeds of summer crops at harvest where the species occurs. |

| **Pathway** | **Grain (for animal feed mixtures, human consumption and processing purposes)** |
|---|---|
| **Important factors for association with the pathway** | Association depends on the exact origin of the imported product and the degree of infestation of this region with *A. palmeri*.<br>Mixture of grains from different origins present a higher risk of contamination because of lack of traceability. Bird seeds are often composed of different grain species. The most common grains found are black or striped sunflower seeds, decorticated sunflower, wheat, barley, (hulled) oats, millet, sorghum, Niger seed, (cracked) maize, safflower, groundnut or groundnut pieces, pine nuts, canary seed and quinoa. Some companies include in their product range special mixes that are intended to attract particular groups or species of birds (e.g. Niger seed to attract finches, peanuts and other large seeded grains for woodpeckers and nuthatches) (FAO, 2005).<br>Association also depends on the use of the commodity and the cleaning performed before exportation:<br>- The grains imported for human consumption are likely to be less contaminated than for animal consumption as grains for human consumption are cleaned before export to a very high standard to ensure quality and consistency for the end product.<br>- The processing of grain for animal feed have less restrictive standards than for human consumption, and therefore such grains may be cleaned and processed to a lesser degree. Therefore, although the probability of entry into the EPPO region would be the same for both human consumption and animal feed, differences in processing should be taken into account.<br>The timing of harvest can influence if *A. palmeri* contaminates the commodity.<br>The likelihood that *A. palmeri* seeds are associated with the pathway at origin greatly depends on the effectiveness of the management measures implemented during cultivation.<br>Seeds of *A. palmeri* are small and can be easily missed with just visual examination of the commodity alone.<br>Some national regulations impose that bird seeds are devitalised before being commercialized. Devitalisation is a process that renders seed inviable and can be achieved by techniques such as heat treatment, irradiation, physically crushing or steaming of the seeds (Blythman & Sansom, 2019). However, customers prefer non-devitalised bird seeds, and this measure is rarely applied before exportation (G Brundu, pers. comm,. 2020). |

| **Pathway** | **Grain (for animal feed mixtures, human consumption and processing purposes)** |
|---|---|
| | Grain lots may be sorted before processing to remove external matters such as weed seeds. If the sorting is performed in the exporting country, especially when the size and/or colour of the seed is very different with *A. palmeri* seeds, this will reduce the association with the pathway. |
| **Survival during transport and storage** | The seeds of *A. palmeri* can remain viable for a number of years enabling their survival along the pathway. Data on the viability of seed dry stored is not available, however, seeds can remain viable more than 10 years.<br>There may also be deviation from the intended use (i.e. imported as grain and used as seed). |
| **Trade** | There is a trade of grain (animal feed and human consumption) from countries where the pest occurs into the EPPO region. The figures in appendix 6 (from FAOStat, imports reported by EPPO countries) give an indication of the existence of a trade for the above commodities.<br>There is no specific data on the import of bird seed into the EPPO region from countries where the pest occurs. |
| **Will the volume of movement along the pathway support entry?** | It is likely that the volume of movement of grain will support entry into the EPPO region. Appendix 6 shows volumes of grain (soybean and maize) entering the EPPO region from USA.<br>Potentially, these figures may contain volumes for various uses (including potential industrial use), but the main volume would be for animal feed or human consumption. The figures for soybean and maize grain imports show a high volume and reasonably consistent volume of import from the USA into the EPPO region. |
| **Will the frequency of movement along the pathway support entry?** | The EWG consider the frequency of movement along the pathway is likely to support entry. Although there are no figures to highlight the frequency of movement of *A. palmeri* seeds as a contaminant of grain it is likely that movement with volumes of the commodity will support entry. Grain is frequently imported into the EPPO region from USA (see Appendix 6). However, although the frequency varies year on year, the frequency of grain imports is regular, with equivalent volumes each year.<br>The frequency of movements along the pathway has no impact on the viability of the seeds of *A. palmeri* introduced or on their quantity. Only the volumes imported can have an impact on the likelihood of introduction. |
| **Transfer to a suitable habitat** | Grain may be directly placed in suitable habitats to feed livestock or in gardens to feed bird (Blythman & Sansom, 2019) or in meadows or along agricultural fields to feed game animals for hunting.<br>Grain can be transferred to a suitable habitat via the ingestion of seed by animals and depositing of feces that contain viable seeds. Seeds have been shown to remain viable following the ingestion process in animals and birds. |

| **Pathway** | **Grain (for animal feed mixtures, human consumption and processing purposes)** |
|---|---|
| | Storage and transport conditions of grains for industrial processing may also allow further spread of *A. palmeri* (e.g. along roads). During loading, transportation and unloading of grains, any *A. palmeri* seeds falling to the ground could lead to an established population. However, in the areas of introduction such as ports, airports or freight stations where cargos of seed for sowing or grain for industry or livestock pass through, *A. palmeri* seeds would have more difficulty becoming established because of the presence of concrete instead of soil and because of the possible management of weeds in these areas.<br>Grain lots may be sorted before processing. If the sorting is performed after exportation, and the waste from the sorting is put in fields, they may become infested. |
| **Likelihood of entry and uncertainty** | The EWG recommended to divide the grain pathways because of the different risk that *A. palmeri* reach the natural environment with these commodities:<br>Grains for animal feed (*Arachis hypogaea*, *Glycine max*, *Sorghum bicolor*, *Zea mays*, *Oryza sativa* and *Helianthus annuus*).<br>- Grains for livestock: High likelihood of entry (high volumes (see appendix 6), reports of association and entry with this pathway, less quality grains than for human consumption, used in a suitable habitat; however, sorting applied and effective due to the difference of size of *A. palmeri* seeds with the grains for livestock), with a moderate uncertainty (uncertainty about the production process).<br>- Bird feed: Very high likelihood of entry (evidences that bird seeds are often contaminated, mixes of grains often of lower quality, used in a suitable habitat), with a high uncertainty (uncertainty about the volume of trade, whether seeds are mixed before or after exportation; no evidence of entry with this pathway)<br>Grains for human consumption and processing purposes (*Arachis hypogaea*, *Glycine max*, *Sorghum bicolor*, *Zea mays*, *Oryza sativa* and *Helianthus annuus*): Low likelihood of entry (higher quality standard, not for use directly in a suitable habitat: for consumption or processing, transient reports in port areas), with a moderate uncertainty ( different quality standards of grains for further processing in the EPPO region). |

| **Pathway** | **Seed** |
|---|---|
| **Coverage (short description why it is considered a pathway)** | This pathway covers both certified and uncertified seeds. This is limited to ***Glycine max*, *Gossypium hirsutum*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor* and *Zea mays***.<br>*Amaranthus palmeri* infests a number of crops in the USA where seed from these crops are imported into the EPPO region for planting (e.g. maize, soybean). In the USA, *A. palmeri* seed production in soybean and maize fields has been shown to exceed 100 000 seeds per m2 (Ward *et al*., 2013) and as an effect, seed can be included as a contaminant in the crop harvest and transported to other regions.<br>Additional summer industrially harvested seeds may need to be considered in the future if there is evidence that *A. palmeri* is associated with these crops. The seed mixes of other species are treated separately due to the lack of information on species composition and traded volume are lacking to fully assess and rate this pathway. |
| **Pathway prohibited in the PRA area?** | No, this pathway is not prohibited in the PRA area.<br>However, some EPPO countries impose import requirements which should contribute to the reduction of the number of *A. palmeri* seeds in the imported seed consignments (for example, at the EU level, in marketing Directives for seeds https://ec.europa.eu/food/plant/plant_propagation_material/legislation/eu_marketing_requirements_en).<br>In particular, cereal seeds (including *Oryza sativa*, *Sorghum bicolor* and *Zea mays* seeds, except popcorn and sweet corn) and oil and fibre plants (including *Glycine max*, *Gossypium* spp. and *Helianthus annuus* seeds) can only be imported from third countries into the EU if an equivalence with certification production conditions in the EU has been granted. The marketing of certified seeds includes purity requirements.<br>- For *Zea mays* seeds, an examination of the seed samples is performed to guarantee that zero seeds of other plant species in a sample of 250g of basic seeds of inbreed lines; or in 1kg for other basic seeds and certified seeds, are present. (Council directive 66/402/EEC of 14 June 1966 on the marketing of cereal seeds).<br>- For *Oryza sativa*, an examination of the seed samples is performed to guarantee that less than 4 seeds of other plant species in a sample of 500g of basic seeds; or 10 seeds in a sample of 500g for certified |

| Pathway | Seed |
|---|---|
| | seeds of 1st category, or 15 seeds in a sample of 500g for certified seeds of 1st category, are present. (Council directive 66/402/EEC of 14 June 1966 on the marketing of cereal seeds).<br>- For *Sorghum bicolor*, an examination of the seed samples is performed to guarantee that less than 4 seeds of other plant species in a sample of 900g of basic seeds; or 10 seeds in a sample of 500g for certified seeds of 1st and 2nd category are present. (Council directive 66/402/EEC of 14 June 1966 on the marketing of cereal seeds).<br>- For *Glycine max* and *Helianthus annuus* seeds, the maximum tolerance is 5 seeds of other plants in 1kg of seeds (Council directive 2002/57/EC on the marketing of seed of oil and fibre plants).<br>- For *Gossypium* spp. seeds, the maximum tolerance is 15 seeds of other plants in 1kg of seeds (Council directive 2002/57/EC on the marketing of seed of oil and fibre plants). |
| **Pathway subject to a plant health inspection at import?** | Partly.<br>In some EPPO countries. For example, seeds of *Sorghum* spp. and *Glycine max* imported from all third countries into the EU and seeds of *Gossypium*, *Helianthus annuus*, *Oryza* spp., *Zea mays* from third countries other than Switzerland are subject to a phytosanitary certificate (Regulation 2019/2072), and to a plant health inspection upon arrival of the consignment at the border control post. Those official controls shall include physical checks, at a frequency depending on the risk (article 49 of 2017/625 Official control regulation). |
| **Pest already intercepted?** | Both Canadian Food Inspection Agency (2018) and PPQ (2019) highlight the movement of *A. palmeri* seed as a contaminant of seed.<br>*Amaranthus palmeri* has been identified from certified soybean in seed lots and seed bags in Louisiana (J. Ferrell, pers. comm., 2020).<br>Uncertified commercial seeds from Australia, USA and Europe (e.g. novel forage seeds) have been demonstrated to harbour seed contaminants, including several *Amaranthaceae* species (Cossu *et al*, 2019) |
| **Most likely stages associated with the pathway** | Seeds may become associated with seeds of summer crops at harvest. |
| **Important factors for association with the pathway** | The probability that seeds of *A. palmeri* are associated with the pathway at origin depends mainly on the crop species concerned, on the exact origin of the imported product and the degree of infestation of this region by *A. palmeri*. The timing of harvest can influence if *A. palmeri* contaminates the commodity.<br>The likelihood that *A. palmeri* seeds are associated with the pathway at the point of origin greatly depends on the effectiveness of the management measures implemented during cultivation and the cleaning |

| **Pathway** | **Seed** |
|---|---|
| | procedures that can be implemented at the origin before export (e.g. certified seeds are often produced in well managed fields with high sorting processes).<br>Seeds may be sorted after harvest and submitted to quality requirements in particular when they are certified, which will reduce the probability of association (EU marketing directives, OECD Standards). Seeds of *A. palmeri* are small (1-2mm) in relation to the commercial seeds imported for planting in agriculture (e.g. maize and soybean). This size difference would facilitate the successful sorting process when performed.<br>However, when performed, physical checks may not allow to detect the presence of *A. tuberculatus* seeds in the consignment. |
| **Survival during transport and storage** | The seeds of *A. palmeri* can remain viable for a number of years enabling their survival along the pathway. Data on the viability of dry stored seed is not available, however, seeds can remain viable for more than 10 years. |
| **Trade** | There is a trade of seed (for planting) from countries where the pest occurs into the EPPO region. The figures in appendix 7 (from FAOStat, imports reported by EPPO countries) give an indication of the existence of a trade for seed of maize, sorghum and soybean from the USA. |
| *Will the volume of movement along the pathway support entry?* | Yes.<br>As an example, Appendix 7 provides figures on the quantities of maize, sorghum and soybean imported into the EPPO region from the USA from 2015-2018. Although there is variation year on year, there are significant volumes of the aforementioned seed entering the EPPO region. The EWG consider it is likely that the volume of *A. palmeri* as a contaminant along this pathway will be proportionate to imports into the PRA area as seeds are expected to come from areas that are heavily infested by *A palmeri* |
| *Will the frequency of movement along the pathway support entry?* | Although the frequency of movement of maize, sorghum soybean and sunflower imported into the EPPO region from the USA, varies year on year, the frequency of seed imports is regular, with equivalent volumes each year (an increase for maize, a decrease for soybeans).<br>The frequency of movements along the pathway has no impact on the viability of the seeds introduced or on their quantity. Only the volumes imported can have an impact on the likelihood of introduction. |
| **Transfer to a suitable habitat** | Transfer to a suitable habitat is likely. Seed for sowing contaminated by *A. palmeri* are most often directly sown in agricultural fields, which is an optimal habitat for this species. |

| **Pathway** | **Seed** |
|---|---|
| **Likelihood of entry and uncertainty** | Seeds of *Glycine max*, *Gossypium hirsutum*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor*, *Zea mays*, : Moderate likelihood of entry (used in a very suitable habitat, reports of association with the pathway, reports of presence in crop fields in the EPPO region; but quality certification standards) with Moderate uncertainty (uncertainty about the source of entry in agricultural crops in Israel, Spain and Turkey, uncertainty about efficiency of the sorting/cleaning process, uncertainty about the use of certified vs. uncertified seeds by EPPO countries) |

- **Seed mixtures and native seeds**
  USDA (2013) details that *A. palmeri* was identified as a contaminant in conservation plantings in Illinois, Indiana, Iowa, Minnesota and Ohio. It was a contaminant in Conservation Reserve Program (CRP) seed mixes. Some native seed mixes planted to foster habitats for honeybees and other pollinators have been found to be contaminated with *A. palmeri* (WSU, 2020). *A. palmeri* was also found in crop pollinator commercial seed mixtures in the USA (Oseland *et al.*, 2017). Additionally, seed mixtures for conservation, pollination and seed mixtures for forage plants for mammals for hunting (for example see: [https://www.plantbiologic.com/products/last-bite-food-plot-seed](https://www.plantbiologic.com/products/last-bite-food-plot-seed)) will be placed directly in habitats that can be suitable for *A. palmeri*. However, data on the seed species composition present in the seed mixtures that were intercepted is lacking. In some EPPO countries (e.g. the EU), all imported seeds should be accompanied with a phytosanitary certificate mentioning the seed species included in the mixture (Regulation EU 2016/2031). However, it may not be the case for every EPPO countries. Seed mixtures may have very variable composition. They are often produced in agricultural fields of a unique species and mixed afterwards (Hartzler, pers. comm., 2020). Information on traded volume is lacking; however, the EWG considered that such mixtures are imported in lower quantities than seeds of *Glycine max*, *Gossypium hirsutum*, *Heliantus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*..

  Likelihood of entry and uncertainty: Moderate (lower volume than the seed pathway) with a high uncertainty (different uses, origin of the mixes used in the EPPO region, composition of the mixes).

- **Used agricultural machinery and equipment.** Seed of *A. palmeri* may become a contaminant of machinery and equipment. However, there is probably very little movement of used machinery from the countries where the pest occurs into the EPPO region and if there is, it is probable that such equipment would undergo phytosanitary procedures such as decontamination (e.g. in the EU, machinery and vehicles imported from third countries other than Switzerland and which have been operated for agricultural or forestry purposes should be cleaned and free from soil and plant debris (Regulation (EU) 2019/2072)). The EWG considered that due to the small size of *A. palmeri* seeds, cleaning procedures applied may not be fully effective, in particular for harvest combines. Agricultural machinery will likely be used in suitable habitats. A few seeds can start a new population. This pathway is covered by an International Standard for Phytosanitary Measures (ISPM 41) (IPPC, 2017a).

