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

Pest Risk Analysis for

Solanum carolinense L.

Solanum carolinense (Courtesy: S. Follak)

EPPO Technical Document No. 1086
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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, *Solanum carolinense* was added to the EPPO A2 List of pests recommended for regulation as quarantine pests in 2022. Measures for grains of *Glycine max, Zea mays* and *Triticum aestivum* are recommended. It was considered that if certified seed is used it should not pose a risk to the endangered area.

Pest Risk Analysis for *Solanum carolinense*

PRA area: EPPO region
Prepared by: Expert Working Group (EWG) on *Solanum carolinense*
Date: 14-18 February 2022. Further reviewed and amended by EPPO core members and Panel on Invasive Alien Plants (see below).

Composition of the Expert Working Group (EWG)

BRUNDU Giuseppe (Mr)	University of Sassari, Department of Agriculture, Italy
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The first draft of the PRA was prepared by Mr Swen Follak (AT).

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. Such a procedure is known as the Delphi technique (Schrader *et al*., 2010).

Following the EWG, the PRA was further reviewed by the following core members: Alan MacLeod, Camille Picard, Francoise Petter, Lucio Montecchio, Muriel Suffert, Roel Potting,

The PRA, in particular the section on risk management, was reviewed and amended by the EPPO Panel on Invasive Alien Plants on 2022-05. EPPO Working Party on Phytosanitary Regulation and Council agreed that *Solanum carolinense* should be added to the A2 List of pests recommended for regulation as quarantine pests in 2022.

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Describe the endangered area: The EWG considered that the endangered area includes agricultural and pastureland in the Mediterranean, Black Sea, Pannonian and southern parts of the Atlantic and continental, areas of the EPPO region. Appendix 5 gives the percentage of suitable areas in each country. The EWG considered the species distribution modelling conducted as part of this PRA (see Appendix 5) to be a realistic projection of the potential area of establishment of *S. carolinense* in the EPPO region.			
Main conclusions ***Solanum carolinense* presents a high phytosanitary risk for the endangered area with moderate uncertainty.** The likelihood of further entry into the EPPO region occurring via grain of soybean (*Glycine max), maize (Zea mays), and wheat (Triticum spp.)* for animal feed is high with a low uncertainty. For seeds of *Glycine max* and *Zea mays* the likelihood of new introductions is moderate with high uncertainty. Entry into the EPPO region via hay is low with a moderate uncertainty. Within the EPPO region, the species predominately grows in managed habitats such as ruderal and agricultural habitats. *S. carolinense* can invade many spring crops in particular late sowing crops like maize, oil-pumpkin and soybean. In agricultural habitats, it is unlikely that competition with cultivated plants and current management practices would prevent the establishment of the species. The likelihood of establishment outdoors is very high with low uncertainty. However, in protected conditions, it is low with moderate uncertainty. The potential for spread within the EPPO region is high with a moderate uncertainty. *S. carolinense* can spread both naturally and via human assisted spread. Seed or root fragments of *S. carolinense* can be spread with the movement of agricultural machinery and plant products (e.g. grains, seeds and hay) within the EPPO region. The magnitude of impact in the current area of distribution (North America and Japan) is high – there are known impacts on agriculture and in pastures in the USA, and once it is established the species is highly difficult to eradicate and therefore continued management is required. In Japan, there are known impacts in landscape areas which incur costs to control. The EWG considered that the potential socio-economic impacts in the EPPO region will be high with a moderate uncertainty.			
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 X	Low ☐
Other recommendations: • ***Specific studies on the potential negative impact on biodiversity and crop yield are lacking for the EPPO region, such studies could be conducted.*** • ***Studies are required to confirm the status of northern European populations which will help to refine the assessment of risk to Northern Europe.*** • ***Monitoring of natural spread by birds, mammals and reptiles in the EPPO region.***			

EPPO Pest Risk Analysis:

Solanum carolinense L.

Prepared by: EPPO Expert Working Group
Date: 2022-02-14/18

Stage 1. Initiation

Reason for performing the PRA:

This PRA was conducted to determine the likelihood and extent of entry into, and establishment and spread within the EPPO region of *S. carolinense*, along with the magnitude of its impacts. *S. carolinense* is particularly a risk to agricultural production. The species has many weedy traits that makes it highly competitive and difficult to control in crop fields and pastures. It grows rapidly in a wide range of environments, produces many seeds per fruit, reproduces vegetatively from an extensive root system and tolerates mechanical control. *S. carolinense* is also a host to many insects, fungi, and viruses that can damage crops (Wahlert *et al*., 2015). As occurrences were detected in the vicinity of harbours and around premises of oilseed re-loading and processing (e.g. Dirkse *et al*., 2007), the species was presumably introduced into the EPPO region as a contaminant of imports of grain for animal feed and products intended for use in the food industry. Contaminated seeds for planting are also likely to have contributed to the introduction of the species (Follak & Strauss, 2010). Thus, *S. carolinense* could negatively affect international trade. At present, casual and established occurrences of the species are known from a number of EPPO countries in disturbed areas and crop fields. In Austria and Italy, *S. carolinense* has established and invaded crops such as maize, soybean, and pastures (Selvaggi *et al*., 2018; Follak, 2020). These occurrences highlight its potential harmful impacts on multiple aspects of agriculture.. In 2021, the EPPO Panel on Invasive Alien Plants considered the occurrence of *S. carolinense* in the EPPO region and the potential for negative impacts, and prioritised the species for an EPPO pest risk analysis (PRA).

PRA area:
EPPO region: (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, *Spermatophyta*, Sub-Division, *Angiospermae*, Class *Dicotyledonae*, Order *Solanales*, Family *Solanaceae*, Genus *Solanum*, Species: *Solanum carolinense* L., Sp. Pl.: 187 (1753).

EPPO code: SOLCA

It should be noted that *S. carolinense* is sometimes considered composed by two distinct varieties. In fact, the taxon *Solanum carolinense* L. var. *floridanum* (Shuttlew. ex Dunal) Chapm., was described by Chapman in 1860 (Chapman, 1860). In Chapman's original protologue this variety is described as less hairy, with stems ascending from a creeping base, leaves narrower, sinuate-lobed or toothed, with more numerous and stronger prickles than *Solanum carolinense* var. *carolinense*. The basonym for this variety is *Solanum floridanum* Shuttleworth ex Dunal, in de Candolle, Prodr. 13(1): 306. 1852, *non* Rafinesque 1840, and the type was collected in Florida [Wakulla Co.: Near St. Marks May 1843, Rugel s.n. (holotype: G-DC; isotypes: K, MO, MPU, NY)]. In 2014, these two varieties were confirmed by Wahlert *et al.* (2014, 2015) based on the analysis of nuclear and plastid DNA sequences of several species included in the *Carolinense* clade. According to Wahlert *et al.* (2014, 2015), *Solanum carolinense* var. *carolinense* has a large native range in the eastern half of the USA and parts of southernmost Canada. *Solanum carolinense* var. *floridanum* is distinguished morphologically by its smaller leaves with rounded lobes and deep sinuses that reach almost to the midrib. When the two varieties are found in proximity to one another at a local scale, var. *floridanum* usually occurs in more mesic sites. Wahlert *et al*. (2014) found a greater DNA sequence divergence among accessions of var. *carolinense* than between the two varieties, and they clearly stated that there remains adequate morphological and ecological differentiation to recognize var. *floridanum* as distinct from var. *carolinense*. Wahlert *et al.* (2015) also published a taxonomic key to distinguish the two varieties as follows:

1. Leaf margins subentire, sinuate, or lobed; sinuses of lobes, when present, reaching less than half the distance to the midvein; apex of leaf lobes subacute to acute, sometimes rounded . . . . *Solanum carolinense* var. *carolinense*

1′. Leaf margins deeply lobed to parted; sinuses of lobes reaching more than half the distance to the midvein or almost to the midvein; apex of leaf lobes typically rounded . . . . *Solanum carolinense* var. *floridanum*

Solanum carolinense var. *floridanum* has sometimes been treated as a synonym under *S. carolinense* var. *carolinense* or even recognized at the rank of species (i.e., as *S. godfreyi* Shinners). The website *Solanaceae* Source (https://solanaceaesource.myspecies.info/) in accordance with D'Arcy (1974) and Wahlert *et al.* (2014, 2015) consider the two varieties as valid ones.

Note: In this PRA, without expressing any position on the validity of the two described varieties, and considering the minor morphological and genetic differences, the EWG consider the species *Solanum carolinense* L. s.l. (in the broad sense, i.e., inclusive of all its lower rank taxa – if any) and the name *Solanum carolinense* is used in the text of the PRA with this meaning – if not otherwise specified. Moreover, published information pertaining the two varieties *S. carolinense* var. *carolinense* and *S. carolinense* var. *floridianum* will always be summarized under *S. carolinense*.

Synonyms (in chronological order):

Solanum obliquatum Raf., Autik. Bot. 106 (1840);
Solanum floridanum Raf., Autik. Bot. 107 (1840);
Solanum carolinense var. *pohlianum* Dunal, Prodr. [A. P. de Candolle] 13(1): 305 (1852);
Solanum pleei Dunal, Prodr. [A. P. de Candolle] 13(1): 305 (1852);
Solanum floridanum Shuttlew. ex Dunal, Prodr. [A. P. de Candolle] 13(1): 306 (1852), *non* Rafinesque 1840;
Solanum occidentale Dunal, Prodr. [A. P. de Candolle] 13(1): 308 (1852);
Solanum carolinense var. *floridanum* (Shuttlew. ex Dunal) Chapm., Fl. South. U.S. 349 (1860) [under the name "floridana"];
Solanum carolinense var. *albiflorum* Kuntze, Revis. Gen. Pl. 2: 454 (1891);
Solanum carolinense f. *albiflorum* (Kuntze) Benke, Amer. Midl. Naturalist 22: 213 (1939);
Solanum godfreyi Shinners, Sida 1: 108 (1962).

This list of synonyms and names is based on Plants of the World Online (http://apps.kew.org/wcsp/), World Flora Online (http://www.worldfloraonline.org/), Solanaceae Source web site (http://www.solanaceaesource.org/), Atlas of Florida Plants (https://florida.plantatlas.usf.edu/) and on original descriptions (available on BHL, https://www.biodiversitylibrary.org/).

Common names:

Croatian: pomoćnica, Czech: lilek karolínský, Dutch: Carolina-nachtschade, English: Carolina horse nettle, horse nettle, Estonian: karoliina maavits, Finish: karoliinankoiso, French: morelle de la Caroline, German: Karolina-Nachtschatten, Italian: morella della Carolina, Russian: Паслен каролинский, Spanish: ortiga de caballo

Ref: https://gd.eppo.int/taxon/SOLCA

Plant type: Perennial herb

Related species in the EPPO region:

The genus *Solanum* is the largest in the family *Solanaceae*, including about 2000 species which are predominantly distributed in the subtropical and tropical regions of Africa, Australia and parts of Asia (e.g. China, India and Japan) (Kaunda & Zhang, 2019). The genus includes a number of economically important and widely distributed crop species, in particular *S. lycopersicum*, *S. melongena* and *S. tuberosum*.

Approximately 60 species of the genus *Solanum* have been recorded in Europe and the Mediterranean basin (Valdés, 2012). Except for a few native species such as *S. dulcamara*, *S. nigrum* or *S. villosum*, most of them are exotic species, several of which are weedy and/or invasive (*S. chenopodioides*, *S. elaeagnifolium* (EPPO A2 List), *S. rostratum*, *S. sisymbriifolium* (EPPO Alert List), *S. physalifolium*).