  Likelihood of entry and uncertainty: High (size of the seeds, difficulty to clean some machinery and equipment, may be higher for some countries without a market for agricultural machinery or involved in cooperation programs) with a high uncertainty (Volume and frequency of movement).

- **Natural spread.** Taking into consideration the current area of distribution (see section 6), it is unlikely that *A. palmeri* can naturally spread from outside into the PRA area. It should also be taken into account, that other Mediterranean countries, e.g. Libya and Syria may have occurrences of the species which are currently not documented, and these foci could naturally spread into the EPPO region. It has been shown that seeds can be dispersed by birds, mice, rabbits, sheep and cattle following ingestion of seeds, and it is suggested via external animal movement (i.e. wool) (USDA, 2019a). Additionally, the species can be spread by water, rivers, canals etc. However, the EWG considered that there is not enough information on the occurrence of *A. palmeri* in countries bordering the EPPO region, and therefore the EWG decided not rating this pathway.

Overall rating of the likelihood of entry combining the assessments from the individual pathways considered:

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the overall likelihood of entry* | *Very low*<br>☐ | *Low*<br>☐ | *Moderate*<br>☐ | *High*<br>☐ | *Very high*<br>☒ |
| *Rating of uncertainty* | | | *Low*<br>☐ | *Moderate*<br>☒ | *High*<br>☐ |

### 8.2 Pathways with a very low likelihood of entry

The uncertainty was assessed to be low for all pathways below.

- **Cotton ginning by-product** is used as a roughage feed for beef cattle in North America. Norsworthy *et al*. (2009) detail that cotton ginning by-product can contain seeds of weed species including *A. palmeri*. In a study analysing samples of cotton ginning by-product from Arkansas, western Tennessee and western Mississippi, viable *A. palmeri* seed occurred in 4.2 % of samples. Although this pathway may be relevant for spread within the USA, there is no evidence that cotton ginning by-product is imported into the EPPO region.

- **Hay.** Both USDA (2019a) and Canadian Food Inspection Agency (2018) detail the potential of movement of *A. palmeri* seed as a contaminant of hay material for the USA and Canada, respectively. FAO (2020) provides limited data on the export of hay from the USA to the EPPO region, where Austria, Finland, Norway, Sweden and Tunisia are reported to have received imports between 2012 -2017 under the item code 859 Hay (unspecified). *A. palmeri* is not growing well in pastures and hay fields (high uncertainty (absence of reports)).

- **Manure.** USDA (2019a) (citing NDSU 2014/15) detail that *A. palmeri* has been introduced into the State of Michigan (USA) through the movement of manure from dairy cows which were fed on cotton ginning by-product. The movement of manure from the USA to the EPPO region is likely to be extremely low.

- **Travellers and their equipment.** *A. palmeri* seed may be a contaminant of travellers and their equipment (e.g. shoes, clothes and leisure equipment (tents, bags, etc.)). However, as *A. palmeri* is mainly associated with agricultural fields, travellers will rarely encounter *A. palmeri* seeds. Data is lacking to fully assess this pathway.

- **Intentional importation of *A. palmeri*:** there is no evidence that *A. palmeri* is cultivated or that seed is available for sale. *A. palmeri* could be imported for research purposes.

- **Soil and other growing media (on its own or associated with plants for planting other than seeds)**(see ISPM 40; IPPC, 2017b): import of growing media is prohibited in most EPPO countries (e.g. importation of soil and growing medium as such is prohibited in the EU and many other EPPO countries, and is regulated when associated with plants (Regulation (EU) 2019/2072)) and therefore there is a very low likelihood of entry as a contaminant on this pathway.

- **Wool products.** Wool products could theoretically be contaminated with *A. palmeri* seeds (Haines, 2011; USDA, 2019a). Indeed, it is not uncommon that farmers grow crops and raise animals in the same farm and that these animals are feeding in these crops after harvesting. Wool wastes are not expected to move internationally. Additionally, wool is expected to be processed locally to maintain the quality of the product.

- **Sweet potato (*Ipomoea batatas*).** *Amaranthus palmeri* has been shown to have negative impacts on yields of this species in North America. However, the EWG considered this pathway as having a very low likelihood of entry as any seed in soil are likely to be discarded when remaining soil is removed from the harvested roots.

## 9. Likelihood of establishment outdoors in the PRA area

Habitats detailed in section 7 are widespread within the EPPO region and thus further establishment is likely in regions where climatic conditions are conducive for establishment.

### 9.1 Natural habitats

In countries where the species is naturalised (e.g. Cyprus, Greece, Spain), information is lacking to confirm if it is present in natural habitats. Within the EPPO region, natural habitats which are suitable for the establishment of the species (e.g. riverbanks or disturbed sites) are widespread. However, climatic suitability in areas would dictate if these species could establish in certain regions.

In stable natural environments interspecific competition may limit population sizes.

### 9.2 Managed habitats

Within the EPPO region, the species mostly grows in managed habitats and it is likely that *A. palmeri* can establish in the managed environment. It is capable of rapidly invading disturbed areas because of copious seed production and the formation of a persistent seed bank.

In the ruderal and agricultural environments, it is unlikely that competition with cultivated plants planted within the emergence timeline of *A. palmeri* would prevent the establishment of the species. *A. palmeri* is capable of invading many summer crops in particular late sowing crops like maize and soybean. The high frequency of maize, and to a lesser extent soybean, in the crop rotation system in many EPPO countries is a factor that may strongly endorse the establishment of *A. palmeri* once the field has become contaminated.

In crops, common weed control methods may not be sufficient to limit the development of the species due to discontinuous emergence pattern and rapid growth. Further complications may arise from the reduced number of herbicide compounds (relative to the options available in the USA) and the herbicide resistance against multiple mode of actions in this species (Ward *et al.*, 2013). All of the aforementioned factors can potentially foster the establishment of *A. palmeri* in managed conditions.

In areas where the climatic conditions are suitable for the establishment of the species, establishment can occur along roadsides, railway networks, nearby processing facilities etc. These habitats may act to promote the spread of the species into other managed habitats in close proximity (e.g. agricultural fields). Establishment is also likely in public and private gardens.

### 9.3 Other factors affecting establishment

High levels of environmental plasticity may facilitate the establishment of populations in sub-optimum conditions (Spaunhorst *et al.,* 2018).

***Natural enemies***

Within the EPPO region, there are no host specific natural enemies of *A. palmeri*. Generalist natural enemies will potentially attack the plant, but these are unlikely to inflect enough damage at the population level to influence establishment.

***Abiotic factors***

- **Climate conditions**

The major factors that could limit the establishment of *A. palmeri* in the EPPO region are assumed to be the potential evapotranspiration (PET), the summer temperatures and the winter minimum temperatures. The minimum suitable conditions of 889 mm/year of PET and of summer temperatures of 14°C are recorded in the current area of distribution of *A. palmeri* (Appendix 3).

PFAF (2019) detail that *A. palmeri* is a frost sensitive species and this may prevent its establishment in higher latitudinal areas of the EPPO region, especially where the growing season is short, and frost may kill the plant before seed set.

The potential distribution in the EPPO region is limited by the low PET and low summer temperatures. The species distribution modelling shows that *A. palmeri* could establish in all countries bordering the Mediterranean sea, especially in the agricultural production areas of southern Iberia (Spain and Portugal), North Africa, the Middle East, Central Asia, Turkey, Greece as well as parts of Romania and Bulgaria.

With moderate and extreme climate change scenarios (RCP 4.5 and 8.5), the projected distribution may expand North to about 50° latitude within the EPPO region (Appendix 3). Current transient populations at the latitudinal limits for establishment (e.g. UK, Belgium, Germany and the Netherlands) may form established populations (Kistner & Hatfield, 2018). If climate change promotes plant growth, populations may produce higher propagule pressure.

- **Soil conditions**

*Amaranthus palmeri* can tolerate a wide range of soil types (section 2.5).

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the likelihood of establishment in the PRA area* | Very low ☐ | Low ☐ | Moderate ☐ | High X | Very high ☐ |
| *Rating of uncertainty* | | | *Low* X | *Moderate* ☐ | *High* ☐ |

The EWG considered that this rating applied to Mediterranean countries and central Asian EPPO countries. The rating would be lower for other areas of the EPPO region.

## 10. Likelihood of establishment in protected conditions in the PRA area

No evidence was found of the presence of *A. palmeri* under protected conditions in North America.

The management of temperatures under protection (e.g. polytunnels, glasshouses) maintains average temperatures between 20 and 35°C which would be more favourable for the development of the species. Protected conditions, such as in nurseries, polytunnels, tropical greenhouses may offer appropriate conditions for the development of *A. palmeri*.

However, these crops are often produced in highly managed production systems (with possible rotation e.g. for polytunnels) that would limit the likelihood of establishment due to short intervals between consecutive management practices.

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the likelihood of establishment in protected conditions* | Very low ☐ | Low ☐ | Moderate X | High ☐ | Very high ☐ |
| *Rating of uncertainty* | | | Low ☐ | Moderate ☐ | High X |

*Uncertainty: level of management applied, variability of production systems, lack of observation of* A. palmeri *in such conditions.*

## 11. Spread in the PRA area

***Natural spread***

*Amaranthus palmeri* has a high natural spread capacity: writing on the distribution patterns of *A. palmeri* in North America, Sauer (1957) details that the early records of *A. palmeri* (75 years ago at the time of publication) were only collected from Sonora, California, Arizona, New Mexico and Texas. Since, there has been a rapid expansion of the species e.g. to the south-east of the USA.

The seeds of *A. palmeri* are naturally spread mainly by barochory (falling from the parent plant) and hydrochory (dispersal via water). In the case of barochory, dispersal takes place over very limited distances (a few metres around the mother plant). In the case of hydrochory, Norsworthy *et al*. (2014) reports that *A. palmeri* seed can travel as far as 114 m in rainwater. Seeds can be spread through water movement, along rivers and streams and throughout a catchment. Natural local dispersal is most likely accomplished by water, as with other *Amaranthus* spp. as both seeds and fruits can float easily (Costea *et al.* 2004).

*A. palmeri* can be spread by animal species. Bird species can disperse *A. palmeri* seeds. Mallard ducks (*Anas platyrhynchos*) and other migratory birds (Farmer *et al*. 2017; Ward *et al*., 2013) have been shown to spread the species. Seeds can maintain viability when moving through the digestive tract of birds. One study showed that seeds retained 60 % viability when moving through killdeer (*Charadrius vociferous*) and species of ducks (de Vlaming & Proctor, 1968). Viable seeds have been collected from 11 different bird species. Additionally, mice, rabbits, sheep and cattle can ingest and spread seeds, and it is suggested via external animal movement (i.e. wool) (USDA, 2019a).

In the USA, hurricanes have been suggested as acting to facilitate the spread of the species (Ward *et al*., 2013). Such a phenomena is rare within the EPPO region, though strong winds could act to facilitate the spread of seeds.

Within the EPPO region, *A. palmeri* has not shown to have spread significantly in space and time, with the exception, potentially, of the occurrence of the species in Israel. The species has been present within the EPPO region, mainly as transient occurrences, since the end of the 19th century, and the low spread seen may be due to abiotic limitations that prevent the establishment of the species. Additionally, the species is not commonly found growing in natural habitats within the PRA area and therefore spread has not been facilitated by natural pathways such as rivers. A similar conclusion was given for the low spread of *Ambrosia trifida* (EPPO, 2019).

With climate change, and the potential increase in established populations, spread may increase within the EPPO region. If climate change promotes establishment, populations may produce higher propagule pressure and the magnitude of spread may be higher.

***Human assisted spread***

Seeds of *A. palmeri* can be moved through agricultural machinery, equipment and agricultural products (e.g. grains, seeds) within the EPPO region and through management practices. In the USA, equipment such as combines have been shown to spread seed of the species from infested fields into clean fields (Norsworthy *et al*., 2014; Barber *et al*., 2015). Ward *et al* (2013) detail that agricultural management practices like ploughing, mowing, harvesting have been shown to spread seeds in North America. Additionally, seed can be spread with the movement of agricultural material such as compost, manure, animal feed and crop seeds (Ward *et al*., 2013).

In agricultural systems, artificial irrigation channels may act to spread *A. palmeri* seeds over extended distances. This has been shown by Norsworthy *et al.* (2014.). In this research, it took only 20,000 seed initially introduced into one $m^2$ to effectively colonize 0.53- to 0.77-ha fields in less than 2 years. It is believed by the authors that rainwater and harvesting equipment dispersed the seeds from the original area of introduction.

In the USA, *A. palmeri* has seen a large range expansion since 1950 where it was first reported as spreading outside of its native range (Runquist et al., 2019). More than 95 % of distribution records are post-1950. A large increase has also been seen over the last decade, where 50 % of records are within this time period.

Range expansion in the USA, is thought to have occured mainly by long distance human assisted dispersal (Runquist *et al.*, 2019).

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the magnitude of spread in the PRA area* | Very low ☐ | Low ☐ | Moderate ☐ | High ☐ | Very high X |
| *Rating of uncertainty* | | | Low X | Moderate ☐ | High ☐ |

## 12. Impact in the current area of distribution

Negative impacts of the species are predominantly associated with economic impacts of crop yield reductions where the species invades agricultural habitats (USDA, 2019a). For management options see section See section 16.2

### 12.1 Impacts on biodiversity

Impacts on biodiversity are not reported within the literature (e.g. see USDA, 2019a assessing the literature).

There is no known information on *A. palmeri* negatively affecting (outcompeting or displacing) native plant communities.

There is no known information on *A. palmeri* negatively affecting native animal species.

### 12.2 Impacts on ecosystem services

There is no known information on *A. palmeri* negatively affecting regulating, supporting or cultural ecosystem services.

Impacts on provisioning ecosystem services are dealt with under ‘socio-economic impacts’.

### 12.3 Socio-economic impacts

*Amaranthus palmeri* with its rapid growth rate and ability to accumulate large quantities of biomass is very competitive, and has also an advantage with its long roots. In the USA, *A. palmeri* is considered a significant weed in agricultural systems (Ward *et al*., 2013). Major impacts have been reported in soybean, peanut, corn, sweet potato and the plant has become one of the most economically damaging weed species in the USA. Lindsay (2017) provides estimates of the potential economic impacts of the species as a result of crop yields. The economic losses by producers in the mid-southern states of the USA for one year (2015) could equate to $250 million for cotton, $1.3 billion for maize and $2.5 billion for soybean. Lindsay (2017) highlights that these estimates do not include weed management costs.

In addition to reducing yields, the large amount of biomass produced interferes with harvesting of crops.

***Impacts on yields***

**Cotton (*Gossypium hirsutum*)**

*Amaranthus palmeri* has in the last years been ranked as the most troublesome cotton weed in the southern USA. In 2014, at least 300 000 ha of cotton are reported as invaded by the weed in Arkansas, and over one million acres in Georgia. In the USA, *A. palmeri* densities of 1 and 10 plants per m² reduced cotton yields of 11 and 59% respectively (Ward et al., 2013 citing Massinga et al., 2001). In cotton, the presence of *A. palmeri* doubled to quadrupled harvest time, compared to a weed free field. Equipment can even be damaged if densities of *A. palmeri* are higher than 0.65 plants per m².

**Maize (*Zea mays*)**

Up to 91 % reduction in yield has been reported in maize in Kansas with a *A. palmeri* density of 10.5 plants per m-$^{2}$ (Massinga *et al*., 2001). Just 0.66 *A. palmeri* plants per m-$^{2}$ can result in yield losses of 11 %.

**Soybean (*Glycine max*)**

In the USA, the maximum predicted soybean loss was 79% from full season interference of *A. palmeri* (density of 10 plants per m²). At just 0.33 plants per m$^{-2}$, yield loss was 17 % (Klingaman and Oliver 1994).

**Peanut (*Arachis hypogaea*)**

Losses in peanut crops have been reported at 28 % and 68 % with an *A. palmeri* density of 1 and 5 plants per m$^{-2}$ (Burke et al., 2007).

**Sweet potato (*Ipomoea batatas*)**

Meyers *et al.*, (2010) details that *A. palmeri* can reduce the quality and quantity of the crop. Ward et al (2013) states 'The highest grade of sweet potatoes, 'Jumbo', is reduced 56 and 94% from Palmer amaranth [*A. palmeri*] densities of 0.47 and 6.13 plants m$^{-2}$, respectively, with 'marketable' grade reduced 36 and 81% at these densities (Meyers et al. 2010). The threshold density of Palmer amaranth [*A. palmeri*] that is equivalent to 10% yield loss is 0.08 plants m$^{-2}$, or one plant every 12.5 m$^{2}$'.

**Sorghum (*Sorghum bicolor*)**

Moore *et al*. (2004) details sorghum yield losses between 38 and 63 % near Chichasha Oklahoma with a *A. palmeri* density of 1.58 plants m$^{-1}$. The presence of *A. palmeri* had a negative effect on the drying of the crop, which could act to delay the harvesting of sorghum seed.

In addition to direct interference with the crop, *A. palmeri* can affect crops in a non-competitive way. *A. palmeri* may also affect or suppress crop growth through allelopathy. 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.

**Watermelon (*Citrullus lanatus*)**
In North America, *A. palmeri* has been shown to have negative impacts on watermelon yield and marketable fruit numbers. Four *A. palmeri* plants per planting hole was shown to reduce marketable yield by 41 %, 38 % and 65 % for the varieties Exclamation, Carnivor, Kazako, respectively (Bertucci et al., 2019).

### ***Impacts on trade***

In the USA, *A. palmeri* is classified as a noxious weed species in a number of states which imposes phytosanitary requirements (inspections) on commodities that can be contaminated by the seed (e.g. grain and seeds (for planting). This can have an impact on trade and incur costs related to delays and inspections (see USDA, 2019a).

Following the interception by China of *A. palmeri* with other pests in canola grains from Canada, the export permit from two Canadian companies (Canada's largest grain processors) was revoked which had a major economic impact (China buys 40 per cent of Canada's canola exports – roughly 3.6 billion Dollars). The price of the active canola contract has fallen to $455 a tonne in March 2019, itis lowest level since 2016. Other Canadian companies remain eligible to export canola grains to China but these imports are subject to enhanced inspections, including increased testing (CBC, 2019; WTO, 2019), which is costly. This import ban led to a communication by Canada to the SPS Dispute Settlement body (WTO, 2019).

### Indirect impacts

It has been reported that *A. palmeri* plants in a crop could act as an alternate host for nematode species such as *Meloidogyne arenaria* and *M. incognita* (Ward *et al.*, 2013) which are regulated in some EPPO countries (e.g. as Regulated non-quarantine pests in the European Union (Regulation 2009/2072)).

### ***Public health***

*Amaranthus* spp. are prolific pollen producer and all pollen types are supposed to be allergenic (e.g. Wurtzen *et al.*, 1995). Thus, they should be considered as "hay fever plants" in areas where they are abundant (Oh, 2018).

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the magnitude of impact in the current area of distribution* | Very low ☐ | Low ☐ | Moderate ☐ | High ☐ | Very high X |
| *Rating of uncertainty* | | | *Low* X | *Moderate* ☐ | *High* ☐ |

The above rating was based mainly on the data from North America.

## 13. Potential impact in the PRA area

### 13.1 Potential impacts on biodiversity in the PRA area

There is no data for negative impacts of the species on native biodiversity in the EPPO region. Within the EPPO region, the species mostly grows in ruderal or managed habitats with relativity low biodiversity value (e.g. Germany; U. Starfinger, pers. comm., 2020).

*A. palmeri* can hybridize with other *Amaranthus* species (Section 2.3), thus adversely affecting the gene pools of other species. Hybridization is also a route by which herbicide resistance can be moved between different *Amaranthus* spp. (Costea *et al.*, 2005). However, native European *Amaranthus* species are monoecious (Steckel, 2007) and are not expected to hybridize in field conditions with *A. palmeri* when present in a limited number.

### 13.2 Potential impact on ecosystem services in the PRA area

There is no known information on *A. palmeri* negatively affecting regulating, supporting or cultural ecosystem services within the PRA area.

Impacts on provisioning ecosystem services are dealt with under 'socio-economic impacts'.

### 13.3 Potential socio-economic impact in the PRA area

Currently, within the EPPO region, there is no data on socio-economic impacts of this species. Impact are likely to be occur only in areas where permanent populations may establish.

Any action targeting control of this species will generate additional production costs (cost of weeding practices, establishment of less profitable crops). In the absence of plant health regulations relating to the control of introduction into the PRA area of seed lots of maize, soybeans, sorghum, the risk of introduction of herbicide-resistant genotypes of *A. palmeri* appears high and such an introduction would result in a very high increase in control costs.

Within the EPPO region, *A. palmeri* occurs already as a weed in different crops (e.g. maize, cotton, and soybean). In Turkey, the species has been reported as showing 'extremely aggressive' behaviour [invasive behaviour] (Raab-Straube & Raus, 2016) and locally as a weed in cotton and maize (Özaslan et al., 2017). Likewise, in Spain, the species invaded crop fields (Recasens *et al.*, 2018) with already some fields infested with high density of *A. palmeri* (Alicia Cirujeda Ranzenberger, pers. comm., 2020). In Israel, *A. palmeri* is found throughout the country in crop fields (cotton, watermelon, maize) and herbicide resistance has already been proven (Flora of Israel Online, 2019; HEAP, 2020; Matzrafi *et al.*, 2017).

Kistner and Hatfield (2018) highlight that climate change will be beneficial to the species in Europe where regions suitable for casual populations may become suitable for established populations. Such effects may act to increase the area available for establishment in the EPPO region where negative impacts on agriculture systems may be seen.

The recent expansion of the species in North America highlights that, coupled with its high environmental plasticity and recorded impacts, even at low weed densities, substantial impacts on crop yields have been observed (Ward *et al*., 2013).

In Europe, fields are generally smaller than in the USA, with a more intensive weed control. Therefore, the impact is likely to be lower in the EPPO region.

Without the implementation of integrated control against this species – effective chemical weed control, rotation including winter crops and appropriate tillage – the negative effects of *A. palmeri* will probably increase. Effective chemical control options (e.g. post-emergence herbicides in soybean in the EU) may be limited within the EPPO region due to the decrease of the number of authorized herbicides, and due to the species being resistant to a number of active ingredients (see section 2.7).

*Consider whether impacts in the area of potential establishment will be similar to that in areas already infested, taking into account availability of plant protection products, natural enemies, cultural practices, etc.in the area of potential establishment. Consider other consequences (e.g. export loss) if applicable.*

Will impacts be largely the same as in the current area of distribution? Yes /[✓ No]

The EWG considered that a lower impact may be observed in the current area of distribution because of different agricultural practices (e.g. scales of production, crop rotation, etc.).

**If No**

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the magnitude of impact in the area of potential establishment* | Very low ☐ | Low ☐ | Moderate ☐ | High X | Very high |
| *Rating of uncertainty* | | | *Low* ☐ | *Moderate* X | *High* ☐ |

*Uncertainty: effect of different production practices in the EPPO region with the USA, absence of yield losses records in the EPPO region even though* A. palmeri *has already been detected 10 years ago in Spain, impact on biodiversity.*

## 14. Identification of the endangered area

The EWG considered that the endangered area includes agricultural environments in the Mediterranean area, Middle East area and Central Asian area of the EPPO region. Appendix 3 gives the percentage of suitable areas in each country.

## 15. Overall assessment of risk

The likelihood of new introductions to the EPPO region occurring via grain of peanut *Arachis hypogaea*, soybean (*Glycine max)*, sunflower (*Helianthus annuus)*, rice (*Oryza sativa)*, sorghum (*Sorghum bicolor)* and maize (*Zea mays)* is high with a moderate uncertainty. For seeds of *Glycine max*, *Gossypium hirsutum*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor* and *Zea mays*, the likelihood of new introductions is moderate with moderate uncertainty. Entry into the EPPO region via seed mixtures and single species native seed packets is moderate with a high uncertainty.

The likelihood of further establishment outdoors is high with low uncertainty. Establishment in protected conditions is moderate with high uncertainty. Protected conditions such as in nurseries and polytunnels may offer appropriate conditions for the development of the pest. The potential for spread within the EPPO region is very high with a moderate uncertainty.

The impacts of *A. palmeri* in North America are primarily the reduction of crop yields and increased management costs. The EWG considered the potential socio-economic impacts in the EPPO region will be high with a moderate uncertainty.

| | **Likelihood** | **Uncertainty** |
|---|---|---|
| **Entry** | **Very high** | **Moderate** |
| Grains for animal feed, human consumption and processing purposes (*Arachis hypogaea*, *Glycine max*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor* and *Zea mays*). | | |
| Grains for livestock | High | Moderate |
| Bird feed: | Very high | High |
| Grains for human consumption and processing purposes | Low | Moderate |
| Seeds of *Glycine max*, *Gossypium hirsutum*, *Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays* | Moderate | Moderate |
| Seed mixtures and native seeds | Moderate | High |
| Used agricultural machinery and equipment | High | High |
| **Establishment outdoors in the PRA area** | **Very high** | **Low** |
| **Establishment in protected conditions in the PRA area** | **Moderate** | **High** |
| **Spread** | **Very High** | **Low** |
| **Impact in the current area of distribution** | **Very High** | **Low** |
| **Potential impact in the PRA area** | **High** | **Moderate** |

## Stage 3. Pest risk management

### 16. Phytosanitary measures

The EWG considered that phytosanitary measures should be recommended for grains and seeds for relevant crops (mentioned in 16.1) and seed mixtures and native seeds. Measures for seeds and grains are considered in detail in Appendix 1. Measures for seed mixtures and native seeds were derived from measures for seeds.

The EWG recommended that measures for grain should apply to all commodities that contain the species specified, i.e. irrespective of whether they are intended for animal feed (incl. bird seeds), human consumption or processing.

The EWG also recommended that new associated crops should be added if *A. palmeri* is shown to develop in these crops and if their seeds or grains may present a risk of contamination with *A. palmeri* seeds. The EWG recommended that *A. palmeri* should be recommended for regulation as a quarantine pest.

### 16.1 Measures on individual pathways to prevent entry

| **Possible pathways *(in order of importance)*** | **Measures identified** |
|---|---|
| **Grains of *Arachis hypogaea, Glycine max, Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*.** | Grains have been produced in a pest-free area for *Amaranthus palmeri* established and maintained according to the requirements outlined below<br>Or<br>Grains have been sampled according to ISPM 31 and inspected, and *Amaranthus* seeds have been tested with an approved test and the grain lot has been found free from *A. palmeri*.<br>Or<br>Grains have been devitalized according to an appropriate method. |
| **Seeds of *Glycine max, Gossypium hirsutum, Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*** | Seeds have been produced in a pest-free area for *Amaranthus palmeri* established and maintained according to the requirements outlined below<br>Or<br>Seeds** have been sampled according to ISPM 31 'Methodologies for sampling of consignments' and inspected, and *Amaranthus* seeds have been tested with an approved test, and the seed lot found free from *A. palmeri*.* |
| **Seed mixtures and native seeds** | Seeds have been produced in a pest-free area for *Amaranthus palmeri* established and maintained according to the requirements outlined below<br>Or<br>Seeds have been sampled according to ISPM 31 and inspected, and Amaranthus seeds have been tested with an approved test, and the seed lot found free from *A. palmeri*. |
| **Used agricultural machinery and equipment** | ISPM 41 'International movement of used vehicles, machinery and equipment' should be implemented |

*Remark: A seed certification schemes include sampling and testing, therefore the option of certification is considered to be already covered by this option.

** The seed lot could have been sorted to avoid the presence of the pest.

**Requirements for establishing a pest-free area (PFA):**

- detailed surveys and monitoring should be conducted in the area and continued every year. If climatic conditions in the PFA are suitable for the establishment of *A. palmeri*, the PFA should not include any area where the species has been reported in the last 10 years.
- Surveys should include high risk locations, such as summer crops, key transportation roads, ports, areas around grain and seed storage facilities etc.
- Where climatic conditions in the PFA are suitable for the establishment of *A. palmeri*, there should be restrictions on the movement of the identified pathways for entry (e.g. seeds, grains and used machinery and equipment) into the PFA, and into the area surrounding the PFA, especially the area between the PFA and the closest area of known infestation.

**National measures**

Early detection is important to identify new occurrences of the species. *A. palmeri* should be monitored and eradicated, contained or controlled where it occurs in the area of potential establishment in the PRA area. In addition, public awareness campaigns to prevent spread from existing populations in countries at high risk are necessary.

### 16.2 Eradication and containment

## Eradication

Eradication measures provided in this section should be promoted where feasible with a planned strategy to include surveillance, containment (see following paragraph), treatment and follow-up measures to assess the success of such actions. Regional cooperation is essential to promote phytosanitary measures and information exchange in identification and management methods. NPPOs should facilitate collaboration with all sectors to enable early identification including education measures to promote citizen science and linking with universities, land managers and government departments.

Eradication is only considered to be possible for *A. palmeri* in case of early detection (newly established populations) of a small population in agricultural productions, or when detected in the natural environment, , cargo areas, roadsides and other transportation networks etc. Deep turning of the soil would promote longevity of the seeds and should be avoided. Moreover, seeds on or near the soil surface are more likely to be subject to decay. Eradication measures should include hand weeding (plants being properly disposed) and herbicide treatments (see containment section) to eliminate any escaping plants.

The EWG noted that if the weed is persistent and present in large quantities in an agricultural field, the only feasible eradication method would consist in turning the field into perennial grass for at least 10 years. However, regular surveys would still be required to ensure the area remains free from *A. palmeri*.

Eradication may be feasible in some EPPO countries where this species is at an early stage of invasion. It is recommended that member countries eradicate this species where feasible to prevent further spread and impact.

## Containment

Unintentional transport of *A. palmeri* seeds through the movement of agricultural products and equipment should be avoided. Equipment and machinery should be cleaned to remove the weed seeds before moving to an uninfested area (see ISPM 41: *International movement of used vehicles, machinery and equipment*; FAO, 2017). NPPOs should provide land managers, farmers and stakeholders with identification guides including information on preventive measures and control techniques.

A pro-active and integrated weed management strategy will be required to effectively manage *A. palmeri*. General considerations are listed below. It should be noted that in natural environments, management practices should be tailored to the habitat invaded.

***Tillage*.** Heavy tillage, as opposed to light soil disturbance, at the beginning of the season will prepare a proper seedbed for crop planting and eliminate all weeds that have emerged up to this point. Following planting, interrow cultivation can assist to eliminate small seedlings from establishment. In general, significant soil disturbance from heavy tillage discourages the small-seeded dicots such as *A. palmeri*.

***Cover crops*.** Planting dense cover-crops can help suppress *A. palmeri* germination and emergence. In general, grass cover-crops (such as wheat, rye, barley) can be terminated herbicidally 2-6 weeks prior to summer crop planting. The summer crop can then be planted directly into the terminated cover. Rolling the cover-crop flat and then planting the summer crop in the same direction as rolling will provide even greater mulch on soil surface to suppress weed growth. However, if the cover-crop is not dense, the level of weed suppression will be reduced or non-existent.

***Crop rotation and management*.** Planting crops with different agronomic life cycles (e.g. winter crops), places *A. palmeri* in a disadvantage to germinate and survive. Moreover, this can allow a greater variety of herbicides and other weed management strategies to be used.
Individual crops should be managed to enhance their competitive ability. Depending on crops, this would include row spacing, planting density and planting date. For example, crops with a narrow row spacing can be useful to suppress *A. palmeri* growth by shading the soil surface more rapidly. This shading decreases weed germination and suppresses growth of emerged seedlings.