2. Pest overview

2.1 Introduction

Solanum carolinense is a perennial herb native to North America (Darlington, 1847; Wahlert *et al*., 2015). The species has become a major weed of crop fields and other disturbed habitats and it has been introduced in parts of North America outside its original range (Wahlert *et al*., 2015). The species has several weedy attributes (e.g., reproduces vegetatively, rapid growth, prolific seed production, grows in a variety of biotic and abiotic conditions) (Bassett & Munro, 1986). *S. carolinense* was introduced into the EPPO region most likely in the middle of the 20th century.

2.2 Identification

The following description is primarily based on Bassett & Munro (1986) and Wahlert *et al*. (2015): *S. carolinense* is a perennial herb, up to 1.2 m tall, unbranched or branched near the base, with both vertical and horizontal roots, the latter spreading horizontally up to 5m, (Appendix 1). Stems are armed with slender yellowish spines (prickles) up to 6 mm long. Leaves are also sparsely to moderately armed with prickles up to 6.5 mm long on the major veins abaxially and adaxially. Leave blades 2–15 × 2–10 cm in size, margins lobed with 1–4 lobes per side, sometimes very deeply lobed almost to the midrib, apex is acute to obtuse, and the petioles are 0.4–4 cm in size. Inflorescences consist of 1–20 flowers. They are white, lilac, or purple and star-shaped with five yellow poricidal anthers. Fruits are 1–2 × 1–1.8 cm in size, light green with darker green mottling or pale greenish-white when immature, bright yellow at maturity and glabrous. Seeds are 1.7–2.4 × 1.6–1.8 mm in size, flattened-reniform, lenticular, yellow, and the surface is finely foveolate.

Solanum carolinense has a gametophytic chromosome number of $n = 12$ as shown by Bassett and Munro (1986), while a sporophytic number of $2n = 24$ was reported by Hill (1989).

Images can be retrieved from the EPPO Global Database (EPPO 2021). Tables and images are provided in Bryson *et al*. (2012) to distinguish *S. carolinense* from other (prickly) *Solanum* spp.

2.3 Life cycle

The distribution of *S. carolinense* in North America was described as present from New Jersey to Iowa and southward with flowering from June to September and seeding August to December (Anonymous, 1896). More recent publications indicated that in the Northeast of the USA, the growing season (i.e. seed emergence) of *S. carolinense* begins in the middle of May (Ilnicki & Fertig, 1962). In northern Florida, the growing season typically begins in April and ends in October (Hakes *et al*., 2018). Bassett & Munro (1986) stated that the species reaches anthesis by early July, while fruits begin to mature by mid-September in Canada. In Japan, the period of shoot emergence is from late April to early June (Miyazaki & Ito, 2004; Miyazaki *et al*., 2005).

Solanum carolinense propagates by creeping roots and seeds. The extensive root system consists of a taproot and horizontally growing roots (Ilnicki & Fertig, 1962; Miyazaki, 2008). The taproot can reach a depth of 240 cm and the roots grow horizontally in soil depths up to 45 cm and become several metres long (Ilnicki & Fertig, 1962). Miyazaki (2008) demonstrated that different sections of the root system had different functions: the bending part forms new shoots; the horizontal part extends into the surrounding area; and the vertical part is used for storage. Shoots are produced from adventitious root buds. In this way, the species can form large clusters (up to 10 m from the parent plant) large areas within a few years. Belowground parts over-winter, and new shoots (= ramets) emerge in the spring. Root fragments form buds within a few weeks and thus new plants. Ilnicki & Fertig (1962) demonstrated that fragments from 2 cm in length and 3.5 mm in diameter show a 100% regeneration success. Root fragments grown in a greenhouse at 23 to 32°C showed regeneration at 63% for 1 cm length and 94% at 2 cm length (Wehtje *et al*., 1987. Root systems of 1-year-old plants grown from either a seed or a root cutting have become approximately 2 m in diameter and 80 cm deep (Miyazaki & Ito, 2004).

Solanum carolinense is also a prolific seed producer. It can produce ca. 40 to 170 seeds per fruit, with a single plant producing up to ca. 5,000 seeds (Ilnicki & Fertig, 1962; Bassett & Munro, 1986). Seeds can emerge from depths of 10 cm (Ilnicki & Fertig, 1962). Seeds retain viability for at least 3 years when buried at depths of 8 to 12 cm according to Brown & Porter (1942). Solomon (1983) remarked that seeds remained viable for at least 7 years when stored under laboratory conditions. However, seed germination and seedling establishment are vanishingly rare in established undisturbed populations according to Hakes *et al*. (2018).

Solanum carolinense is pollinated by a variety of generalist insects. In North America, non-specialist bees (*Lasioglossum* spp., *Bombus* spp. *Xylocopa* spp.) are described as the main pollinators of this species (Quesada-Aguilar *et al*., 2008; Wahlert *et al*., 2015). The species has poricidal anthers that must be vibrated by pollinators to release pollen (i.e., buzz pollination; Hardin *et al*., 1972). *S. carolinense* is an andromonoecious species (i.e. plants bear either hermaphrodite flowers or male flowers or both) with a system of gametophytic self-incompatibility (GSI) (Travers *et al*., 2004), which is quite uncommon among other weed species. Travers *et al*. (2004) showed that there is some plasticity in the strength of GSI in *S. carolinense*: flowers become more self-compatible as they age and self-fertility increases on plants when cross pollen is scarce. Moreover, genotypes differ in their degree of self-fertility indicating "… that there is broad sense heritability for plasticity in the strength of self-incompatibility" (Travers *et al*., 2004). See also for further details Kariyat *et al*. (2011).

2.4 Environmental requirements

Solanum carolinense occurs over a wide climatic range. In North America, *S. carolinense* occurs preferably between northern latitudes of 28° to 45° and western longitudes of 70 to 98° (Wahlert *et al*. 2015; GBIF 2021).

The distribution of *S. carolinense* is limited in cool environments by intense frost and the length of the growing season (Bassett & Munro, 1986). Stems are frost sensitive and tops usually die following frost in autumn. Roots of *S. carolinense* can tolerate low temperatures of 3 °C (in 6 cm soil depth), but were killed at temperatures between -2 °C and -4 °C (Basset & Munro, 1986; Wehtje *et al*., 1987). Nishida *et al*. (2004) reported that roots (0.5 mm in diameter and 35 cm in length) from seedlings were not killed at -4 °C for 12 hours.

Solanum carolinense needs warm temperatures for germination, sprouting and growth. The plant grows rapidly during hot weather (Ilnicki & Fertig, 1962). Miyazaki *et al*. (2005) demonstrated that under controlled conditions, sprouting of detached roots was highest at temperatures between 15 °C and 30 °C. This temperature range for optimal growth is in accordance with results of Onen *et al*. (2006) under western Japanese conditions (Osaka Prefecture). Nishida *et al*. (2000) pointed out that germination of *S. carolinense* does not occur at temperatures below 14 °C under field conditions. Seeds were killed by exposure to heat at 55 °C for 72h and at 60 °C for 24 h (Nishida *et al*. 1999b).

Seedlings of *S. carolinense* are resistant to shading. Urakawa & Koide (2004b) reported that the growth of shoots and roots of *S. carolinense* did not decrease by shading (50% of sunlight), while it sharply declined under shading of ≥ 75% of sunlight.

Experimental data indicated that *S. carolinense* can tolerate a broad range of soil types and textures, but thrives best on light textured, well-drained soils (Ilnicki & Fertig, 1962). It can also grow under high moisture conditions, as it can persist on riverbanks, along field margins of paddy rice fields, in ditches and other moist to periodically saturated locations (e.g. Imaizumi *et al*., 2006). Moreover, the species was found to be drought resistant, which was attributed to its deeply penetrating roots (Ilnicki & Fertig, 1962; Bassett & Munro, 1986).

2.5 Habitats

In North America, *S. carolinense* grows in various habitats, such as "… prairies, deciduous woodlands, swamps, and pine forests, and in disturbed areas such as roadsides, grazed and mowed pastures, ditches, cultivated fields, urban waste areas, and utility and railroad rights of way" (Wahlert *et al*., 2015). The species is a weed in many crops (e.g. Hackett *et al*., 1987; Van Wychen, 2015, Table 1).

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

2.6 Association with crops

Solanum carolinense is able to persist and thrive in crops which have a similar agronomic lifecyle to the species. *S. carolinense* has been found in fields of a number of crop types (Table 1).

Table 1. Main crops which *Solanum carolinense* is associated with. Country codes are ISO Country codes

Crop	Country	Reference
Arachis hypogaea	US	Hackett *et al*., (1987)
Glycine max	AT, IT, RU, US	Follak, 2020; Hackett *et al.* (1987), Van Wychen (2015)
Triticum aestivum	US	Hackett *et al*. (1987), Van Wychen (2015)
Beta vulgaris	IT	Vidotto & Selvaggi, 2018
Medicago sativa	US	Van Wychen (2015), Van Wychen (2020)
Cucurbita pepo	AT	Follak (2020)
Zea mays	AT, FR, IT, US	Whaley & Vangessel, 2002), Vidotto & Selvaggi, (2018)
Solanum tuberosum	US	Hackett *et al*. (1987), Van Wychen (2015
Phaseolus vulgaris	US	Frank, (1990)
Gossypium hirsutum	US	Hackett *et al*., (1987), Van Wychen (2015)

Solanum carolinense may be associated with other summer crops in its area of origin.

In addition to the crops listed in Table 1, *S. carolinense* can also be problematic in fruit crops, such as blueberry (*Vaccinium* spp.), blackberry (*Rubus fruticosus*), raspberry (*Rubus idaeus*), strawberry (*Fragaria* spp.), grape (*Vitis vinifera*), apples (*Malus domestica*) and peaches (*Prunus persica*) as well as in coniferous forest trees and Christmas tree production (John Byrd unpublished).

Webster (2008) showed that *S. carolinense* is among others a troublesome weed in pastures and rangelands in particular in southern parts of the USA.

2.7 Existing PRAs

The California Invasive Plant Council prepared a risk assessment (https://www.cal-ipc.org/plants/risk/solanum-carolinese-risk/). The outcome was that *S. carolinense* has a "high risk of invasiveness".

3. Is the pest a vector? Yes ☐ No X

Although *S. carolinense* is not a vector, it has been reported as a weed reservoir for plant viruses, such as tobacco mosaic virus (TMV) and cucumber mosaic virus (CMV) (Wahlert *et al*., 2015). Additionally, *S. carolinense* supports the reproduction and feeding of various insect pests including for example *Leptinotarsa decemlineata* (Say) and *Epitrix cucumeris* (Harris)] (Nichols *et al*. 1992; Wise & Sacchi, 1996), both are on the EPPO A2 list. In chapter 12.3 (socio-economic impact) further pests are listed.

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

5. Regulatory status of the pest

Table 2. Regulatory status of *Solanum carolinense* based on EPPO (2022)

Country	List	Year
Azerbaijan	A1 list	2007
Belarus	Quarantine pest	1994
Chile	A1 list	2019
Georgia	A2 list	2018
Israel	Quarantine pest	2009
Jordan	A1 list	2013
Kazakhstan	A1 list	2017
Mexico	Quarantine pest	2018
Russia	A1 list	2014
Ukraine	A1 list	2019
Uzbekistan	A1 list	2008

Notably, *S. carolinense* is black-listed (banned from sale) in the Italian region of Piemonte (Piedmont) according to D.G.R. no. 46-5100 of 18 December 2012 and under monitoring in the network of protected areas (Natura 2000).

In Canada, *S. carolinense* is listed as a "Primary Noxious Weed Seeds" under the Weed Seeds Order of the Seeds Act (http://www.gazette.gc.ca/rp-pr/p2/2016/2016-05-18/html/sor-dors93-eng.html).

In the USA, *S. carolinense* is declared as "noxious weed" in Alaska, Michigan, Maryland, Iowa and Nevada (https://www.invasive.org/browse/subinfo.cfm?sub=6440).

In New Zealand, *S. carolinense* has the status of a "Quarantine pest" (Official New Zealand Pest Register: https://pierpestregister.mpi.govt.nz/PestsRegister/ImportCommodity/).

6. Distribution

Solanum carolinense is native to North America. USDA, NRCS (2021) shows the current distribution of the species throughout the USA. The species occurs in all states except Nevada, Montana and North Dakota, Hawaii and Alaska (USDA, NRCS, 2021; Wahlert *et al*. 2015). It also can be found in the southernmost parts of Canada (Quebec, Ontario) as well as in Nova Scotia (Bassett & Munro, 1986; VASCAN, 2021).

Note: The database USDA, NRCS (2021) indicates "native" for all states, although it is clear that the species has spread and has now invaded other parts of the USA (Wahlert *et al*. 2015). Thus, the categorisation "introduced" and "native" is ambiguous. USDA Grin (2021), for example, recognizes 35 states including Canada (Ontario) and Mexico (Sonora) as native. Wahlert *et al*. (2015) pointed out that the native range prior to European settlement could not be determined with full certainty. In their study, they interfered its native distribution based on herbarium specimens and stated that its distribution "… extends from central Florida north to New York and Massachusetts and west to Texas, Oklahoma, Kansas, and Nebraska to about the 97th meridian west". A distribution map from Wahlert *et al*. (2015) is provided in the Appendix 1. The EWG considered that the assessment of Wahlert *et al*. (2015) is the most realistic depiction of the native range of *S. carolinense* and this has been followed in Table 3.

The occurrence of the species in Central (Mexico, Haiti) and South America is not entirely conclusive. Websites like inaturalist.org and databases (CABI, 2021; GBIF, 2021; USDA Grin, 2021) list findings of *S. carolinense*. However, Martínez *et al*. (2017) do not list the species in Mexico. Wahlert *et al*. (2015) stated that there is no evidence that *S. carolinense* "… has been collected in Brazil since the time of Pohl's collections [from 1852] (Stehmann *et al*., 2013)". The authors also do not recognize any further occurrences in Central or South America.

Asia

Bangladesh: The species was mentioned in Holm *et al*. (1979). Recent publications reveal local occurrences near Maimansingh (Bangladesh Agricultural University campus; Khatun *et al*., 2019) and Dhaka (Agronomy field, Sher-e-Bangla Agricultural University; Mandal *et al*., 2014).

China: The species is reported to be present in China by CABI (2021) and Li *et al*. (2006), however it is not mentioned in Jiang *et al*. (2011) nor in the Flora of China (http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=130618).

India: *S. carolinense* occurs along roadsides from tropical to temperate zones in the regions Arunachal Pradesh and Assam (Kosaka *et al*., 2010).

Japan: The species was initially recorded in 1906 in Japan (Miyazaki *et al*., 2011; "Accidental: With pasture [at a pasture field in Sanrizuka, Chiba Pref.]", see https://www.nies.go.jp/biodiversity/invasive/DB/detail/80320e.html). It is now found throughout Japan except for Hokkaido (Tominaga & Kurokawa, 2020). According to Kurokawa (2001), *S. carolinense* has become a major weed in many regions in Japan (see map within the reference).

South Korea: It is on the *List of Invasive Alien Plants in South Korea* (Jung *et al*., 2017). *S. carolinense* can be found in the provinces of Gyeonggi-do, South Jeolla, the metropolitan area of Busan (Lim *et al*., 2009; Kim *et al*., 2017; Ryu *et al*., 2017, You *et al*., 2017) and offshore islands (Kim *et al*., 2020). The species was first observed "before 1980" (Jung *et al*., 2017).

Oceania

Australia: According to Parsons & Cuthbertson (1992), the weed is considered to occur in Australia, but Auld (2003) reported that it has not been recorded as established. The EWG consider the species is probably transient in Australia.

New Zealand: *S. carolinense* was first recorded in 1934 and is distributed on the North Island in the Bay of Plenty, Poverty Bay and Waikato according to Webb *et al*. (1988), established by the 1940s.

EPPO Region

Solanum carolinense was first introduced into the EPPO region presumably in the second half of the 20th century. Early records were of small, transient populations scattered across the EPPO region (e.g. Belgium, Croatia, Georgia, Netherlands, and Norway). At present, established populations occur in more countries (see Table 3).

The global distribution of *Solanum carolinense*

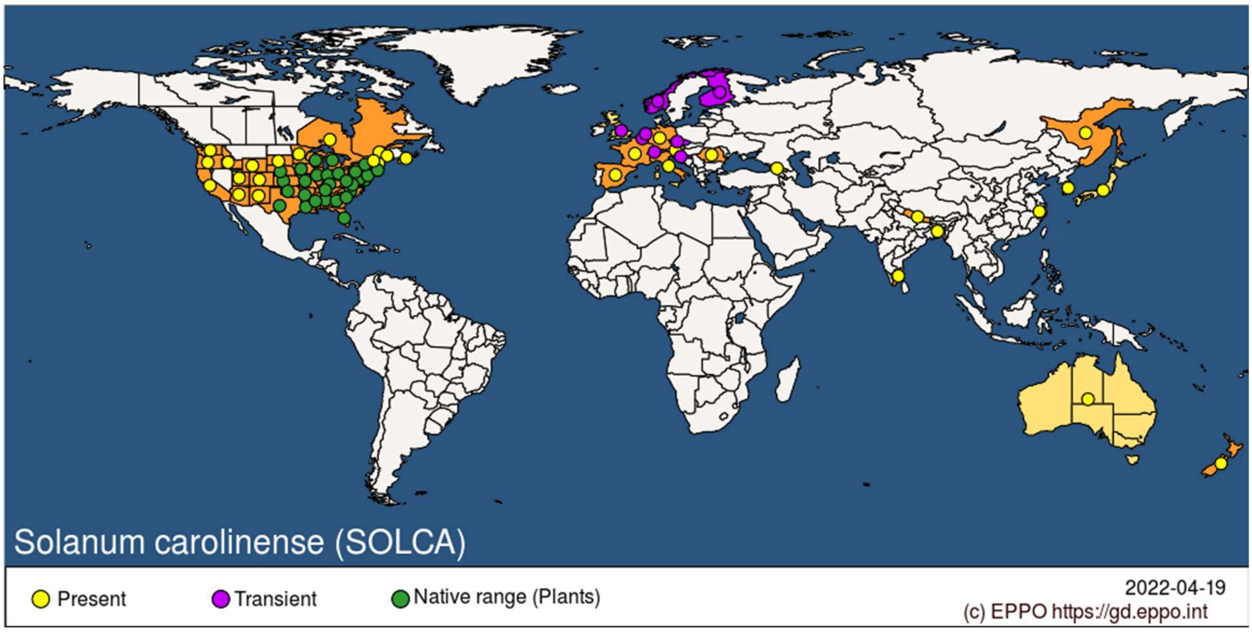

Table 3. Distribution and status of *Solanum carolinense*

Region	Distribution	Status	References and comments
North America			
Canada	Ontario	Introduced	Established. Bassett & Munro (1986), VASCAN (2021)
	Quebec	Introduced	Established. VASCAN (2021)
	Nova Scotia	Introduced	Established. VASCAN (2021)
USA	Alabama	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Arizona	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Arkansas	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	California	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Colorado	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Connecticut	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Delaware	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Florida	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Georgia	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Idaho	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Illinois	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Indiana	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Iowa	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Kansas	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Kentucky	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Louisiana	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Maine	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Maryland	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Massachusetts	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Michigan	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Minnesota	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Mississippi	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Missouri	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Nebraska	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	New Hampshire	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	New Jersey	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	New Mexico	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	New York	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	North Carolina	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Ohio	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Oklahoma	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Oregon	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Pennsylvania	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Rhode Island	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	South Carolina	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	South Dakota	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Tennessee	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Texas	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Utah	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Vermont	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)

	Virginia	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	West Virginia	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Wisconsin	Native	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Wyoming	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
	Washington	Present	USDA, NRCS (2021); Wahlert *et al*. (2015)
Central and South America			
	Haiti	Absent	D'Arcy, 1974; Wahlert *et al*., 2015)
	Brazil	Absent	(D'Arcy, 1974; Wahlert *et al*., 2015)
EPPO region			
	Austria	Introduced	(Follak, 2020)
	Belgium	Transient	(Manual of Alien Plants of Belgium, 2021)
	Croatia	Transient	(Milović & Mitić, 2012)
	Czech Republic	Transient	(Pysek *et al*. 2012)
	Finland	Transient	(FinBIF, 2021)
	France	Introduced	(G. Fried, pers. communication. 2021)
	Germany	Introduced	(Junghans, 2013)
	Georgia	Introduced	(Aleksidze *et al*., 2021)
	Italy	Introduced	(Portal to the Flora of Italy, 2021)
	The Netherlands	Transient	(Dirkse *et al*., 2007)
	Norway	Transient	(Ouren, 1987)
	Romania	Introduced	(Anastasiu *et al*., 2011)
	Russia	Introduced	(Vinogradova *et al*., 2000)
	Spain	Introduced	(Pino Pérez *et al*., 2020)
	Switzerland	Transient	(Brodtbeck *et al*., 1999)
	United Kingdom	Transient	(Stace, 2019)
Asia			
	Japan	Introduced	(Miyazaki *et al*., 2011)
	India	Introduced	(Kosaka *et al.*, 2010)
	South Korea	Introduced	(Kim *et al*., 2011; Ryu *et al*., 2017)
	Bangladesh	Introduced	(Mandal *et al*., 2014)
	China	Introduced	(Li *et al*., 2006)
	Nepal	Absent	(Mentioned in Holm *et al*., 1979 as present; but not mentioned in the Annotated Checklist of the Flowering Plants of Nepal, 2021)
Oceania			
	Australia	Absent	(Auld, 2003)
	New Zealand	Introduced	(Webb *et al*., 1988)

Specific details about the distribution in selected EPPO countries

Austria: *S. carolinense* was accidentally introduced to Austria over 20 years ago. The species was first found in 1998 in southern Austria (Styria) and further locations – distinct from its first occurrence – were reported a few years later in 2004 and 2008 (Eberwein & Litscher, 2007; Follak & Strauss, 2010; Follak, 2020).

Belgium: The species is considered to be casual. It has been first observed as a 'wool alien' [contaminant of wool imports] in the Vesdre valley in 1947. It then occurred temporally in 1990s in different regions of Belgium, such as in port areas (always associated with soybean imports; "…especially around the silos at Ghent Grain Terminal several vegetative plants grew"; Verloove & Vandenberghe, 1994) in Antwerp and Gent, on the area of a demolished oil mill along Albertkanaal at Merksem. Recently, it was recorded again at the Ghent Grain Terminal in the port area in Gent in 2013 (Manual of Alien Plants of Belgium, 2021).
Croatia: *S. carolinense* was first found in 1976 on the island of Plavnik (Gaži-Baskova & Šegulja, 1978). Recently, the species has been detected in North Dalmatia in the city of Zadar (Milović & Mitić, 2012).

Czech Republic: According to Pyšek *et al*. (2012), the species is considered casual. Jehlik (1989) summarized few early occurrences of the species, mainly from port areas along the river Elbe (e.g. cities Kolín, Děčín).

Finland: Casual occurrences (1981, 1985) of *S. carolinense* have been documented near the town Turku and Helsinki (FinBIF, 2021).