***Surveying and hand weeding.*** The field should be surveyed, and remaining weeds should be hand weeded.

***Herbicides*.** Herbicides can be an important component of an integrated weed management plan. However, they must be applied in a timely and proactive manner. Allowing plants to emerge and reach 10-15 cm in height will greatly complicate management with herbicides. Multiple applications of herbicides are necessary to control *A. palmeri*.

> **Preemergence.** This refers to soil active herbicides applied after crop planting, but prior to crop or weed emergence. Preemergence herbicides allow the crop to emerge and establish in weed-free conditions. Preemergence strategy is important because it prevents weed establishment and allows the crop to grow unimpeded. Examples include s-metolachlor, dimethenamid-P, metribuzin, and mesotrione.
>
> **Postemergence.** This refers to herbicides applied after crop and weed emergence. For this application timing to be effective, the herbicide must be applied with sufficient carrier volume to maximize spray coverage on the target weed. It is also important to target *A. palmeri* before it exceeds 5 cm in height. Management of larger weeds is considerably more difficult and increases the likelihood of herbicide failure. Examples include thifensulfuron and nicosulfuron.

Lastly, herbicide resistance to several modes of action is widely documented in *A. palmeri*. Prior to developing or planning an herbicide program, analysis of the existing weed population to document the presence or absence of herbicide resistance will be essential.

Specific management programs for individual crops as applied in the USA are available in Ward *et al*. (2013).

## 17. Uncertainty

Main sources of uncertainties in this risk assessment are linked to

- Effect of different crop systems on the spread and impact in the PRA area compared to the USA (use of herbicide resistance crops, differences in the scale of cultivation areas e.g. for maize and soybean, reliance on herbicides, narrow crop rotation).
- Trade volumes and frequency of movement for some commodities (bird seeds, seed mixtures).
- Uncertainty about additional summer crops *A. palmeri* is associated with.
- Role of harvesting equipment and machineries in contaminating other grain commodities before exportation (e.g. rapeseed or winter grains).
- Exact distribution of *A. palmeri* in the endangered area of the EPPO region.
- Impact on biodiversity

## 18. Remarks

The EWG conducted two PRAs simultaneously on *A. palmeri* and *A. tuberculatus*. Text written in these PRAs have similarities. *Amaranthus palmeri* and *A. tuberculatus* are very similar in their biology, pathways and both are important weeds in North America. However, these species show differences in terms of competitiveness and area of potential establishment in the EPPO region.

The EWG recommended

- to perform a proper botanical survey in the EPPO region (e.g. during August). This can be performed for *A. palmeri* and *A. tuberculatus* together. If performed on the endangered area identified for *A. tuberculatus*, this would already cover the *A. palmeri* endangered area.
- take samples to determine herbicide resistance of the established populations. To develop educational materials to help people identifying this species and promote early detection in new areas.

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## *Appendix 1. Consideration of pest risk management options*

The table below summarizes the consideration of possible measures for the pathways '*seeds*' and '*grains (for animal feed mixtures and human consumption)*'. Additional measures were proposed for '*seed mixtures and native seeds* and '*used machinery and equipment*' but are not included in the following table.

For measures, seeds and grains are considered for crops in which *A. palmeri* may grow.
When a measure is considered appropriate, it is noted "*yes*", or "*yes, in combination*" if it should be combined with other measures in a systems approach (see after the table). "*No*" indicates that a measure is not considered appropriate. A short justification is included. Elements that are common to several pathways are in bold.

| **Option** | **Grains of *Arachis hypogaea, Glycine max, Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*.** | **Seeds of *Glycine max, Gossypium hirsutum, Helianthus annuus, Oryza sativa, Sorghum bicolor* and *Zea mays*** |
|---|---|---|
| Existing measures in EPPO countries | Partly, see Section 8. | Partly, See section 8. |
| **Options at the place of production** | | |
| Visual inspection at place of production | **Yes, in combination* (for measures marked with '*', see after the table).**<br>**The place/site of production when inspected at pre-harvest should be free from any *A. palmeri* plants.**<br>**Detection by visual inspection is unlikely to be completely effective at the place of production in plants used to produce grains or seeds and needs to be used within a systems approach.** | Yes, in combination*<br>As for grains |
| Testing at place of production | **No**<br>**Testing would only allow to confirm the identity of *Amaranthus* spp. observed at or around the place of production based on visual examination.** | No<br>As for grains |
| Treatment of crop | **Yes, in combination***<br>**No weed management strategy is considered to be 100% effective against *A. palmeri*.** | Yes, in combination*<br>As for grains |
| Resistant cultivars | **No, not relevant for invasive alien plants** | No, not relevant for invasive alien plants |

| | | |
|---|---|---|
| | | As for grains. |
| Growing the crop in glasshouses/ screenhouses | Not relevant for grain production. | No<br>This option could only very rarely be used for some of the listed species (e.g. for maintenance and production of maize parent lines or production of parent seed stocks and has therefore not been kept as an option. Such material for scientific or selection purpose may be imported under a post-entry quarantine bilateral agreement between the importing and the exporting country. Growing the crop in glasshouses alone would not prevent the risk of entry in the glasshouse with the planted seeds themselves. |
| Specified age/size of plant, growth stage or time of year of harvest | **No,**<br>***A. palmeri* may be present and produce seeds during the entire growing season.** | No<br>As for grains. |
| Produced in a certification scheme | No, not relevant for grains | Yes.<br>The seeds should be free from *A. palmeri* seeds, based on a sampling conducted in accordance with ISPM 31. A purity check will be performed on the sample to guarantee the absence of *A. palmeri* seeds. In case *Amaranthus* seeds are present, these seeds should be tested, and the seed lot found free from *A. palmeri*. |
| Pest free production site | **No**<br>**The EWG considered that due to the high seed production, the longevity of the soil seed bank and the spread potential, a pest-free production site is not a feasible option in an area where *A. palmeri* is present.** | No<br>As for grains |
| Pest free place of production | **No, as for pest free production sites** | No<br>As for grains |
| Pest-free area | **Yes**<br>• **To establish and maintain the PFA, detailed surveys and monitoring should be conducted in the area and continued every year. If climatic conditions in the PFA are suitable for the establishment of *A.*** | Yes,<br>As for grains. |

| | | |
|---|---|---|
| | ***palmeri*, the PFA should not include any area where the species has been reported in the last 10 years.**<br>• **Surveys should include high risk locations, such as summer crops, key transportation roads, ports, areas around grain and seed storage facilities etc.**<br>• **Where climatic conditions in the PFA are suitable for the establishment of *A. palmeri*, there should be restrictions on the movement of the identified pathways for entry (e.g. seeds, grains) into the PFA, and into the area surrounding the PFA, especially the area between the PFA and the closest area of known infestation.** | |
| **Options after harvest, at pre-clearance or during transport** | | |
| Treatment of the consignment: sorting | Yes, in combination*<br>Automatic sorting (e.g. optical, density, with vibrating mesh, rotary drum, with aspirator, etc.) can be performed, especially in grain and seeds with a very different size, weight and/or colour.<br>The efficiency of screening depends on the sorting methodology used (e.g. type of screens) and the seed size of grain and weeds (Australia biosecurity, 2002). | Yes, in combination*<br>As for grains. |
| Treatment of the consignment: devitalization | Yes<br>When sorting is not feasible, devitalization may be performed such as described in Australia-Biosecurity (2002) for maize or Blythman & Samson (2019) for bird seeds.<br>In particular, Australia-Biosecurity (2002) reported that steam treatment at 95-100°C for 12-15 minutes killed several weed species including *Amaranthus* spp. Therefore, steam heat treatment of imported maize would manage the risk effectively, particularly if the treatment could be conducted at the port of entry or just prior to export, minimising the opportunities for post-treatment re- | No<br>Devitalization is not possible for seeds |

| | | |
|---|---|---|
| | contamination. | |
| Visual inspection of consignment and confirmation by testing | **Yes,**<br>**Tests allow to detect the weed seeds in mixed grains/seeds. After having performed a purity/noxious weed examination, *Amaranthus* seeds, either individually or in pools from the same lot, may be submitted for testing. The sampling of the consignment should be conducted in accordance with ISPM 31. Remark: because of the size of *A. palmeri* seeds, they will not be equally distributed in the seed/grain commodity**<br>**Remark: this may not be cost-effective for some grain commodities.** | Yes,<br>As for grain. |
| **Options that can be implemented after entry of consignments** | | |
| Pre or Post-entry quarantine | Not relevant for grain. | Not relevant for seed. |
| Limited distribution of consignments in time and/or space or limited use | Not relevant.<br>The use of grains cannot be limited to reduce the probability of introduction: processing grain could be partially or totally destructive but seeds of *A. palmeri* may be spread during storage and transportation. | Not relevant.<br>The use of seeds cannot be limited to reduce the probability of entry. |
| Only surveillance and eradication in the importing country | **No.**<br>**Eradication is difficult.** | No.<br>As for grains |

*The EWG considered whether the measures identified above as ‘Yes in combination’ (listed below) could be combined to achieve a suitable level of security. This was not possible for all these commodities. It is considered that there is too much variability in the application of the treatment methods of the crop and the sorting to allow a combination of these measures.

| **Grains of *Arachis hypogaea*, *Glycine max*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor* and *Zea mays*** | **Seeds of *Glycine max*, *Gossypium hirsutum*, *Helianthus annuus*, *Oryza sativa*, *Sorghum bicolor* and *Zea mays*** |
|---|---|
| Visual inspection at place of production | Visual inspection at place of production |
| Treatment of crop | Treatment of crop |
| Treatment of consignment: sorting | Treatment of consignment: sorting |

## Appendix 2. Relevant illustrative pictures (for information)

*Amaranthus palmeri* growing in CRP (Conservation Reserve Planting) North America EPPO Global Database: **Courtesy:** Bob Hartzler (Iowa State University)

*Amaranthus palmeri* seeds with three fruits Photo: J. K. Clark, © 2007, The Regents of the University of California

Invading roadside in North America EPPO Global Database: Courtesy: Bob Hartzler (Iowa State University)

*Amarnthus palmeri* removal **Courtesy:** Jason Ferrell (University of Florida)

By road and agriculture land (Lleida, Spain) Courtesy: Guillaume Fried (ANSES)

## Appendix 3 Projection of climate suitability for *A. palmeri* establishment in the EPPO region

### Aim

To project the climatic suitability for potential establishment of *Amaranthus palmeri* in Europe and the Mediterranean region, under current and predicted future climatic conditions.

### Data for modelling

Species occurrence data were obtained from the Global Biodiversity Information Facility (GBIF), Integrated Digitized Biocollections (iDigBio), USGS Biodiversity Information Serving Our Nation (BISON), Atlas of Living Australia and additional literature records (Greuter & Raus, 2006; Iamonico, 2015; Von Raab-Straube & Raus, 2016; Iamonico & Mokni, 2017; Özaslan *et al.*, 2017; Sánchez-del Pino *et al.*, 2019). With the EWG, the records were scrutinised to remove any considered too old (<1970) or of dubious quality. This included removing records from the countries in which the species is classified as casual. Records were classified as native or non-native based on published distributions at US state level (Plants of the World Online, BONAP, CABI ISC).

The records were gridded at a 0.25 x 0.25 degree resolution for modelling (Figure 1a). This resulted in 677 grid cells containing records of *A. palmeri* (Figure 1a), which is a sufficient number for distribution modelling.

Based on the life history requirements of *A. palmeri* and likely limiting factors for establishment in Europe, the following predictor variables were assembled on the same grid:

- Minimum temperature of the coldest month (Bio6 °C) from WorldClim v2 (Fick & Hijmans, 2017). Seed germination in *Amaranthus* species is known to benefit from low temperature winter stratification (Leon *et al.*, 2007).
- Mean temperature of the warmest quarter (Bio10 °C) from WorldClim v2 (Fick & Hijmans, 2017). Low summer temperature limits growth of *A. palmeri* (Steinmaus *et al.*, 2000).
- Potential Evapotranspiration (PET mm yr$^{-1}$) estimated using monthly WorldClim v2 temperatures (Fick & Hijmans, 2017) following Zomer et al (2008). This is an alternative measure of solar energy available for growth, more strongly linked to latitude than Bio10.
- Climatic moisture index (CMI, ln+1 transformed) calculated as annual precipitation (Bio12 from Worldclim v2; Fick & Hijmans, 2017) divided by PET and reflecting moisture availability for plants. As a desert-adapted species, *A. palmeri* may avoid very humid areas.
- Urban cover derived from GlobCover 2009 v2.3 urban class ("Artificial surfaces and associated areas (Urban areas >50%)") (Bontemps *et al.*, 2011). *Amaranthus palmeri* is a successful weed in artificial habitats (Ward *et al.*, 2013).
- Cropland cover derived from GlobCover 2009 v2.3 cropland classes ("Post-flooding or irrigated croplands (or aquatic)", "Rainfed crops", "Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)" and "Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)") (Bontemps *et al.*, 2011). *Amaranthus palmeri* is a successful weed in croplands (Ward *et al.*, 2013).
- Preferred crop area (km$^2$) derived from global harvested areas of maize, rice, sorghum, soybean and sunflower (Monfreda *et al.*, 2008).
- River length (km) calculated from the hydroRIVER database (Lehner & Grill, 2013). Riverbanks are a preferred habitat of *A. palmeri* in the native range (Sauer, 1955).

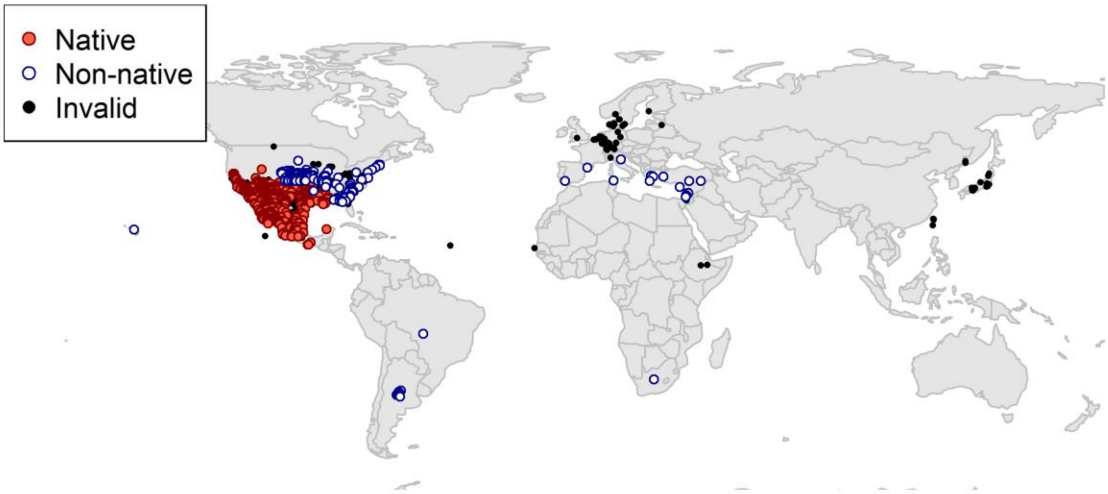
To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for the 2070s under the Representative Concentration Pathway (RCP) 4.5 and 8.5 were also obtained. For both scenarios, the above variables were obtained as averages of outputs of eight Global Climate Models (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, IPSL-CM5A-LR, MIROC-ESM, MRI-CGCM3, NorESM1-M), downscaled and calibrated against the WorldClim v1 baseline.

RCP 4.5 is a moderate climate change scenario in which $CO_2$ concentrations increase to approximately 575 ppm by the 2070s and then stabilise, resulting in a modelled global temperature rise of 1.8 °C by 2100. RCP8.5 is the most extreme of the RCP scenarios, and may therefore represent the worst case scenario for reasonably anticipated climate change. In RCP8.5 atmospheric $CO_2$ concentrations increase to approximately 850 ppm by the 2070s, resulting in a modelled global mean temperature rise of 3.7 °C by 2100.