France: *S. carolinense* is established very locally in SW France. The species was detected in a maize field in 2020 in the Département Aveyron, where it seems to be already present for some years. The plant had also been found along a roadside in 2013 in the Département Tarn-et-Garonne (still present, but not spreading rapidly). There is also an older record (detected around 2010) in the Département of Haute-Garonne: the species has been observed in summer crops there but has not been confirmed recently despite specific surveys in this area in 2021 (G. Fried, pers. communication 2021).

Germany: Henker (1980) showed that the species was detected near pig farms in Mecklenburg-Western Pomerania. Further observations were from port areas of Hamburg (1988: Jehlik, 1989; 2003: Schwarzenstein, 2005), Neuss (1981: Stieglitz, 1981) and Mannheim (since 2004: Junghans, 2013). Lately, the species was found in crop fields in North Rhine-Westphalia (Klingenhagen *et al*. 2012) and Bavaria (Hohla & Zahlheimer, 2018).

Georgia: *S. carolinense* was observed in Abkhazia, Adzharia, Mingrelian and Gurian regions of Georgia (Larina & Budrevskaya 2004). According to Trapaidze (1972), the species was first noticed in 1960 in Abkhazia. Mikeladze & Sharabidze (2020) recognized the species during more recent surveys (2015-2018) on a landfill site in Batumi (Adjara).

Italy: The species occurs in seven regions: Friuli-Venezia Giulia, Veneto, Lombardia, Piemonte, Emilia-Romagna, Lazio, Puglia (Portal to the Flora of Italy, 2021). Early records were dated 1987, 1992 & 1993 in maize in Lombardia (San Gervasio Bresciano, Mairano, Chiari; Zanotti 1993). In other Italian regions, the species was detected after 1993. For example, in Friuli Venezia Giulia, the species was first found 2002 in Palmanova (Merluzzi *et al*., 2003).

The Netherlands: The species was first collected in 1983 near Ochten (province of Gelderland.). Since 2004, *S. carolinense* has been found in several localities on sandy riverbanks particularly along the River Waal (Dirkse *et al*., 2007; FLORON Verspreidingsatlas Vaatplanten, 2021).

Norway: The species was detected in 1974 and 1978 in Fredrikstad and Larvik, respectively.

Romania: The species occurs in the Constanţa harbor, which is an important entrance point of alien species in Romania. It is considered naturalized at this location (Anastasiu *et al*., 2011; Memedemin *et al*., 2016).

Russia: The species has been found several times in the different parts of Russia. The first findings were noticed in the Primorye Krai (Far East region) on a black currant (*Ribes nigrum*) plantation in the vicinity of the village of Banevurovo in 1975-1976 (Charkevicz, 1991) and on soybean fields near the village of Vozdvizhenka (Buch *et al*., 1981). A single specimen of the species was collected on a ruderal place in the city Grozny (Republic of Chechnya) in 2008 (Terekbaev, 2016).

Switzerland: *S. carolinense* has been observed in the port area of Basel (Brodtbeck & Huber, 1988; Brodtbeck *et al*., 1999).

Spain: The first references came from by Patino & Valencia (2000) for Marina de Cudeyo in Cantabria. Then, it has been found scattered over the country. It occurs as a casual or established in the western Atlantic valleys of the Pais Vasco (Province: Biscay; Anonymous, 2004, Campos & Herrera, 2009). The first detection dates back to 1995. Further observations are from Cataluna (littoral area, Aymerich & Sáez, 2019) and Galicia (roadsides, edge of meadows; Pérez *et al*., 2020).

Ukraine: *S. carolinense* is considered to be absent. It has been collected once in 1992 near a grain mill in Kyiv (Mosyakin & Fedoronchuk, 1999; Burda, 2018). The species in the flowering phase was collected on the railway in the port of Odessa in 1983 (Report of Odessa Plant Quarantine Laboratory, 1983).

7. Habitats and where they occur in the PRA area
(Habitat classification based on EUNIS habitat types)

Habitat (main)	**Classification**	**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	Temporary running waters (C2.5), Littoral zone of inland surface waterbodies (C3)	Protected in part	Yes	Major	Dirkse *et al.* (2007)
E : Grasslands and lands dominated by forbs, mosses or lichens	Low and medium altitude hay meadows (E2.2); E5.1. Anthropogenic herb stands: on hard-surfaced areas of ports (J4.5), road networks (J4.2)	None	Yes	Major	Follak (2020) Junghans, (2013), Jehlik (1989), Pérez *et al*. (2020)
G: Woodland, forest and other wooded land		Protected in part	No	Major	Wahlert et al., (2015), You et al. (2017)
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	Selvaggi *et al.* (2018), Follak (2020)

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

Note: You *et al*. (2017) and Kim *et al*. (2020) mention natural forests as a potential habitat for the species in South Korea. The EWG however, did not consider that the species would colonize forests within the EPPO region, and therefore do not consider that it is a significant habitat for the species.

Within the EPPO region, the species is recorded growing in different habitats including banks of major rivers (e.g. Waal; Dirkse *et al*., 2007), ruderal habitats (e.g. roadsides, port areas; Junghans, 2013; Pérez *et al*., 2020), pastures and crop fields (Klingenhagen *et al*., 2012; Selvaggi *et al*., 2018; Hohla & Zahlheimer, 2018; Follak, 2020; Appendix 2). In Austria, it invades roadsides and crop fields, such as maize, oil-pumpkin and soybean (Follak 2020). In Italy, the species has been recorded in crops, such as sugar beet, beans and soybean, mainly in Northern Italy (Saglia *et al*., 2005; Selvaggi *et al*., 2018). Additionally, the species has also been reported from disturbed sites like roadsides and ditches (Zanotti, 1993; Barberis *et al*., 2014). In the Netherlands, since 2004, *S. carolinense* has been found in several localities on sandy riverbanks particularly along the River Waal (Dirkse *et al*., 2007; FLORON Verspreidingsatlas Vaatplanten, 2021).

Apart from its presence on banks of rivers, *S. carolinense* is not recorded in natural habitats in the EPPO region.

8. Pathways for entry

Seed and grain should be understood in this PRA as defined in ISPM 5.
Seeds: seeds (in the botanical sense) for planting.
Grain: seeds (in the botanical sense) for processing or consumption, but not for planting.

Solanum carolinense was presumably first introduced into the EPPO region as a grain contaminant. Records from ruderal sites in port areas and along (nearby) riverbanks indicate its introduction via imported goods. More recently, a contamination of seeds has been identified as a further pathway.

The following pathways for entry of *S. carolinense* 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**
- **Hay**
- Used machinery and equipment
- Seed mixtures and native seeds
- Manure
- Soil and other growing media (on its own or associated with plants for planting other than seeds)

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 *S. carolinense* may be a contaminant in grain imported for (1) animal feed mixture and (2) human consumption, including for processing. The grain imported for human consumption is likely to be less contaminated than for animal consumption as regulations are stricter. Grain for human consumption is cleaned to a very high standard to ensure quality and consistency for the end product. In addition, the processing of grain for human consumption may be partially or totally destructive. This is different for the processing of grain for animal feed where the standards are less restrictive, and grain may be cleaned and processed to a lesser degree. In addition, grain may be used whole for animal feed. Therefore, although the entry into the EPPO region would be the same for both human consumption and animal feed, differences in processing in the importing country should be taken into account. Both commodities would be transferred to a processing facility and then separated for the two different uses. This pathway covers grain of the following species: *Glycine max, Zea mays, Triticum spp.*
Pathway prohibited in the PRA area?	No. The EU Directive 2002/32/EC has requirements on the purity of the grain for animal feed.
Pathway subject to a plant health inspection at import?	No The EWG was not aware of plant health regulations imposing inspection at import in the EPPO region on these commodities. Countries that regulate the species (see section 5) are likely to perform import inspections.
Pest already intercepted?	Yes, *S. carolinense* has been intercepted along this pathway. Imports of soybean seem to be the main commodity concerned. China reported detecting 36 different species of weed seeds in US soybean shipments including *S. carolinense* (Dellis and Galasso, 2017). In EPPO countries, it is assumed that the species was introduced from North America together with soybean (e.g. Norway: Ouren, 1987; Romania: Costea, 1996, Belgium: Verloove & Vandenberghe, 1994). This could not be proven, but is based on observations and locations of the plant in the port areas (around silos, growing together with “soybean waste”). In Norway, the species was introduced as a contaminant of imported soybean (so called “soybean adventive”) most likely from the USA (Ouren, 1987). For Germany Jehlik (1989) and Junghans (2013) noted that contaminated soybean originating from America was the probable source of the diaspores. In Romania it is reported by Costea (1996) as probably originated from shipping, especially from trade (“soya-bean waste”).

<table>
<tr><th>Pathway</th><th>Grain (for animal feed mixtures, human consumption and processing purposes)</th></tr>
<tr><td></td><td>
Kurokawa (2001) assumed that it has further been most likely introduced to Japan from the USA via contamination of grain.
Russia reported detecting more than 40 different weed seeds in wheat, soybean and corn shipment from the USA, including S. carolinense in the period 1983-2000.
Table 5. Interceptions of S. carolinense seed in grain imports (data from quarantine laboratory in Primorye (Vladivostok, RU)
<table>
<tr><th>Year</th><th>Crop</th><th>Detection cases per year</th></tr>
<tr><td>1983</td><td>wheat (USA); soybeans (USA); soybeans (Singapore)</td><td>1; 2; 1</td></tr>
<tr><td>1984</td><td>soybeans (USA)</td><td>1</td></tr>
<tr><td>1985</td><td>wheat (USA); Corn (USA)</td><td>4; 4</td></tr>
<tr><td>1988</td><td>wheat (USA); soy meal (USA)</td><td>6; 6</td></tr>
<tr><td>1990</td><td>wheat (USA)</td><td>2</td></tr>
<tr><td>1991</td><td>soy meal (USA)</td><td>2</td></tr>
<tr><td>1992</td><td>soybeans (USA)</td><td>1</td></tr>
<tr><td>1994</td><td>wheat (USA)</td><td>1</td></tr>
<tr><td>1999</td><td>soybeans (USA); wheat (USA)</td><td>15; 2</td></tr>
<tr><td>2000</td><td>soybeans (USA)</td><td>1</td></tr>
</table>
Ikeda et al. (2022) did not find any seeds of S. carolinense in wheat samples from Canada, USA and Australia, although wheat and other grains could be contaminated.
</td></tr>
<tr><td>Most likely stages associated with the pathway</td><td>Seeds (or fruits) of S. carolinense is the most likely stage to be associated with the pathway. In North America, S. carolinense is a weed of many crops in particular maize (e.g. Prostko et al., 1994) and soybean (Wiles et al., 1992).</td></tr>
<tr><td>Important factors for association with the pathway</td><td>The probability that seeds of S. carolinense are associated with the pathway at the point of origin depends mainly on the crop species concerned (spring crops such as maize and soybean are more likely to be contaminated while winter cereals can be excluded; Ikeda et al., 2022), on the exact origin of the imported product and the degree of infestation of this region by S. carolinense.</td></tr>
</table>

Pathway	Grain (for animal feed mixtures, human consumption and processing purposes)
	Ripe berries with seed will be present on *S. carolinense* plants when crops are being harvested. The small seeds can be released from ripe berries during the harvesting process. Mixture of grains from different origins present a higher risk of contamination because of lack of traceability. The likelihood that *S. carolinense* seeds are associated with the pathway at origin greatly depends on the effectiveness of the management measures implemented during cultivation and the cleaning procedures that can be implemented at origin before export. Grain can become contaminated at harvest in the area of origin.
Survival during transport and storage	The seeds of *S. carolinense* can remain viable for three years (Brown & Porter, 1942) enabling their survival along the pathway.
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 3 (from FAOStat, imports reported by EPPO countries) give an indication of the existence of a trade for the above commodities.
Will the volume of movement along the pathway support entry?	It is likely that the volume of movement of the commodity will support entry. Appendix 3 shows volumes of grain (soybean and maize) entering the EPPO region from the USA. 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 frequency of movement along the pathway is likely to support entry. Although there are no figures to highlight the frequency of movement of *S. carolinense* 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 North America (see Appendix 3). Frequency is not crucial as even if imports only occur in the winter, seed can survive and germinate in the spring.
Transfer to a suitable habitat	In the areas of introduction, such as ports where cargos where grain for industry or livestock pass through, any seeds falling to the ground can become established as shown by species' records on such sites (Junghans, 2013; Memedemin *et al*., 2016). Grain lots may be sorted after import before processing to remove external matters such as weed seeds. If the waste from the sorting is disposed in fields, they may become infested. There may also be deviation from the intended use (i.e. imported as grain, and used as seed).

Pathway	**Grain (for animal feed mixtures, human consumption and processing purposes)**
	It was reported that seeds of *S. carolinense* (mixed in feed) remained viable after being digested by cattle (Nishida *et al*., 1998). Crop fields and pastures can be infested directly be animal faeces.
Likelihood of entry and uncertainty	The EWG noted that the entry of grain into the EPPO region may differ for different EPPO countries. Grain may be processed for animal feed or human consumption before it is exported or it may be imported unprocessed and separated at points of entry in the EPPO region. Therefore, the EWG decided to score both separately. Grains for livestock (*Glycine max, Zea mays, Triticum* spp.): **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), with a **low uncertainty** (evidence to support entry). Grains for human consumption and processing purposes (*Glycine max, Zea mays, Triticum* spp.): **Low likelihood of entry** (higher quality standard, not used directly in a suitable habitat), with a **low 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* and *Zea mays.* *Solanum carolinense* infests many crops, however, in particular maize and soybean (Wiles *et al*., 1992; Prostko *et al*., 1994, Van Wychen, 2015), and these crops are harvested at a period when seeds of *S. carolinense* are present. Seed lots can therefore be infested by seeds of *S. carolinense*. Seed lots of soybean and maize are most at risk of being contaminated. Seed of wheat was not included as wheat would be harvested to early in the season for seed of S. carolinense to be present.
Pathway prohibited in the PRA area?	No, this pathway is not prohibited in the PRA area. There are some requirements at EU level in marketing Directives for seed https://ec.europa.eu/food/plant/plant_propagation_material/legislation/eu_marketing_requirements_en
Pathway subject to a plant health inspection at import?	Yes, partly in some EPPO countries.
Pest already intercepted?	No, to-date, *S. carolinense* has not been intercepted along this pathway. There is only speculation as to how the species was introduced, based on observations of the species' first appearance e.g. in Austria, France, Germany and Italy. Klingenhagen *et al*. (2012) and Zanotti (1993) assumed that the occurrence of *S. carolinense* in Germany and Italy was due to the cultivation of contaminated maize varieties (*Zea mays*) from abroad. In Austria, *S. carolinense* first appeared in a maize field following soybean, where the seeds were presumably obtained from Canada (Follak, pers. communication 2021). There is no direct evidence for these cases. However, Robbins *et al.* (1942) state a main mode of spread in the USA has been via contaminant in soybean seed.
Most likely stages associated with the pathway	Seeds of *S. carolinense* may become associated with seeds of *Glycine max* and *Zea mays* at harvest.

Pathway	Seed
Important factors for association with the pathway	The probability that seeds of *S. carolinense* are associated with the pathway at origin depends mainly on the crop species concerned (spring crops, such as maize and soybean, are more likely to be contaminated), on the exact origin of the imported product and the degree of infestation of this region by *S. carolinense*. Ripe berries with seed will be present on *S. carolinense* plants when crops are being harvested. The small seeds can be released from ripe berries through the harvesting process. The likelihood that *S. carolinense* 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 sorting procedures that can be implemented at the origin before export. There will be less risk of contamination in certified seed. Seed is 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). for *Glycine max* the following requirement: Maximum 5 seeds of other plant species in a sample of 1Kg of Glycine max seeds. **Council Directive 2002/57/EC of 13 June 2002** **on the marketing of seed of oil and fibre plants:** https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02002L0057-20200216&from=EN For Zea maize: Maximum 0 seeds of other plant species in a sample of 1Kg of Zea maize seeds. **Council Directive 66/402/EEC of 14 June 1966 on the marketing of cereal seed** https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01966L0402-20220201&from=EN
Survival during transport and storage	The seeds of *S. carolinense* can remain viable for three years (Brown & Porter, 1942) enabling their survival along the pathway.
Trade	There is a trade of seed (for planting) from countries where the *S. carolinense* occurs into the EPPO region. The figures in Appendix 4 (from FAOStat, imports reported by EPPO countries) give an indication of the existence of a trade for seed of maize and soybean from the USA.

Pathway	Seed
Will the volume of movement along the pathway support entry?	Yes, Appendix 4 provides figures on the quantities of maize 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. It is likely that the volume of *S. carolinense* as a contaminant along this pathway will be proportionate to imports into the PRA area
Will the frequency of movement along the pathway support entry?	As mentioned, although the frequency of movement of maize and soybean 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). 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 very likely. Seed for sowing contaminated by *S. carolinense* seed would be directly sown in agricultural fields, which is an optimal habitat for this species.
Likelihood of entry and uncertainty	Certified seed of *Glycine max* and Zea *mays*: **Very low likelihood of entry** with **low uncertainty** (seed is certified) Non-certified seeds of *Glycine max* and Zea *mays*: **Moderate likelihood of entry** (used in a suitable habitat, indirect evidence of association with the pathway, reports of presence in crop fields in the EPPO region) with **high uncertainty** (not intercepted on the pathway; uncertainty about the use of certified vs. uncertified seeds by non-EU EPPO countries)

- **Hay (***Paspalum notatum*, and other forage grasses). A recent survey (2020) revealed that *S. carolinense* is the fourth most common and the second most troublesome weed in pastures, rangeland, or other hay in the USA (Van Wychen, 2020). Indeed, it is considered that the spread of *S. carolinense* (both berries and seed) in the USA has occurred through the movement of hay (Robbins *et al*., 1942). Imported hay from the USA may be contaminated with fruits or seeds (Anonymous 1898). Kurokawa (2001) checked samples of imported hay into Japan. Although many seeds were recognized in each sample, they were not those of the recently observed exotic noxious weed species (incl. *S. carolinense*). Likewise, Asai *et al*. (2009) did not detected seeds of *S. carolinense* in imported hay from the USA and Canada (including *Phleum pratense*, alfalfa, Sudan grass). Thus, this pathway is possible in principle, but contamination with seeds seems unlikely. 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). Likelihood of entry and uncertainty: **Low** (lower volume, no interceptions) with a **moderate uncertainty** (uncertainty on the movement of hay into the EPPO region and the treatment of hay)

8.2 Pathways with a very low likelihood of entry

- **Used machinery and equipment:** Seed of *S. carolinense* 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 *S. carolinense* 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). The EWG consider a very low likelihood of entry with a low uncertainty.
- **Seed mixtures and native seeds:** Seed mixtures for conservation, pollination and seed mixtures for forage plants for mammals (*Trifolium* species for example) for hunting, or for horticultural purposes can be imported to the EPPO region from North America, and for EU countries 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. There is no evidence of interceptions of contaminated seed mixtures and native seeds with *S. carolinense* seed. The difference in the size of native seeds and berries of *S. carolinense* may be one factor that prevents contamination as the berries are removed during- or post-harvest. Seed mixtures and native seed are often produced in agricultural fields of a unique species and mixed afterwards. Information on traded volume is lacking; however, the EWG considered that such mixtures are imported in lower quantities than seeds of *Glycine max* and *Zea mays*. The EWG consider a very low likelihood of entry with a high uncertainty.
- **Manure:** *Solanum carolinense* has been recorded to spread via manure in the USA. The movement of manure from the USA to the EPPO region is likely to be extremely low. The EWG consider a very low likelihood of entry with a low uncertainty.
- **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)). Consideration was given to seed attached to potato tubers and beetroot with soil attached. Although *S. carolinese* is reported as occuring in these crops in USA, it is not frequent and seed is likely to be removed when harvesting and packing. A very low likelihood of entry as a contaminant on this pathway with a low uncertainty.

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

Rating overall	Very low ☐	Low ☐	Moderate ☐	High X	Very high ☐
Rating of uncertainty			Low X	Moderate ☐	High ☐

9. Likelihood of establishment outdoors in the PRA area

Solanum carolinense is locally established in Austria, France, Georgia, Germany, Italy, Romania and Spain.

Habitats which are suitable for *S. carolinense* are detailed in section 7. These habitats are widespread within the EPPO region and further establishment is likely in regions where habitats and climatic conditions are conducive for establishment.

9.1 In the natural environment

Apart from its limited presence on banks of rivers (Dirkse *et al*., 2007), *S. carolinense* is not currently established in natural habitats in the EPPO region. It is likely that *S. carolinense* can establish in the natural environment within the EPPO region, in particular in disturbed habitats. In stable natural habitats, interspecies competition patterns may limit the establishment of *S. carolinense*. Hakes *et al*. (2018) noted that "... seed germination and seedling establishment are vanishingly rare in established undisturbed populations". Nevertheless, it can be assumed that clonal species, such as *S. carolinense*, can make use of immediate growth and regeneration from root fragments and thus, are predicted to establish and compete with other plants quite effectively.

9.2 In the managed environment

It is likely that *S. carolinense* can establish in the managed environment in the EPPO region. It is capable of rapidly invading disturbed areas due to its seed production, the formation of a long-lived seed bank and its creeping root system.

In ruderal and agricultural environments, it is unlikely that competition with plants would prevent the establishment of the species. *S. carolinense* can invade many spring crops in particular late sowing crops like maize, oil-pumpkin and soybean. The high frequency of spring crops in the crop rotation system in many EPPO countries is a factor that may strongly favor the establishment of *S. carolinense* once the field has become contaminated by seeds or root fragments.

In crops, common weed control methods may not be sufficient to limit the development of the species due to its extensive root system, capacity to regenerate from small root fragments and tolerance against certain herbicide groups (Ilnicki & Fertig, 1962; Prostko *et al*., 1994). Further complications may arise from the reduction in the number of herbicide active substances (compounds with systemic activity against perennial weeds) and the decrease in the number of herbicides treatments associated with the reduction in the use of plant protection products. To control perennial weeds, such as *S. carolinense*, multiple annual application may be required for adequate control. *S. carolinense* benefits in part from reduced soil tillage (e.g. Ball *et al*., 2019), which has become increasingly popular in European cropping systems. All these factors potentially foster the establishment of *S. carolinense*.

9.3 Other factors affecting establishment

Natural enemies
Within the EPPO region, there are no host specific natural enemies of *S. carolinense*. Generalist natural enemies will potentially attack the plant, but these are unlikely to cause enough damage to influence establishment.

Climate conditions
A model to project the climatic suitability for potential establishment of *Solanum carolinense* in Europe and the Mediterranean region, under current and predicted future climatic conditions was elaborated for this PRA (see appendix 5). The strongest limiting factors were excessively low or high growing degree days (gdd10) and low or high precipitation (bio12). There was also relative strong limitation by very low winter temperature (bio6) and highly seasonal precipitation regimes (bio15). At the scale of the model, very weak preferences for croplands and other human influenced habitats were shown in the model output.