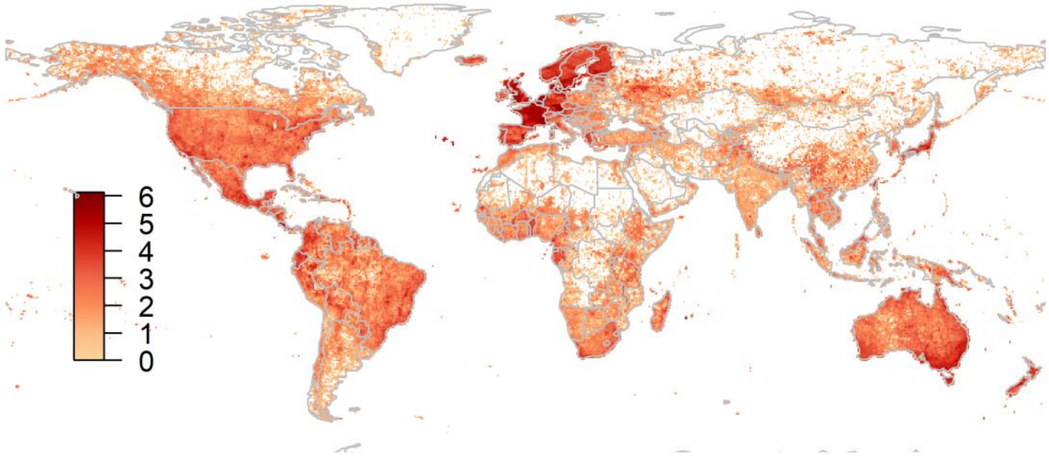
Finally, the recording density of vascular plants on GBIF was obtained as a proxy for spatial recording effort bias (Figure 1b).

**Figure 1.** (a) Occurrence records obtained for *Amaranthus palmeri*, showing the native and non-native records used in modelling as well as the invalid records not used in the modelling (old, undated, inaccurate or casual). (b) A proxy for recording effort – the number of post-1970 vascular plant records held by the Global Biodiversity Information Facility, displayed on a $\log_{10}$ scale.

(a) Species distribution used in modelling



(b) Recording effort (target group record density, log10-scaled)



**Species distribution model**

The modelling followed a recent modification of standard presence-background (presence-only) ensemble distribution modelling for emerging invasive non-native species (Chapman *et al.*, 2019). This accounts for dispersal constraints on non-equilibrium invasive species' distributions (Elith *et al.*, 2010) by excluding locations suitable for the species but where it has not been able to disperse to.

To do this, background samples (pseudo-absences) were sampled from two distinct background regions:

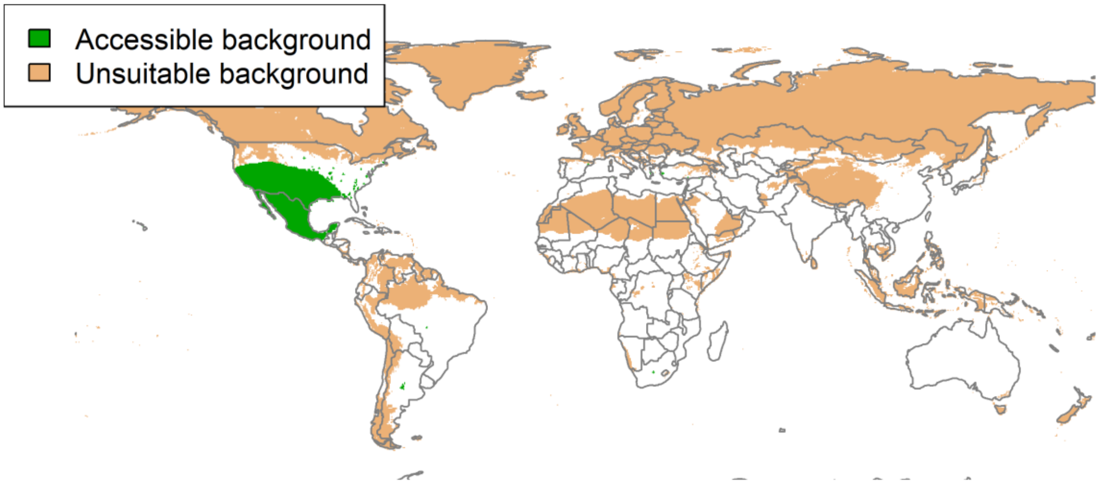
- An <u>accessible background</u> includes places close to *A. palmeri* populations, in which the species is likely to have had sufficient time to disperse and sample the range of environments. The accessible background was defined as a 200 km buffer around the native range (minimum convex polygon bounding native occurrences) and a 30 km buffer around non-native occurrences (capturing a 4-cell neighbourhood of the non-native occurrences). Sampling was more restrictive from the invaded range to account for stronger dispersal constraint over a shorter residence time. Alternative buffer radii were also tested but did not substantively affect the model projections.
-
- An <u>unsuitable background</u> includes places expected to be physiologically unsuitable for the species, so that absence will be irrespective of dispersal constraints. A combination of ecophysiological information and extreme values of the predictors at the species occurrences was used to define unsuitability as:
    - Mean temperature of the warmest quarter (Bio10) < 16.6 °C, the known base temperature for *A. palmeri* development (Steinmaus *et al.*, 2000); OR
    - Minimum temperature of the coldest month (Bio6) > 20 °C, presumed too warm for seed stratification; OR
    - PET < 880 mm yr$^{-1}$, presumed too low energy for growth; OR
    - Climatic moisture index < 0.04, presumed too dry for occurrence.

Three occurrences (0.7%) fell in the unsuitable background.

For modelling, five random background samples were obtained as follows:

- From the accessible background 677 samples were drawn, which is the same number as the occurrences. Sampling was performed with realistic recording bias using the target group approach (Phillips, 2009) in which sampling was weighted by GBIF recording density (Figure 1b). Taking the same number of background samples as occurrences ensured the background sample had the same level of bias as the data.
- From the unsuitable background 5000 simple random samples were taken. Sampling was not adjusted for recording biases as we are confident of absence from these regions.

**Figure 2.** The background regions from which 'pseudo-absences' were sampled for modelling. (a) The accessible background is assumed to represent the range of environments the species has had chance to sample. (b) The unsuitable background is assumed to be environmentally unsuitable for the species.



Using these data, a presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7 (Thuiller *et al.*, 2009, 2016). Each dataset (presences and the five individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, seven statistical algorithms were fitted with the default BIOMOD2 settings (except where specified below) and rescaled using logistic regression:

- Generalised linear model (GLM)
- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per effect.
- Artificial neural network (ANN)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)
- Maxent (Phillips *et al.*, 2008)

Prevalence weights were applied to give equal overall importance to the occurrences and the background. Normalised variable importance was assessed and variable response functions were produced using BIOMOD2's default procedure. Model predictive performance was assessed by calculating the Area Under the Receiver-Operator Curve (AUC) for model predictions on the evaluation data, which were reserved from model fitting. AUC is the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected pseudo-absence.

An ensemble model was created by rejecting poorly performing algorithms and then averaging the predictions of the remaining algorithms, weighted by their AUC. To identify poorly performing algorithms, AUC values were converted into modified z-scores based on their difference to the median and the median absolute deviation across all algorithms (Iglewicz & Hoaglin, 1993). Algorithms with $z < -2$ were rejected. In this way, ensemble projections were made for each dataset and then averaged to give an overall suitability.

Global model projections were made for the current climate and for the two climate change scenarios, avoiding model extrapolation beyond the ranges of the input variables. The optimal threshold for partitioning the ensemble predictions into suitable and unsuitable regions was determined using the 'minRocDist' method (Manel *et al.*, 2001).

Limiting factor maps were produced following Elith et al. (2010). Projections were made separately with each individual variable fixed at a near-optimal value (median values at the occurrence grid cells). Then, the most strongly limiting factors were identified as the one resulting in the highest increase in suitability in each grid cell.

## Results

The ensemble model suggested that suitability for *A. palmeri* at the global scale and resolution of the model was most strongly limited by low solar energy (PET), with additional limitation by low summer temperature (Bio10) or very high or extremely low winter temperature (Bio6). The model also fitted weaker preferences for low but non-zero humidity (CMI). Habitat predictors had less effect on the model, but there were clear preferences for croplands and places with few rivers (Table 1, Figure 3).

Global projection of the ensemble model in current climatic conditions indicates that virtually all native and known invaded records fell within regions predicted to have high suitability (Figure 4).

Across Europe and the Mediterranean region, the model predicts a climatically suitable range in most countries bordering the Mediterranean Sea (especially in Iberia, North Africa, Greece and Turkey) and also the Middle East and central Asia (Figure 5). The model predicts that the main limiting factor in northern Europe is low potential evapotranspiration, associated with lower solar radiation at higher latitude than the native range (Figure 6). In the south of the region, drought stress (low CMI) warm winters and lack of crops are predicted to be limiting (Figure 6).

The projection for the native range is similar to a model developed independently using CLIMEX (Kistner-Thomas & Hatfield, 2018). However, that model predicted greater suitability in Europe, with most of France, Italy and south Eastern Europe, including the Pannonian Plain, Ukraine and the Caucasus region predicted as suitable for invasion. The difference between these predictions because the current model included potential evapotranspiration (PET) and crop cover while the CLIMEX model was solely driven by temperature and precipitation without any predictors relating to solar radiation or land use. As such it projected greater suitability at higher latitudes. Failure of the species to establish from casual introductions in northern Italy, northern France, Germany, Belgium and Netherlands (Figure 1a), support predictions of the current model though these may be inaccurate if solar radiation is less of a limiting factor than the model estimated.

Predictions of the model for the 2070s, under the moderate RCP4.5 and extreme RCP8.5 climate change scenarios, suggest large increases in suitability in Europe driven by warmer summers (Figures 7 and 8). The climatically suitable range may extend northwards into central France, the Pannonian Plain, Ukraine and southern Russia. No major areas currently predicted as suitable become unsuitable as a result of climate change, though thre is a small reduction in the suitable area in North Africa.

As for the current day projections, the published CLIMEX model suggested greater potential establishment under climate change, extending as far as the southern Baltic coast (Kistner-Thomas & Hatfield, 2018). This reflects the former model not using PET as a predictor.

These results are reflected in the suitability of different European Biogeographical Regions (Bundesamt fur Naturschutz (BfN), 2003) (Figure 9). Regions highly suitable under current and future climate scenarios are the Mediterranean and Anatolian. Regions predicted to markedly increase in suitability under climate change include Black Sea, Pannonian and Steppic.

In terms of EPPO member states, Cyprus, Malta, Tunisia, Israel, Uzbekistan, Greece, Spain, Azerbaijan, Jordan, Turkey and Morocco are all predicted >50% suitable in the current climate (Table 2). Under the extreme warming scenario (RCP8.5), those countries mostly remain highly suitable and the following countries are also predicted to become >50% suitable: Hungary, Macedonia, Moldova, Bulgaria, Serbia, Albania, Portugal, Romania, Croatia, Italy, Kazakhstan, Bosnia and Herzegovina, Georgia, Slovakia and France (Table 2).

**Table 1.** Summary of the cross-validation predictive performance (AUC) and variable importances of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing algorithms). Results are the average from models fitted to five different background samples of the data.

| **Algorithm** | **AUC** | **In the ensemble** | **Variable importance** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Minimum temperature of coldest month (Bio6)** | **Mean temperature of warmest quarter (Bio10)** | **Potential Evapotranspiration (PET)** | **Climatic moisture index (CMI)** | **Cropland cover** | **Urban cover** | **Preferred crop area** | **River length** |
| GLM | 0.9610 | yes | 19% | 21% | 44% | 14% | 0% | 0% | 0% | 2% |
| GAM | 0.9608 | yes | 25% | 19% | 40% | 11% | 1% | 0% | 0% | 3% |
| ANN | 0.9458 | no | 19% | 25% | 47% | 3% | 1% | 0% | 1% | 4% |
| GBM | 0.9674 | yes | 10% | 32% | 41% | 15% | 2% | 0% | 0% | 0% |
| MARS | 0.9684 | yes | 15% | 11% | 58% | 15% | 0% | 0% | 0% | 0% |
| RF | 0.9610 | yes | 15% | 22% | 42% | 7% | 6% | 2% | 4% | 2% |
| Maxent | 0.9610 | yes | 17% | 17% | 36% | 8% | 15% | 0% | 2% | 5% |
| **Ensemble** | 0.9680 | | 17% | 21% | 43% | 12% | 4% | 0% | 1% | 2% |

**Figure 3.** Partial response plots from the individual algorithms and ensemble model (thick black lines), ordered from most to least important. In each plot, other model variables are held at their median value in the training data. Variable codes: Bio10 = mean temperature of warmest quarter (°C); Bio6 = minimum temperature of coldest month (°C); PET = potential evapotranspiration (mm yr$^{-1}$); CMI = climatic moisture index (ln+1); crops = proportion cover of cropland; rivers = river length (km); pref_crops = area of preferred crops; urban = proportion cover of urban areas.

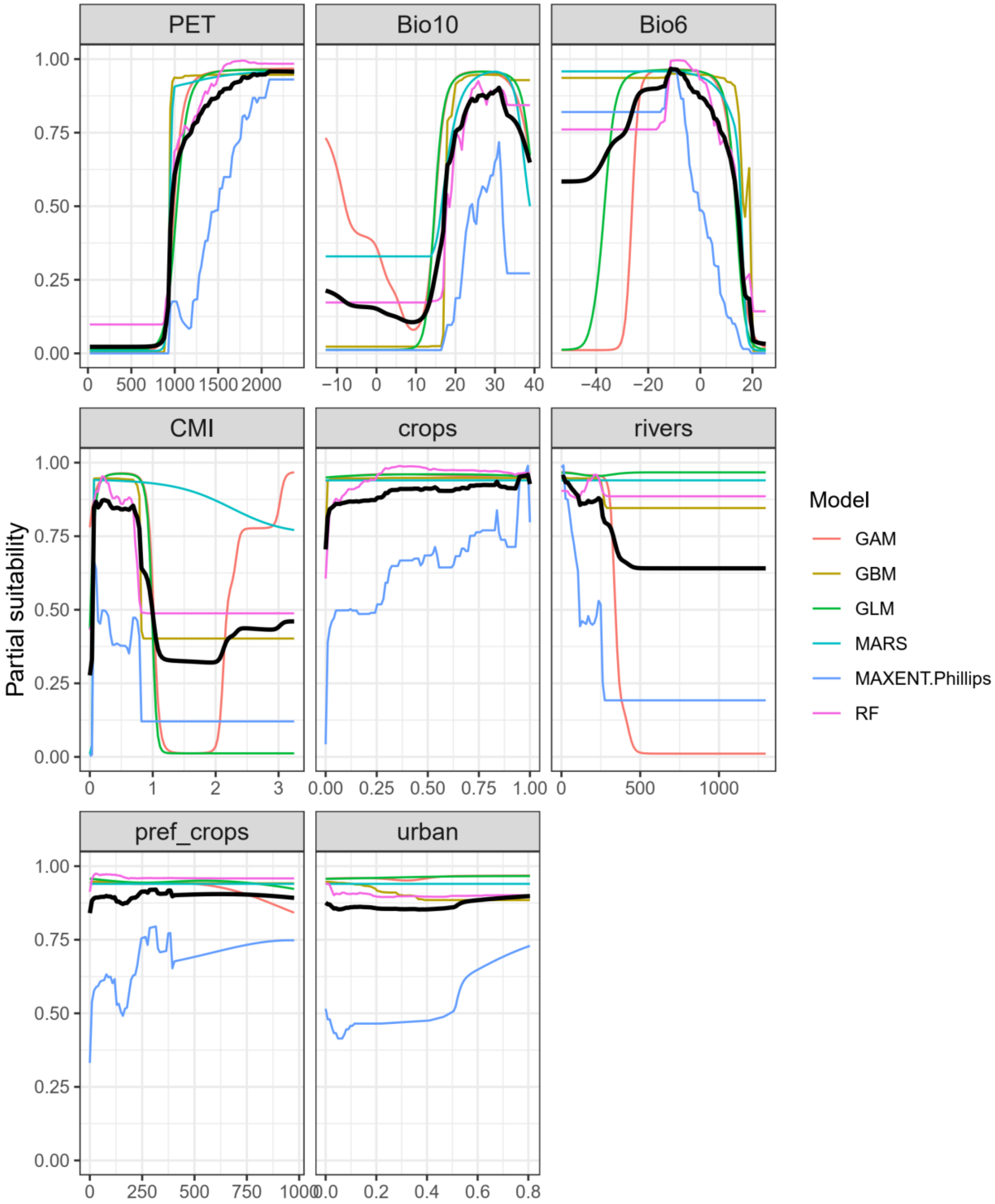
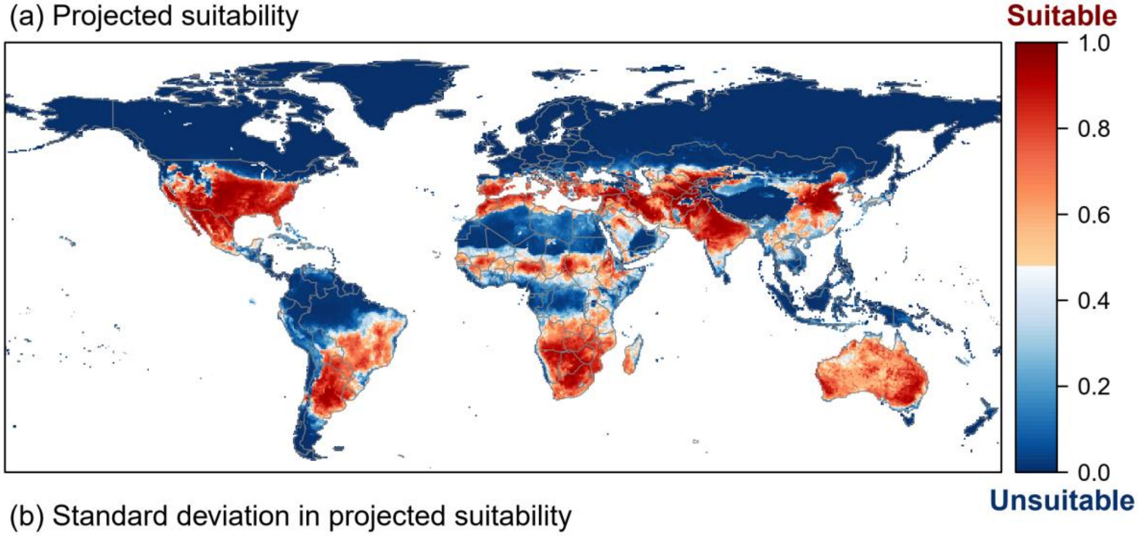


**Figure 4.** (a) Projected global suitability for *Amaranthus palmeri* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Red shading indicates suitability, according to the selected threshold. White areas have climatic conditions outside the range of the training data so were excluded from the projection. (b) Uncertainty in the suitability projections, expressed as the standard deviation of projections from different algorithms in the ensemble model.

(a) Projected suitability



(b) Standard deviation in projected suitability

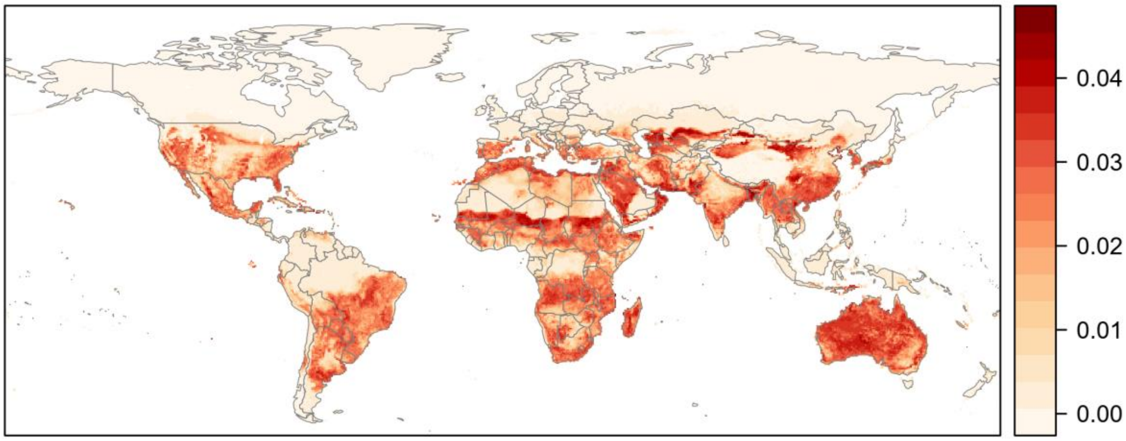


**Figure 5.** Projected current suitability for *Amaranthus palmeri* establishment in Europe and the Mediterranean region. The white areas have climatic conditions outside the range of the training data so were excluded from the projection.

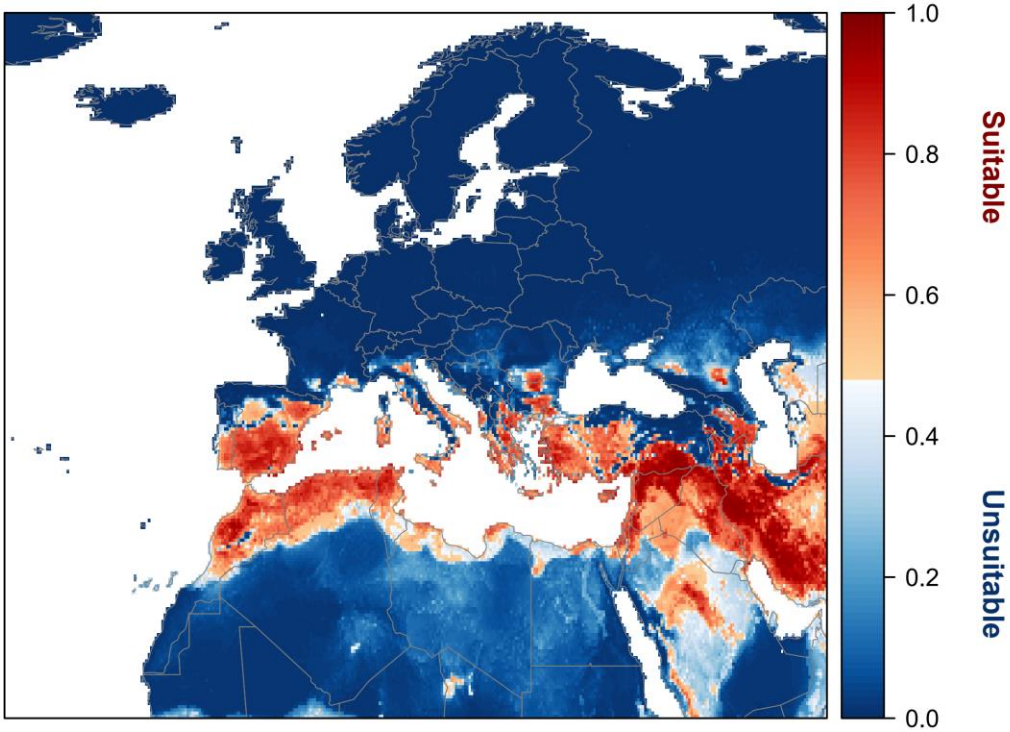


**Figure 6.** Limiting factor map for *Amaranthus palmeri* in Europe and the Mediterranean region in the current climate. Colours show the variable most strongly limiting suitability.

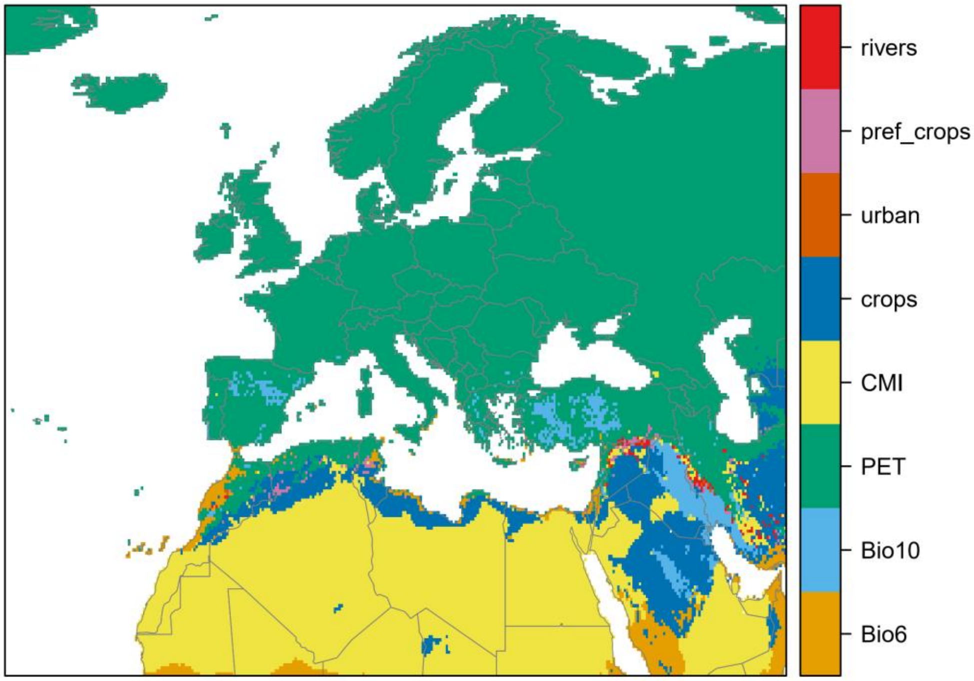


**Figure 7.** Projected suitability for *Amaranthus palmeri* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP4.5, as Figure 5.

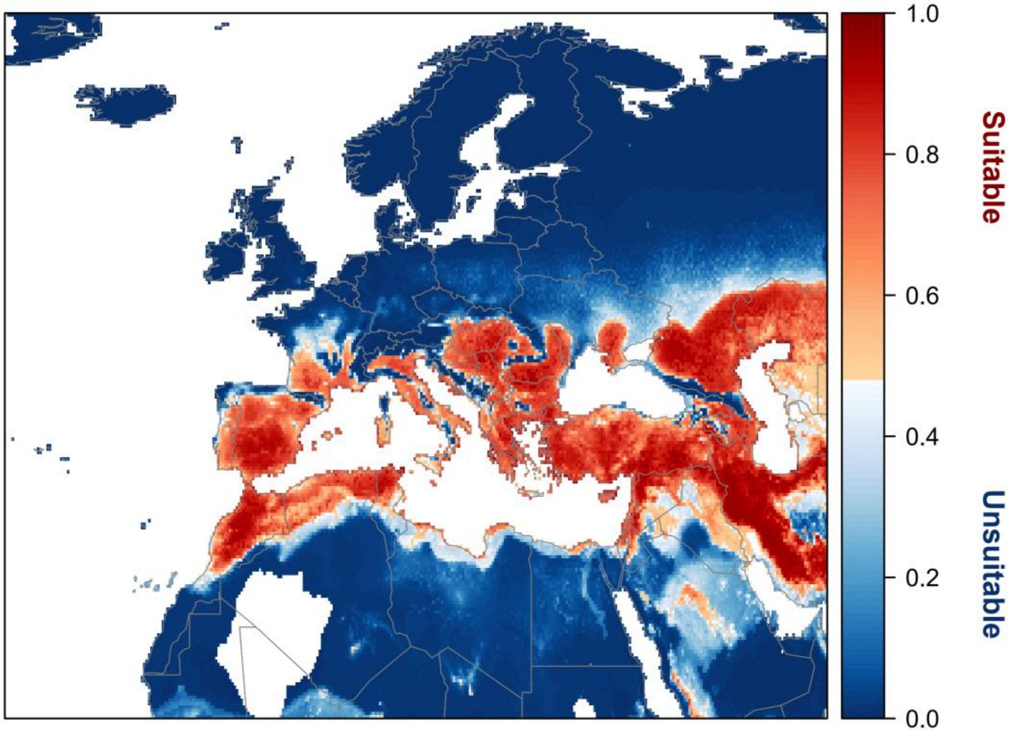


**Figure 8.** Projected suitability for *Amaranthus palmeri* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP8.5, as Figure 5.

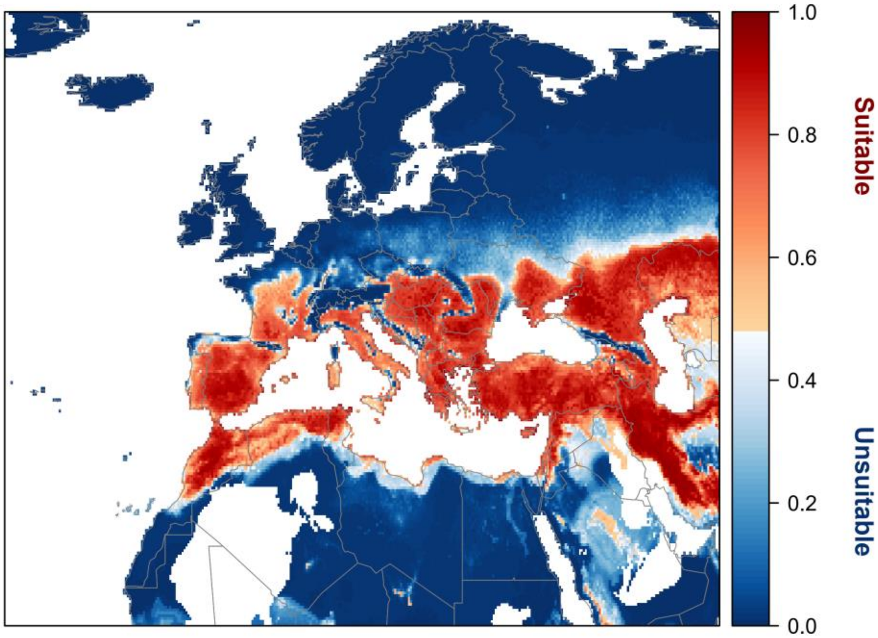


**Figure 9.** Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). Bar plots show the proportion of grid cells in each region classified as suitable in the current climate and projected climate for the 2070s under emissions scenarios RCP4.5 and RCP8.5. The coverage of each region is shown in the map below.