In the EPPO region, the model predicts a large climatically suitable area south of about 48°N across most of Central, and Southern Europe, and around the Black Sea coast into southern Russia. The currently invaded areas in the EPPO region are all projected as suitable, though the occurrence records from further north (Germany and the Netherlands) are projected to be in marginally unsuitable climatic conditions. The model suggests the main limiting factor in northern Europe is low temperature (low gdd10), while drought stress (low bio12) is more important in unsuitable areas of southern Europe and North Africa.

Predictions of the model for 2041-2070, under the moderate SSP1-2.6 climate change scenario suggests a northwards expansion of the suitable area, especially in western Europe, Ukraine and southern Russia, driven by warmer summer temperatures. Similar but more pronounced patterns are projected for the more extreme SSP3-7.0 scenario (Figures 7 and 8). Note that these projections assume no change in land use of human influence.

These results are reflected in the suitability of different European Biogeographical Regions (Bundesamt fur Naturschutz (BfN), 2003). Regions highly suitable for establishment in the current climate are the Pannonian, Black Sea, and Mediterranean, though we note pockets of high current suitability are in southern parts of the Atlantic and Continental regions. By 2041-2070, the Pannonian, Black Sea, Continental, Atlantic and Steppic regions all increase markedly in suitability. Overall suitability in the Mediterranean is little changed.

Follak & Strauss (2010) showed that a large area of Central Europe is climatically suitable for *S. carolinense* using a Climex model. The land area climatically suitable for *S. carolinense* under current climate is highest in Hungary (100% of the total land area), Poland (83.6%), followed by Slovenia (70.5%), Slovakia (64.5%), Germany (41.5%), Czech Republic (37.0%), Austria (34.9%) and Switzerland (16.6%).

Seeds need comparable warm temperatures for germination (> 15 °C) (Nishida *et al*., 2000).

Soil conditions
Soil conditions are suitable for the species in the EPPO region. *Solanum carolinense* tolerates a wide range of soil types and grows best in sandy or gravelly soils (Ilnicki & Fertig, 1962; Bassett & Munro, 1986). It has also been observed on medium and heavy textured soils (Mississippi/USA) (J. Byrd, pers. communication 2022).

The EWG considered that the rating of the likelihood of establishment should be based on the worst-case scenario: the species is already established in the EPPO region and further establishment is likely. The EWG considered that this rating applies to Mediterranean countries and countries in the Atlantic and Continental areas of the EPPO region where the species can enter to a suitable cropping system.

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

10. Likelihood of establishment in protected conditions the PRA area

No evidence was found of the presence of *S. carolinense* 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 favourable for the development of the species.

Protected conditions in the EPPO region, such as in nurseries, polytunnels, tropical greenhouses may offer appropriate conditions for the development of *S. carolinense*. However, these facilities produce crops 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.

The EWG considered that the likelihood of *S. carolinense* establishing in protected conditions in the EPPO region is low with a moderate uncertainty. Climate in these conditions would be suitable for the establishment however, other conditions e.g. the substrate and the intense management of the system are likely to reduce the likelihood of establishment. Additionally, the most documented infested crops are not cultivated in protected conditions. Moderate uncertainty: Protected conditions themselves vary, with different intensities of management.

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

11. Spread in the PRA area

In North America, and in Japan, *S. carolinense* has shown to have spread over long distances presumably by both natural and human assisted mechanisms. In the USA, long distance spread has been speculated with the inter-state movement of hay (Robbins *et al*., 1942).

Imaizumi *et al*. (2006) reported that *S. carolinense* has been recorded in pastures and orchards from the 1970s onwards. The species was limited to a small area in 1981 and from the 1990s onwards, it has become more widespread and infested areas have increased rapidly. In 1994, *S. carolinense* was reported on approximately 25% of all surveyed pastures (Nishida *et al*., 1999a). In 2013, a survey recorded that *S. carolinense* had infested 76.3% of the total surveyed area of forage crop fields (11,200 ha) (cited in Tominaga & Kurokawa, 2020).

Natural spread
Solanum carolinense propagates by seed and its creeping roots system. It is capable of producing ca. 40–170 seeds per fruit, with a single plant producing up to ca. 5,000 seeds (Bassett & Munro, 1986). Clonal reproduction and vegetative spread of *S. carolinense* is extensive (Miyazaki & Ito, 2004; Miyazuki, 2008). The horizontal distribution of the subterranean root system was ~130 cm in 10-month-old plants compared to ~580 cm in 16-month-old plants (derived from seeds). New shoots typically occur less than one to two meters from the center of the root system (Miyazuki, 2008).

The establishment of root fragments is assumed to be very successful, as the species can grow vegetatively from very small cuttings, less than 2.5 cm long and 5 mm in diameter (Ilnicki & Fertig, 1962). However, for natural spread root fragments are not considered important.

In the native range, the fleshy fruits remain on the fruiting stalk and may be dispersed by birds and mammals (e.g. *Turdus migratorius*, *Didelphis virginiana*, *Odocoileus virginianus*) suggesting that long-distance dispersal may occur (Martin *et al*., 1951; Cippolini & Levey, 1997).

Seeds passing through a birds gut appear to be nearly 100% intact, while those passing through the digestive systems of some mammals may be damaged (Cippolini & Levey, 1997). However, the extent of seed dispersal is probably limited, as Cippolini & Levey (1997) noted very low and sporadic dispersal rates for *S. carolinense* ("most fruits generally fall to the ground and rot") based on field observations over four years. Cipollini & Levey (1997) showed that *S. carolinense* has high levels of secondary metabolites (glycoalkaloids) in ripe fruit and wild animals were deterred by such levels (compared to *Solanum americanum* Mill.). Williams & Ward (2006) demonstrated that the white-tailed deer (*Odocoileus virginianus*) was an important dispersal agent of seeds of *S. carolinense* (Connecticut/USA). Seeds were frequently found in the pellet samples examined.

Spread by natural dispersal mechanisms, in particular small mammals has the potential to occur in the EPPO region though to-date, this has not been studied and there is some uncertainty if small mammals within the region will consume the berries and spread seed. In Japan, dispersal by birds and animals has not yet been confirmed (Miyazaki *et al*., 2011). In the EPPO region, natural spread is likely to act locally for the movement of the species but as propagules are not wind dispersed, and there is no information on the buoyancy of seeds.

Human assisted spread

Propagules of *S. carolinense* can be spread by agricultural machinery by contaminated soil attached to farm implements, such as disc, harrow or plough within fields and from field-to-field. Additionally, management and/or construction works in habitats that act as corridors for spread (e.g. roadsides) may facilitate the spread of the species.

Imaizumi *et al*. (2006) pointed out that human mediated introduction from distant regions have mainly contributed to the development of the weed population of *S. carolinense* along the Takano River (Kyoto/Japan), and that this introduction was most likely via planting activities (soil contaminated with root fragments or seeds).

The species can be spread across fields by cultivation equipment through sectioning the roots and spreading the cuttings to other areas in the field (Wehtje *et al*., 1987). In Japan, Urakawa & Koide (2004a) noted that, rotary tillage has led to the spread of *S. carolinense* via root fragmentation in maize fields. The study started with three root fragments buried in a maize field, and aboveground stems increased from 21 in the second year to 218 in the third year, and to more than 900 (approximately one thousand) in the fourth year. In each year, rotary plowing was conducted in early May before sowing maize, and the survey was conducted at harvest time (mid-August) (Urakawa & Koide, 2004a).

In the EPPO region, in Austria, Follak (2020) noted that the movement of root fragments via agricultural machinery was strongly suspected to be the main dispersal vector from field-to-field. This was underlined by the fact that most observed populations of *S. carolinense* occurred at field margins and headlands along farm tracks and roads (southern Styria/Austria). It was observed that the species has spread at least 2 km within 10 years.

The movement of contaminated grain, seed and hay, and agricultural products and equipment (see section 8) within and between countries of the EPPO region can act to spread the species over long distances.

The potential for spread is likely to increase with further establishment in the EPPO region (see section 9).

The EWG considered the rating of magnitude of spread to be high. In the EPPO region, *S. carolinense* has the potential to spread by natural and human assisted means. Although natural spread is likely to be limited, human assisted spread has the potential to spread propagules long-distances mainly through contamination of agricultural products and equipment. A moderate rating of uncertainty is given as there is uncertainty if small mammals and water will act to spread seeds. Additionally, a high rate of spread has not been seen at present in the EPPO region but the EWG considered with increased establishment the potential is there for increased spread.

Rating of the magnitude of spread	Very low ☐	Low ☐	Moderate ☐	High X	Very high ☐
Rating of uncertainty			Low ☐	Moderate X	High ☐

12. Impact in the current area of distribution (excluding the PRA area)

12.1 Impacts on biodiversity

There are currently no studies available on the potential negative impact of *S. carolinense* on biodiversity. In general, for *S. carolinense* most natural habitats of high conservation value have a low potential to be invaded, thus negative effects of this plant on biodiversity are considered of low importance.

However, in South Korea, *S. carolinense* has invaded island ecosystems and the interior of natural forests (You *et al*., 2017; Kim *et al*., 2020).

No natural hybrids have been reported for *S. carolinense* (Bassett & Munro, 1986).

12.2 Impact on ecosystem services

Solanum carolinense has an impact on ecosystem services within the current area of distribution (see table below).

Ecosystem service	**Does the pest impact on this Ecosystem service?** Yes/No	**Short description of impact**	**Reference**
Provisioning	Yes	Reduces yields in agricultural cropping systems and pastures	Frank (1990), Hackett *et al*. (1987), Beeler *et al*. (1994)
Regulating	Yes	No studies have investigated regulating impacts. However, in Japan *S. carolinense* has been observed to impact on regulating ecosystem services.	pers. communication Ito (2012)
Supporting	No	No studies have investigated supporting impacts	
Cultural	Yes	In Japan, due to the occurrence in many urban and semi-urban areas (e.g. road sides and in parks), can reduce the aesthetic value of such habitats.	pers. communication Ito (2012)

12.3 Socio-economic impact

Anecdotal quotes showed that *S. carolinense* was perceived as a serious weed very early on in the USA. Darlington (1847) stated that *S. carolinense* monopolized infested sites, was exceedingly pernicious, almost impossible to eradicate, but should be removed quickly and completely everywhere it was found on the farm. Michener (1872) stated a landowner cannot have a more problematic weed than *S. carolinense.* He emphasized his disdain for this plant with the suggestion that a law to forcibly remove any landowner that allowed *S. carolinense* to spread on their property and onto neighbouring property were as essential to agriculture as quarantine laws were to the health of a community.

Information on socio-economic impacts is mainly available from North America. The economic consequences associated with the presence of *S. carolinense* are considered important from an agricultural point of view:

(1) it is a common weed in many crops and pastures and affects crop yield and quality
(2) it is considered toxic to livestock
(3) it is a host to many crop diseases and pests

Solanum carolinense infests many crops, in particular spring crops such as peanuts, maize, cotton, potato, alfalfa, green beans, tomato, vegetables, and soybeans (e.g. Webster, 2008; Van Wychen, 2015; Van Wychen, 2020). Unfortunately, competition of *S. carolinense* with crops is not well documented. Only a few studies focused on the impact of the species on crop yield. The extent of yield loss depends largely on the density of *S. carolinense* but also on the crop type, and low-growing crops seem to be more affected.

Some authors have documented effects of various densities of *S. carolinense* on yield of peanut (*Arachis hypogaea* L.) and snap bean (*Phaseolus vulgaris* L.). The impacts are expressed as crop yield reductions. The study of Hackett *et al*. (1987) seemed to indicate that *S. carolinense* is not a major problem in peanuts. They showed that in one year 32 specimens in a 10 m of row (the highest density) reduced yield, but in the second year the same density did not have any effect on the yield of the peanuts. In contrast, Frank (1990) demonstrated that the yield of snap bean was greatly reduced due to the presence of *S. carolinense*. Eight

S. carolinense specimens planted in a 4.6-m row the first year and 16 specimens per row for the second year reduced snap bean yield 36 and 55%, respectively.