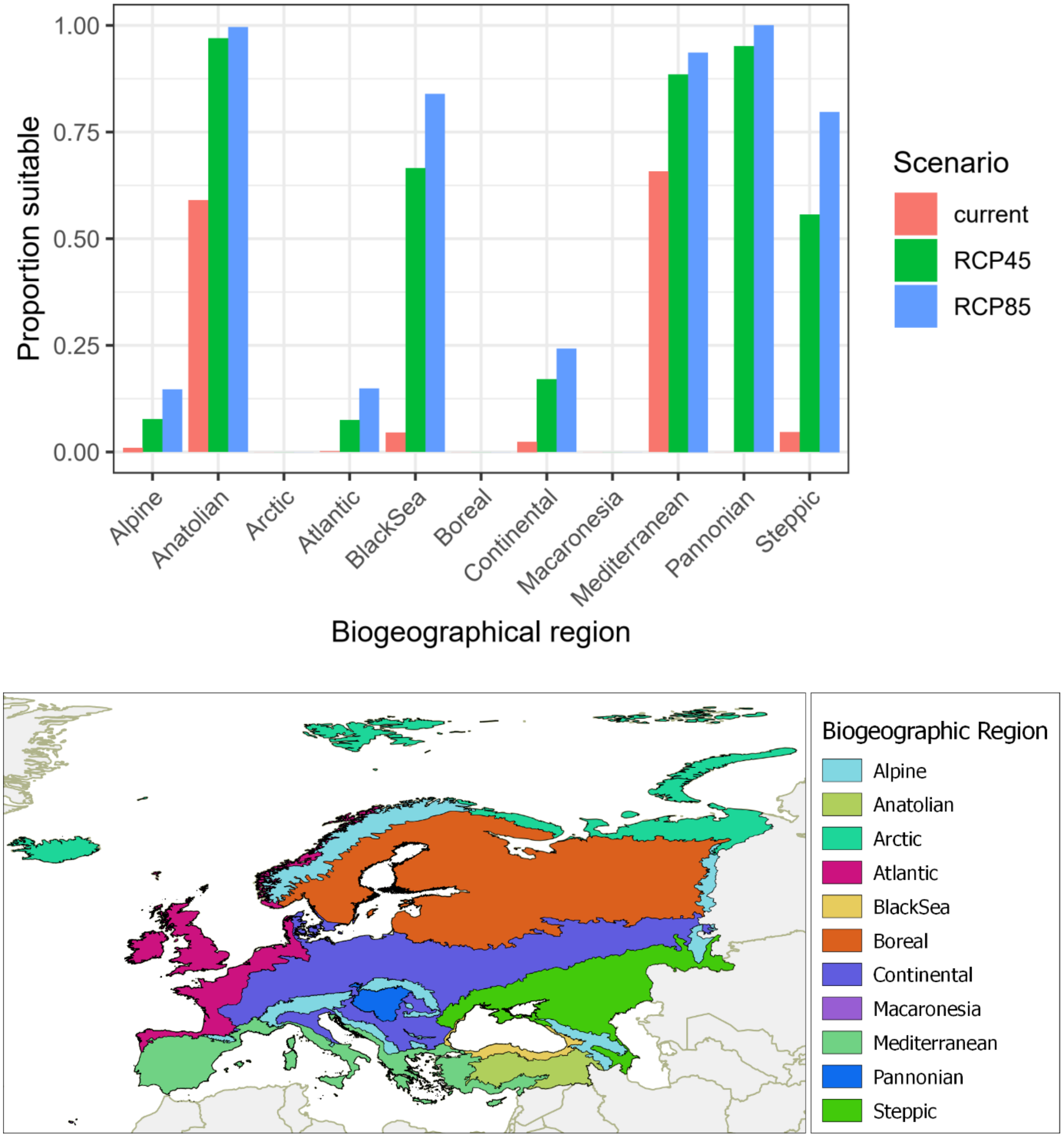


**Table 2.** Projected % suitability among EPPO member countries, sorted from high to low. Values are the % of grid cells in each country classified as suitable in the current climate and projected climate for the 2070s under emissions scenarios RCP4.5 and RCP8.5.

| EPPO country (ISO3) | Current | RCP4.5 | RCP8.5 |
|---|---|---|---|
| CYP | 100 | 100 | 100 |
| MLT | 100 | 100 | 100 |
| TUN | 80 | 57 | 52 |
| ISR | 79 | 62 | 59 |
| UZB | 70 | 98 | 97 |
| GRC | 70 | 97 | 99 |
| ESP | 65 | 79 | 84 |
| AZE | 61 | 90 | 96 |
| JOR | 61 | 42 | 36 |
| TUR | 60 | 96 | 99 |
| MAR | 58 | 58 | 58 |
| PRT | 44 | 81 | 88 |
| MKD | 43 | 90 | 98 |
| BGR | 35 | 92 | 97 |
| ITA | 31 | 63 | 75 |
| ALB | 20 | 69 | 90 |
| DZA | 18 | 15 | 14 |
| KGZ | 14 | 25 | 34 |
| KAZ | 12 | 56 | 68 |
| GEO | 10 | 39 | 54 |
| ROU | 9 | 72 | 83 |
| FRA | 2 | 23 | 50 |
| SRB | 1 | 87 | 94 |
| BIH | 1 | 41 | 65 |
| HRV | 1 | 68 | 76 |
| RUS | 0 | 2 | 3 |
| HUN | 0 | 99 | 100 |
| MDA | 0 | 76 | 97 |
| SVK | 0 | 29 | 54 |
| UKR | 0 | 16 | 47 |
| SVN | 0 | 15 | 41 |
| AUT | 0 | 9 | 27 |
| MNE | 0 | 0 | 13 |
| CZE | 0 | 0 | 8 |
| POL | 0 | 0 | 1 |
| DEU | 0 | 0 | 1 |
| BEL | 0 | 0 | 0 |
| BLR | 0 | 0 | 0 |
| CHE | 0 | 0 | 0 |
| DNK | 0 | 0 | 0 |
| EST | 0 | 0 | 0 |
| FIN | 0 | 0 | 0 |
| GBR | 0 | 0 | 0 |
| GGY | 0 | 0 | 0 |
| IRL | 0 | 0 | 0 |
| JEY | 0 | 0 | 0 |
| LTU | 0 | 0 | 0 |
| LUX | 0 | 0 | 0 |
| LVA | 0 | 0 | 0 |
| NLD | 0 | 0 | 0 |
| NOR | 0 | 0 | 0 |
| SWE | 0 | 0 | 0 |

### Caveats and uncertainties

Modelling the potential distributions of range-expanding species is always difficult and uncertain. In this case study, uncertainty arises because:

- The models were constructed using convenient climate and habitat layers, which may not be the most appropriate for *A. palmeri*. Specific predictors layers capturing requirements for different stages of the life cycle (e.g. for germination in spring or seed ripening in late summer) may have improved the predictions.
- Projected suitability in Europe is more restricted than a CLIMEX model (Kistner-Thomas & Hatfield, 2018), because CLIMEX did not include solar radiation-related predictors of suitability. The current model was given both summer temperature and a measure of radiation (potential evapotranspiration, PET) and found PET to be a stronger predictor of the distribution. However, if it over-estimated the effect of PET because the species has not reached its northernmost maximum spread in North America then the European region at risk of establishment could be larger than is represented here.
- The selection of the background sample was weighted by the density of vascular plant records on the Global Biodiversity Information Facility (GBIF) to reduce spatial recording bias. While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species recording, especially because additional data sources to GBIF were used.

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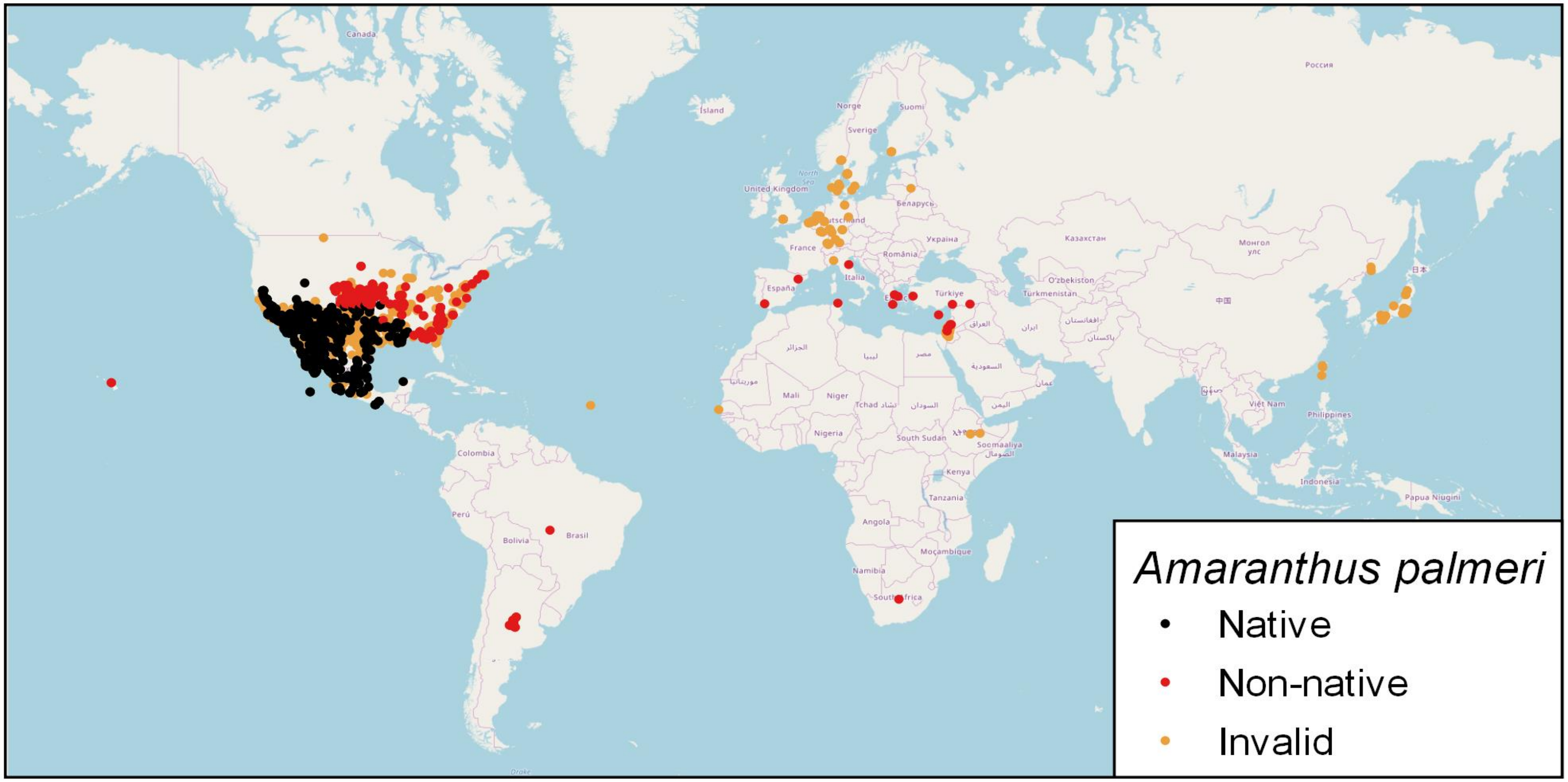
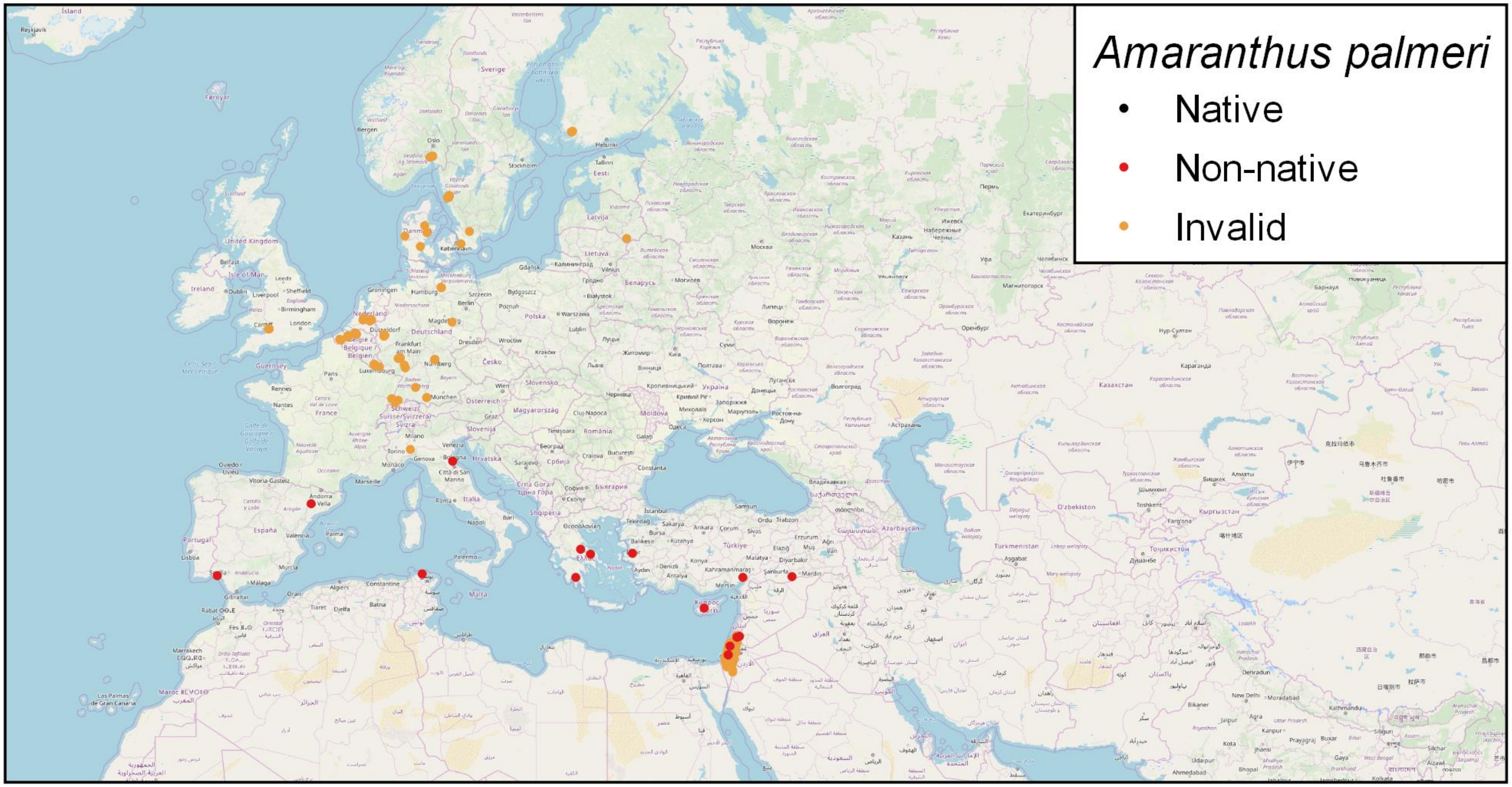
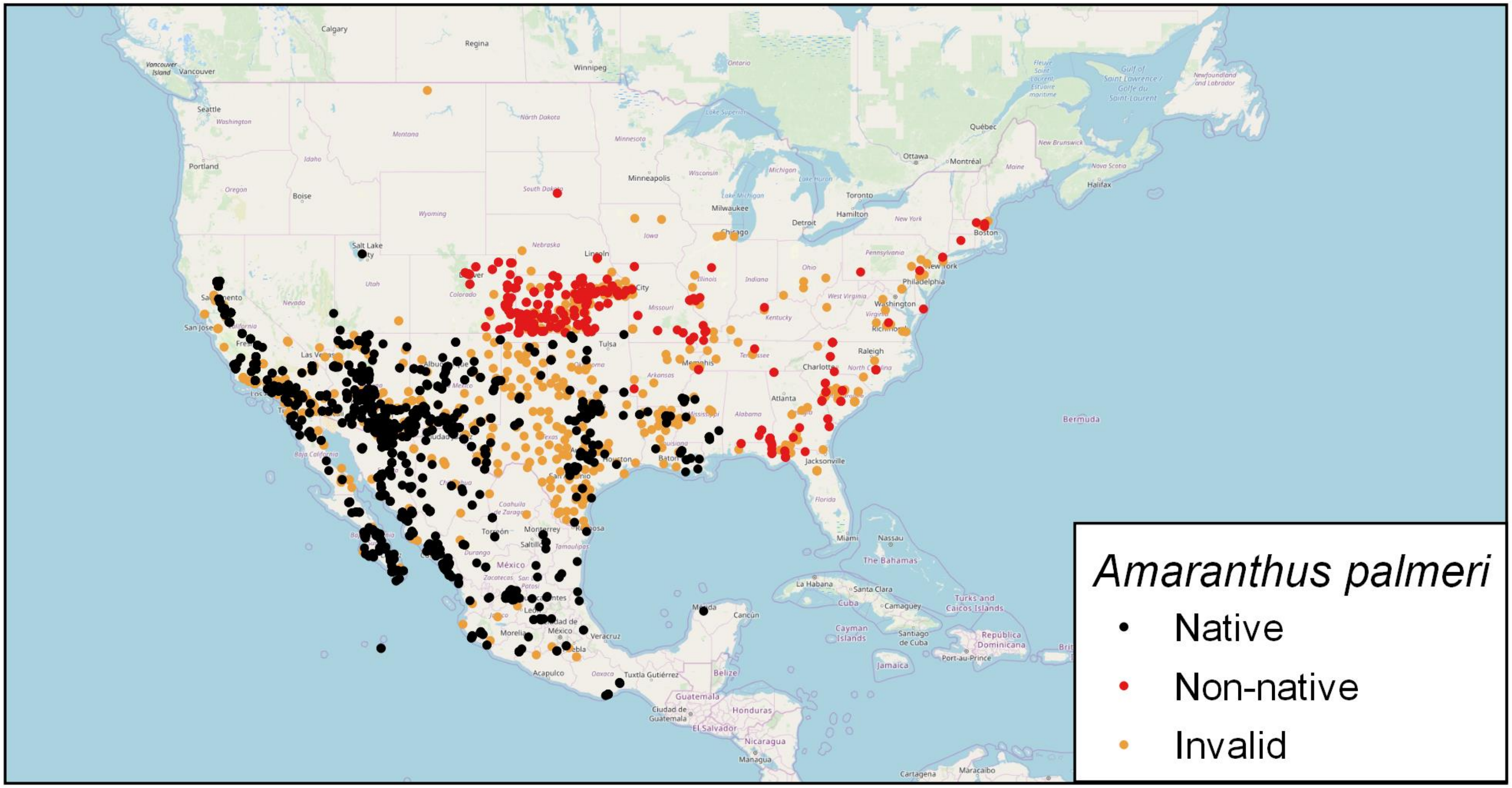
**Appendix 4 Distribution of *Amaranthus palmeri* data used for the modelling**