Whaley & Vangessel (2002) noted that *S. carolinense* was not a strong competitor with maize. At all sites (Delaware/USA), no significant differences or trends in maize yield were observed in field trials (untreated control vs. different herbicide control options). Prostko *et al*. (1994) demonstrated similar findings, although a trend of higher yields was observed in plots with herbicide treatments.

A recent survey (2020) revealed that the species is the fourth most common and the second most troublesome weed (just after *Cirsium arvense*) in pastures, rangeland, or other hay in the USA (Van Wychen, 2020). In pastures, *S. carolinense* is considered as a drought-resistant competitor and is presumed to reduce the yield and quality of forages (Beeler *et al*., 1994). For example, population density of *S. carolinense* on an experimental site averaged 86 stems in 10 m^2 in a tall fescue dominated pasture (Richmond/USA; Tolson *et al*., 2012). Pasture weeds, such as *S. carolinense*, reduce desirable forage biomass through direct competition for resources or displacement of valuable forage species. However, specific data on forage yield loss are not available.

Solanum carolinense is considered toxic to livestock (Bassett & Munro, 1986). Fortunately, the species is not palatable and is not readily grazed unless animals are confined in overgrazed fields. The species contains glycoalkaloids, primarily a-solasonine and a-solamargine (Cipollini & Levey, 1997). Glycoalkaloids may induce gastrointestinal and systemic effects, with potential neurotoxicity. Bassett & Munro (1986) presented few anecdotal data on intoxication of livestock.

Solanum carolinense is a host to many pests that can cause damage to a variety of crops. The species is a reservoir for pathogens, such as *Alternaria solani* Sorauer, *Septoria lycopersici* Speg., tobacco mosaic virus (TMV) and cucumber mosaic virus (CMV). Some of the important phytophagous insect pests include *Leptinotarsa decemlineata* (Say), *Leptinotarsa juncta* (Germar), *Gargaphia solani* (Heidemann), *Trichobaris trinotata* (Say), *Epitrix fuscula* (Crotch), *Epitrix cucumeris* (Harris), *Manduca sexta* (Haworth), *Zonosemata electa* (Say), and *Phthorimaea operculella* (Bassett & Munro, 1986; Nichols *et al*., 1992; Wise & Sacchi, 1996; Wahlert *et al*., 2015; Wise, 2018).

In Japan, due to the occurrence in many urban and semi-urban areas (e.g. roadsides and parks), the species is managed and this incurs higher management costs (pers comm, ITO 2022).

The EWG considered the magnitude of impact in the current area of distribution is high – there are known impacts on agriculture and in pastures in the USA, and once it is established the species is highly difficult to eradicate and therefore continued management is required. It is regarded in the top ten of problematic weed species in pasture in the USA. In Japan, there are known impacts in landscape areas which incur costs to control.

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

13. Potential impact in the PRA area

13.1 Potential impacts on biodiversity in the PRA area

At present, there is no evidence that *S. carolinense* invades protected areas within the EPPO region or areas with a high conservation status. There is the potential for impacts on biodiversity along riverbanks and grasslands.

13.2 Potential impact on ecosystem services in the PRA area

There is no known information on *S. carolinense* 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

The potential economic impact of *S. carolinense* in the EPPO region for farmers could be significant if the species spreads and establishes in further areas. The studies conducted in North America (chapter 12.3) indicate the degree to which *S. carolinense* may impact upon crop and forage yield. Thus, effective weed control is essential in *S. carolinense* infested crops and pastures.

Solanum carolinense occurs already locally in crop (maize, soybean, oil-pumpkin) fields in the EPPO region (Austria: Follak, 2020; Italy: Selvaggi *et al*., 2018; Germany: Klingenhagen *et al*., 2012), though extensive data on the area of distribution and infestation levels are not available.

Specific studies on yield loss or additional operating costs are not accessible. Except Todua (1975), who showed in Georgia (Abkhazia) that the yield of essential oil crops (*Pelargonium roseum* Wild) was decreased with the presence of *S. carolinense*. In addition, the yield of tea (*Camellia sinensis*) in plantations was shown to decrease with the presence of *S. carolinense* and the quality of tea deteriorated.

In general, *S. carolinense* can be managed in crops and pastures like other weeds by herbicide use or mechanical measures. However, the control of the species by ploughing, cultivation and mowing is considered difficult because of its extensive root system and high capacity of regeneration. Moreover, *S. carolinense* is only moderately susceptible to several herbicides and multiple applications are required for adequate control (e.g. Beeler *et al*., 1994; Armel *et al*., 2003). The species will most likely show the same behaviour in the EPPO region. Therefore, additional weed management actions, such as specific herbicide programs (e.g. Whaley & Vangessel, 2002) or multiple tillage passes, may be required and this could raise control costs.

Will impacts be largely the same as in the current area of distribution? **Yes (in part)**

A high score is given as the species is already established in some suitable cropping systems and pastures in the EPPO region, and has the potential for further spread. There is also the potential for increased coverage of suitable crops in the EPPO region which will increase the magnitude of impact. Additionally, the impact will be high because the availability of effective herbicides is increasingly reduced due to regulations to reduce the use of plant protection products and because generally few herbicides are used in forage crops (ryegrass, clover, alfalfa) and pastures which are most at risk. *S. carolinense* benefits in part from reduced soil tillage (e.g. Ball *et al*., 2019), which has become increasingly popular in European cropping systems.

The EWG considered a moderate rate of uncertainty due to a limited number of scientific evidence on the negative impacts of the species despite its limited presence in the EPPO region.

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 ☐

14. Identification of the endangered area

The EWG considered that the endangered area includes agricultural and pasture land in the Mediterranean, Black Sea, Pannonian and southern parts of the Atlantic and continental, areas of the EPPO region. Appendix 5 gives the percentage of suitable areas in each country.

15. Overall assessment of risk

	Likelihood	Uncertainty
Entry	**High**	**Low**
Grains for animal feed, human consumption and processing purposes (*Glycine max, Zea mays, Triticum spp.*).		
Grains for livestock	High	Low
Grains for human consumption and processing purposes	Low	Low
Seeds of *Glycine max* and *Zea mays*	Moderate	High
Hay (*Paspalum notatum*, and other forage grasses)	Low	Moderate
Establishment outdoors in the PRA area	**Very high**	**Low**
Establishment in protected conditions in the PRA area	**Low**	**Moderate**
Spread	**High**	**Moderate**
Impact in the current area of distribution	**High**	**Low**
Potential impact in the PRA area	**High**	**Moderate**

The likelihood of new introductions to the EPPO region occurring via grain of *Glycine max, Zea mays, Triticum spp.* for animal feed is high with a low uncertainty. For seeds of *Glycine max*, and *Zea mays*, the likelihood of new introductions is moderate with high uncertainty. Entry into the EPPO region via hay is low with a moderate uncertainty.

Within the EPPO region, the species predominately grows in managed habitats such as ruderal and agricultural environments. *S. carolinense* can invade many spring crops in particular late sowing crops like maize, oil-pumpkin and soybean. In ruderal and agricultural environments, it is unlikely that competition with cultivated plants would prevent the establishment of the species.

The likelihood of further establishment outdoors is very high with low uncertainty. However, in protected conditions, it is low with moderate uncertainty. Temperature within protected conditions would be suitable for the establishment however, other conditions, e.g., the substrate and the intense management of the system are likely to reduce the likelihood of establishment.

The potential for spread within the EPPO region is high with a moderate uncertainty. *S. carolinense* can spread both naturally and via human assisted spread. Seeds of *S. carolinense* can be moved through agricultural machinery and plant products (e.g., grains, seeds) within the EPPO region.

The magnitude of impact in the current area of distribution (North America and Japan) is high – there are known impacts on agriculture and in pastures in the USA, and once it is established the species is highly difficult to eradicate and therefore continued management is required. In Japan, there are known impacts in landscape areas which incur costs to control. The EWG considered the potential socio-economic impacts in the EPPO region will be high with a moderate uncertainty.

Stage 3. Pest risk management

16. Phytosanitary measures

Phytosanitary measures should be recommended for grains for relevant crops (mentioned in 16.1). Measures for grains are considered in detail in Appendix 6. The EWG considered that seed is already regulated in many EPPO countries and if certified seed is used it should not pose a risk to the endangered area.

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 or human consumption.

The EWG recommended that *S. carolinense* 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 *Glycine max, Zea mays, Triticum aestivum*	Grains have been produced in a pest-free area (PFA) for *S. carolinense* established and maintained according to the requirements outlined below Or Grains have been produced in a Pest free production site (PFPS) or Pest free place of production (PFPP)[1] for *S. carolinense* established and maintained according to the requirements outlined below + Treatment of the consignment: sorting Or Grains have been sampled according to ISPM 31 and inspected, and the grain lot has been found free from *S. carolinense*. Or Grains have been devitalized according to an appropriate method
Seeds of *Glycine max* and *Zea mays*	Use of certified seed

[1]: The choice between PFPP and PFPS is a decision to be taken by the NPPO based on the operational capacities of the producers and biological elements

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

- Detailed surveys and monitoring should be conducted in the area and continued every year, throughout the year, especially at times of harvest. If climatic conditions in the PFA are suitable for the establishment of *S. carolinense*, the PFA should not include any area where the species has been reported in the last 5 years.
- Surveys should include high risk locations, such as summer crops, key transportation roads, ports, areas around grain storage facilities etc.
- Where climatic conditions in the PFA are suitable for the establishment of *S. carolinense*, there should be restrictions on the movement of the identified pathways for entry into the PFA, and into the area surrounding the PFA, especially the area between the PFA and the closest area of known infestation.

Requirements for establishing a Pest free production site (PFPS) or Pest free place of production (PFPP)

- Detailed surveys and monitoring should be conducted in the area and continued every year, throughout the year, especially at times of harvest.
- PFPS/PFPP should be established for at least 2 years before planting of grain production.
  - PFPS/PFPP will not be able to be formed where *S. carolinense* has been reported in the last four years.
  - A buffer zone (200 m) could be established where any *S. carolinense* plants are eradicated. Conditions in the buffer zone would include cleaning of machinery before movement.

16.2 Eradication and containment

National measures
Early detection is important to identify new occurrences of the species. *S. carolinense* 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.

Management of *Solanum carolinense*

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 *S. carolinense* 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.

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. Eradication measures should include hand weeding (plants being properly disposed) and herbicide treatments (see containment section) to eliminate any remaining plant parts

Containment
A pro-active and integrated weed management strategy is required to effectively manage *S. carolinense*. It should be noted that in natural environments, management practices should be tailored to the habitat invaded.

NPPOs should provide land managers, farmers and stakeholders with identification guides including information on preventive measures and control techniques.

Control of the species is difficult, because of its extensive root system, its ability to grow from small root fragments and the number of seeds produced. It is most successful when multiple tactics are employed, such as the combination of preventive methods, chemical, mechanical, and cultural control techniques.

***Prevention*:** Unintentional dispersal of *S. carolinense* seeds and root fragmnets fragments 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).

***Crop rotation*:** Planting crops with different life cycles (e.g. winter crops), places *S. carolinense* in a disadvantage to germinate or sprout 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, tall-growing crops (e.g. maize) and crops with a narrow row spacing can suppress *S. carolinense* growth by shading.