Global data

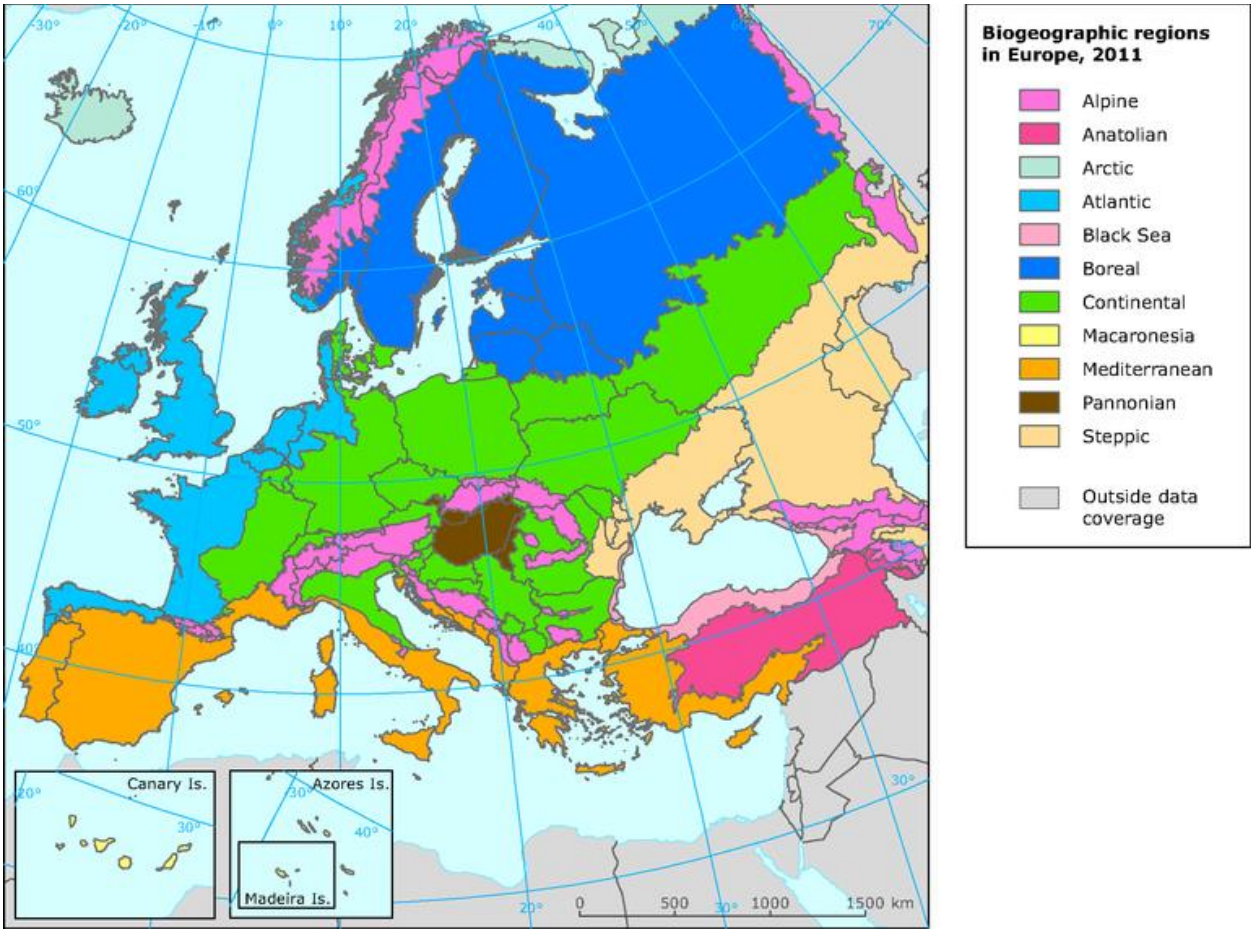


EPPO region



North America

## Appendix 5: Biogeographical regions in Europe



## Appendix 6 Grain imports from USA into the EPPO region

**Table 1. Imports of soybean grain into EPPO countries from the USA from 2015-2018.** The following commodities have been combined (Soybean (other) HS code: 1201900095), Soybean seeds of a kind used as oil stock HS code: 1201900005). The data for 2018 is from Jan-Nov. Figures detail in metric tonnes per year.

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Azerbaijan | 0 | 0 | 0 | 10493 |
| Finland | 333 | 234 | 273 | 272 |
| France | 104165 | 272466 | 64900 | 182732 |
| Germany | 2191796 | 1308642.3 | 1314686 | 901860 |
| Greece | 0 | 17000 | 14114 | 57038 |
| Ireland | 0 | 2600 | 4637 | 0 |
| Israel | 73 | 74141 | 79454 | 119956.1 |
| Italy( | 50089.7 | 201452 | 75523 | 881304 |
| Lithuania | 0 | 0 | 0 | 2.9 |
| Morocco | 109222 | 66092 | 55722 | 39785 |
| Netherlands | 1119010 | 1909165 | 2045877 | 3784707.2 |
| Poland | 1453 | 0 | 105 | 30000 |
| Portugal | 197565 | 57812 | 123156 | 472551 |
| Romania | 67822 | 0 | 0 | 113477 |
| Russia | 510507 | 155547 | 0 | 0 |
| Spain | 1041898 | 895232 | 607995 | 1812908.1 |
| Tunisia | 152036 | 362771 | 221094 | 448182 |
| Turkey | 509695.8 | 157369 | 368627 | 240078 |
| Ukraine | 20 | 232 | 120 | 47 |
| United Kingdom | 200185 | 229897 | 100 | 326894.5 |

**Table 2. Imports of maize grain into EPPO countries from the USA from 2015-2018.** The following commodities have been combined (HS Code: 1005902045 No. 4 corn X SD, HS code: 1005904055 corn white EX SD, HS code: 1005904065 corn NES, 1005902020 No. 1 Corn EX SD, HS Code: 1005902035, No. 3 corn, EX SD). The data for 2018 is from Jan-Nov. Figures detail in metric tonnes per year.

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Algeria | 238846 | 678575 | 75373 | 47627 |
| Austria | 0 | 3396 | 0 | 0 |
| France | 0 | 799 | 19 | 0 |
| Germany | 0 | 743 | 343 | 0 |
| Greece | 0 | 0 | 0 | 81 |
| Ireland | 61322 | 280515 | 140149 | 111 |
| Israel | 16180 | 387811 | 107459 | 814810 |
| Italy | 0 | 19 | 27816 | 29502 |
| Jordan | 80441 | 61778 | 155984 | 38 |
| Lithuania | 0 | 0 | 0 | 42 |
| Morocco | 268286 | 772927 | 575272 | 822679 |
| Netherlands | 0 | 84457 | 210197 | 439800 |
| Norway | 0 | 0 | 0 | 47 |
| Poland | 0 | 0 | 0 | 51 |
| Portugal | 152089 | 109026 | 118335 | 227473 |
| Romania | 0 | 0 | 0 | 0 |
| Russia | 1313 | 0 | 0 | 0 |
| Spain | 66299 | 85079 | 185613 | 1167083 |
| Tunisia | 38189 | 177691 | 20000 | 451707 |
| Turkey | 13199 | 2679 | 80 | 585 |
| Ukraine | 0 | 0 | 42 | 0 |
| United Kingdom | 293 | 43851 | 434 | 19888 |

## Appendix 7: Imports of seed of crops that may be contaminated by *A. palmeri* from USA into the EPPO region (Data from FAO Stats)

**Table 1. Maize seed for planting imports into EPPO countries from the USA from 2015-2018.** The following commodities have been combined (Corn SD Other (HS code: 1005100090), Corn SD Yellow (HS code 1005100010), Sweet Corn SD (HS code: 712908550)). The data for 2018 is from Jan-Nov. Figures detail in metric tonnes per year.

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Albania | 0 | 40.2 | 0 | 18.6 |
| Algeria | 0 | 5.9 | 119.9 | 0 |
| Austria | 52.6 | 67 | 0 | 221 |
| Belgium | 0.1 | 19.6 | 105.5 | 111.8 |
| Croatia | 2.4 | 3 | 0 | 0.2 |
| Cyprus | 0 | 0 | 4.5 | 54.3 |
| Denmark | 0 | 0.2 | 0 | 0.7 |
| Finland | 0.9 | 0 | 0 | 0 |
| France | 2848.4 | 2586.5 | 3269.5 | 2028.7 |
| Germany | 77 | 109.7 | 126.7 | 139.4 |
| Greece | 44.1 | 164.3 | 22.8 | 99.1 |
| Hungary | 155.2 | 103.4 | 86.6 | 84.5 |
| Ireland | 4.6 | 0 | 0 | 0 |
| Israel | 35 | 52.3 | 87.4 | 66.5 |
| Italy | 674.1 | 1123.1 | 693.3 | 485.5 |
| Jordan | 91.2 | 18.9 | 26.8 | 24.4 |
| Kazakhstan | 0 | 0.9 | 7 | 102 |
| Kyrgyzstan | 0.4 | 1.1 | 0.4 | 0.1 |
| Morocco | 0 | 0 | 0 | 2.5 |
| Netherlands | 844.2 | 372.5 | 232 | 308.5 |
| Poland | 0 | 0 | 40 | 0 |
| Portugal | 0 | 15 | 11.4 | 1.1 |
| Romania | 5.4 | 0.7 | 0 | 2.1 |
| Russia | 0 | 0 | 0 | 5.8 |
| Serbia | 1.6 | 1.2 | 2.2 | 4.2 |
| Spain | 2059.5 | 407 | 132.6 | 62.1 |
| Switzerland | 1.8 | 9.1 | 0 | 0 |
| Turkey | 236.2 | 133.9 | 103.2 | 72.2 |
| Ukraine | 18.3 | 14.3 | 29.2 | 152.2 |
| United Kingdom | 294.2 | 216.1 | 354.2 | 380 |
| Uzbekistan, Republic of | 3.6 | 5.8 | 6.9 | 1.3 |

**Table 2. Sorghum seed for planting imports into EPPO countries from the USA from 2015-2018.** The following commodities have been combined (Sorghum seed (HS code: 1007100000) and Sorghum/Sudan SD (HS code: 1209299150)). The data for 2018 is from Jan-Nov. Figures detail in metric tonnes per year.

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Algeria | 641.9 | 1092.1 | 599.3 | 293.6 |
| Austria | 4.7 | 0 | 0.8 | 0 |
| Cyprus | 14 | 0 | 0 | 0 |
| France | 1785.3 | 215.1 | 329.2 | 377.2 |
| Germany | 279.9 | 536.9 | 102.3 | 47.5 |
| Greece | 119 | 118 | 118 | 72 |
| Hungary | 236.6 | 555.2 | 287.4 | 0 |
| Israel | 38.8 | 0.8 | 0 | 0 |
| Italy | 1513.4 | 417.7 | 1021.2 | 1379 |
| Jordan | 0 | 0 | 3 | 0 |
| Kazakhstan | 0 | 0 | 25.2 | 0 |
| Morocco | 79.1 | 239.9 | 197.5 | 38.8 |
| Netherlands | 0 | 4.1 | 359.5 | 60 |
| Poland | 0 | 0 | 20 | 32.5 |
| Portugal | 10 | 134 | 115 | 130 |
| Romania | 0 | 0 | 17 | 39.2 |
| Russia | 79.3 | 327.6 | 390 | 589 |
| Slovenia | 0 | 0 | 20 | 0 |
| Spain | 640.8 | 267.7 | 202.2 | 281.1 |
| Tunisia | 551 | 357 | 408.5 | 95 |
| Turkey | 434 | 299.2 | 237.5 | 356 |
| Ukraine | 101.5 | 667.5 | 733 | 334.7 |
| United Kingdom | 36 | 24 | 24 | 0 |

**Table 3. Soybean seed (HS code: 1201100000) for planting imports into EPPO countries from the USA from 2015-2018.** The data for 2018 is from Jan-Nov. Figures detail in metric tonnes per year.

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Austria | 0 | 2.8 | 268.8 | 232 |
| Finland | 5.3 | 0 | 0 | 0 |
| France | 0 | 13.2 | 183.5 | 196.4 |
| Germany | 435.4 | 450.9 | 20.7 | 15.6 |
| Israel | 0 | 0 | 14 | 0 |
| Italy | 11261.5 | 12476.4 | 12868.4 | 10109.1 |
| Malta | 0 | 0 | 5.8 | 0 |
| Netherlands | 10.6 | 0 | 9.7 | 155 |
| Poland | 29.2 | 0 | 0 | 0 |
| Portugal | 49.1 | 0 | 0 | 0 |
| Romania | 1269.4 | 6572.5 | 1761.3 | 161.5 |
| Spain | 0 | 0 | 0 | 37 |
| Switzerland | 0 | 89 | 110.3 | 0 |
| Ukraine | 40 | 0 | 0 | 0 |
| United Kingdom | 0 | 41.9 | 11.7 | 15.8 |

**Table 4. Sunflower seed (HS code: 1206000031) for planting imports into EPPO countries from the USA from 2015-2018.** The data for 2018 is from Jan-Nov. Figures detail in metric tonnes per year.

| Country | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Austria | 663.6 | 4165.7 | 7045.1 | 5948 |
| Belgium | 3209.3 | 5399.1 | 4286.3 | 2990.6 |
| Denmark | 9.5 | 0 | 14.7 | 1.2 |
| France | 12477.4 | 3425 | 1864.4 | 7570.4 |
| Germany | 774.6 | 127.6 | 215.6 | 282.2 |
| Hungary | 1072.2 | 194.7 | 255.4 | 692 |
| Italy | 1526.5 | 1057.4 | 67.7 | 98.7 |
| Jordan | 19.4 | 0 | 0 | 0 |
| Kazakhstan | 44.3 | 0 | 0 | 0 |
| Netherlands | 12 | 20.7 | 0 | 0.4 |
| Romania | 1433.3 | 1062.9 | 777.1 | 487.8 |
| Russia | 1882.7 | 206.6 | 657.2 | 1394.7 |
| Serbia | 3.1 | 0 | 0 | 0 |
| Spain | 485.4 | 14.3 | 0 | 0 |
| Turkey | 87.2 | 69.6 | 84 | 71.3 |
| Ukraine | 860.6 | 132.9 | 2260.8 | 5720.7 |
| United Kingdom | 0.3 | 0 | 1.6 | 1.7 |