***Tillag*e:** Deep tillage practices (plough) normally reduce perennial weed populations, because the underground root system (i.e. the development of below-ground storage organs) is disturbed. Tillage by plows, disks, or cultivators is seen critical and may even increase *S. carolinense* infestations by relocating root fragments to new areas of the crop field or by breaking the dormancy of adventitious buds, resulting in new shoot growth (Wehtje *et al*., 1987).

***Mowing*:** Frequent mowing is ineffective in the control of *S. carolinense* (Gorrell *et al*., 1981). In this respect, Ilnicki & Fertig (1962) demonstrated that *S. carolinense* likely forms a rosette growth pattern and thus keeps root system sufficiently supplied with carbohydrates when mowed frequently at very low heights.

***Herbicides*:** Herbicides are the most common method of controlling the species in fields and pastures. Applications with certain mixtures and treatments of glyphosate, auxin-type herbicides (e.g. dicamba, picloram, aminopyralid), sulfonylureas (primisulfuron, nicosulfuron) and triketones (mesotrione) are somewhat effective (e.g. Prostko *et al.*, 1994; Whaley & Vangessel, 2002; Armel *et al*., 2003; Beeler *et al*., 2004, Klingenhagen *et al*., 2012).

17. Uncertainty

Main sources of uncertainties in this risk assessment are linked to:

- Trade volumes and frequency of movement for some commodities (hay).
- Uncertainty in the potential establishment in northern Europe
- Will spread mechanisms (natural spread and human assisted spread) in current area of distribution be the same for the EPPO region. Little information on natural spread mechanism in the EPPO region,
- Lack of scientific evidence for impacts in agricultural systems in the EPPO region.
- It is difficult to predict the effect of irrigation which can promote establishment in drier regions.

18. Remarks

The EWG consider:

- Specific studies on potential negative impact on biodiversity and crop yield are lacking for the EPPO region, such studies could be conducted.

- Studies are required to confirm the status of northern European populations which will help to refine the assessment of risk to Northern Europe.

- Monitoring of natural spread by birds and mammals and reptiles in the EPPO region

19. References

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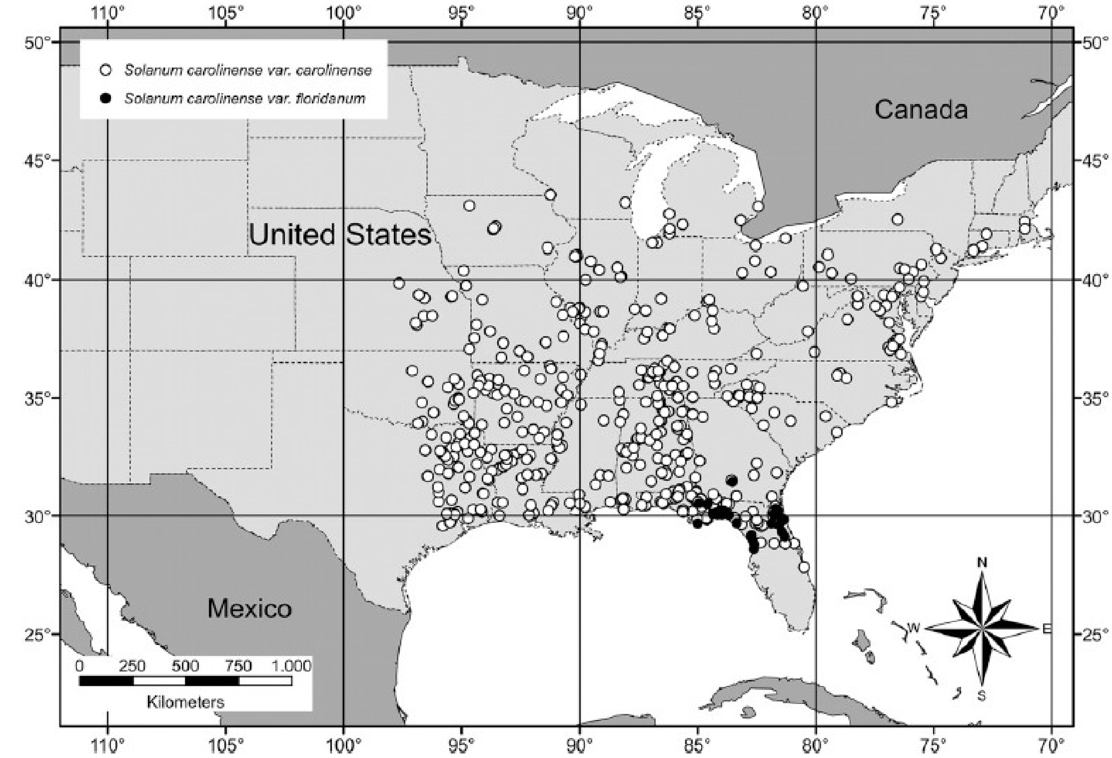
Appendix 1 Potential native distribution of Solanum carolinense in North America
(from Wahlert *et al*. 2015)



Appendix 2. Relevant illustrative pictures (for information)

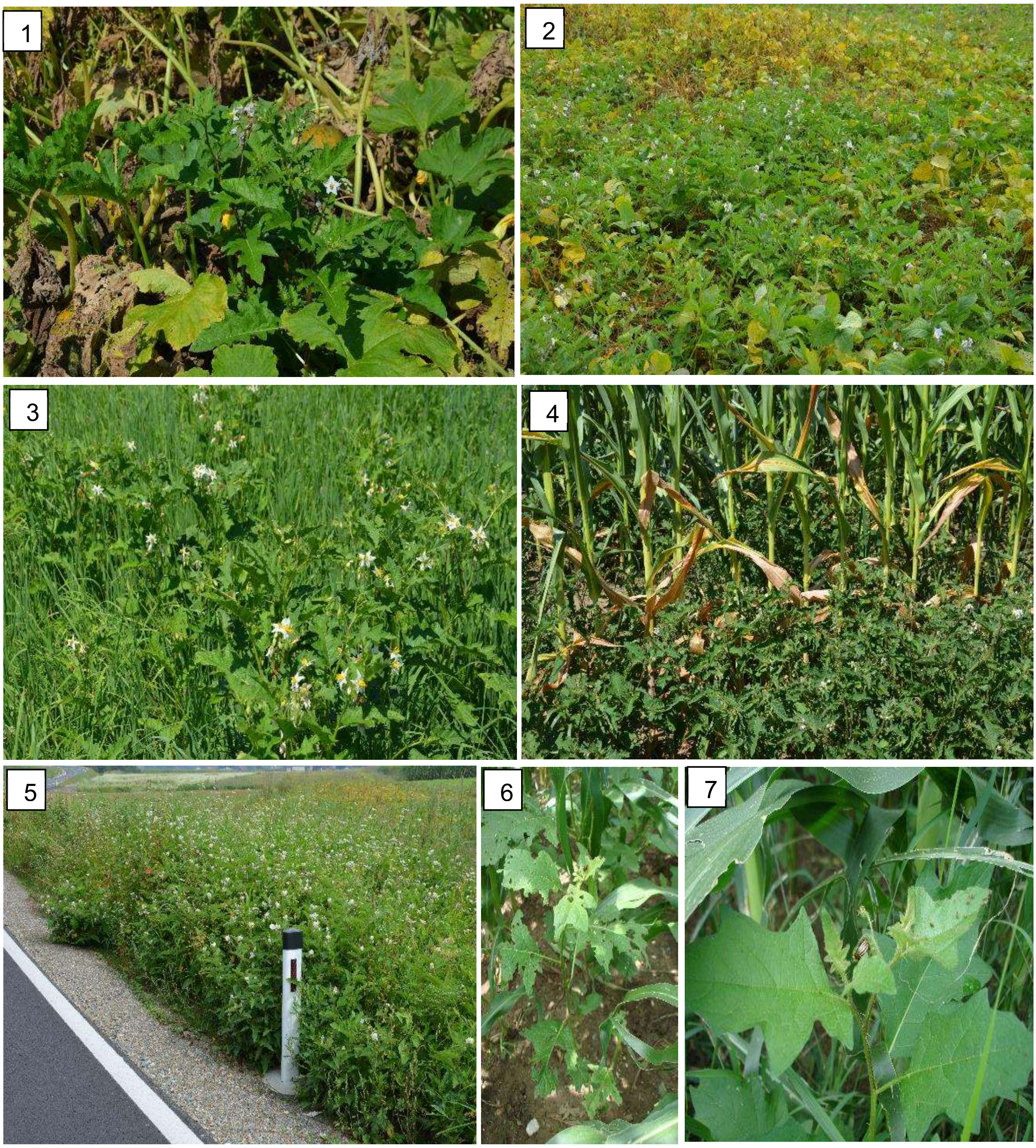


Fig. 1. *Solanum carolinense* in oil-pumpkin, Fig. 2. *Solanum carolinense* in soybean, Fig. 3. *Solanum carolinense* in a pasture, Fig. 4. *Solanum carolinense* in maize (field margin), Fig. 5. *Solanum carolinense* along a roadside, Fig. 6 & 7. *Solanum carolinense* attacked by the potato beetle (*Leptinotarsa decemlineata*) in Carinthia (Austria). All images are courtesy of Swen Follak.

Appendix 3 Grain imports from USA into the EPPO region

Table 1. Imports of soybean grain into EPPO countries from the USA from 2015-2018. Figures detail in metric tonnes per year. 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. Only countries with import on the period are listed.

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
Total	6 255 870.5	5 710 652.3	4 976 383	9 422 287.8

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. Only countries with import on the period are listed.

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
Total	936 457	2 689 346	1 617 116	4 021 524

Appendix 4 Seed imports from USA into the EPPO region

Table 1. Maize seed for planting imports into EPPO countries from the USA from 2015-2018 (Figures detail in metric tonnes per year)**.** 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.. Only countries with import on the period are listed.

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
Total	4830.2	4668.6	4782.4	3747.8

Table 2. 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 tons per year. . Only countries with import on the period are listed.

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
Total	13100,5	19646,7	15254,2	10922,4

Appendix 5 Climatic suitability modelling for *Solanum carolinense* establishment in the EPPO region

Aim

To project the climatic suitability for potential establishment of *Solanum carolinense* 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.Org, 2022), Integrated Digitized Biocollections (iDigBio), USGS Biodiversity Information Serving Our Nation (BISON), and additional records provided by the EWG. The records were scrutinised to remove any considered of dubious quality (e.g. known casual or cultivated occurrence, imprecise or bad coordinates, no date or older than 1970). In the EPPO region, records from Netherlands were retained for the modelling. The establishment status there is somewhat uncertain (Follak & Strauss, 2010) but the EWG considered there is evidence of potential establishment on ruderal riverbank sites with warm local microclimate.
The native range of the species was characterised based on Wahlert *et al.* (2015). According to this source, the species was historically restricted to central and southeastern USA but has expanded its range in crop fields and other disturbed habitats throughout eastern North America in the past 200 years. As in the PRA, records falling in the following US states were classified as native: Alabama, Arkansas, Connecticut, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Massachusetts, Michigan, Mississippi, Missouri, Nebraska, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Virginia, West Virginia, Wisconsin. All other records were classified as non-native.

The records were gridded at a 0.125 x 0.125 degree resolution for modelling (approximately 8 x 13 km in central Europe) (Figure 1a). This resulted in 4272 grid cells containing valid records of *S. carolinense* (Figure 1a), which is a sufficient number for distribution modelling.

Predictor variables were selected based on the life history and habitat requirements of *S. carolinense* and likely limiting factors for establishment in Europe. Predictors included climate from 1981-2010 from the Chelsa database V2.1 (Karger *et al.*, 2017), and preferred land cover types in 2013 from the FAO Global Land Cover - SHARE database (Latham, Cumani, Rosati, & Bloise, 2014):

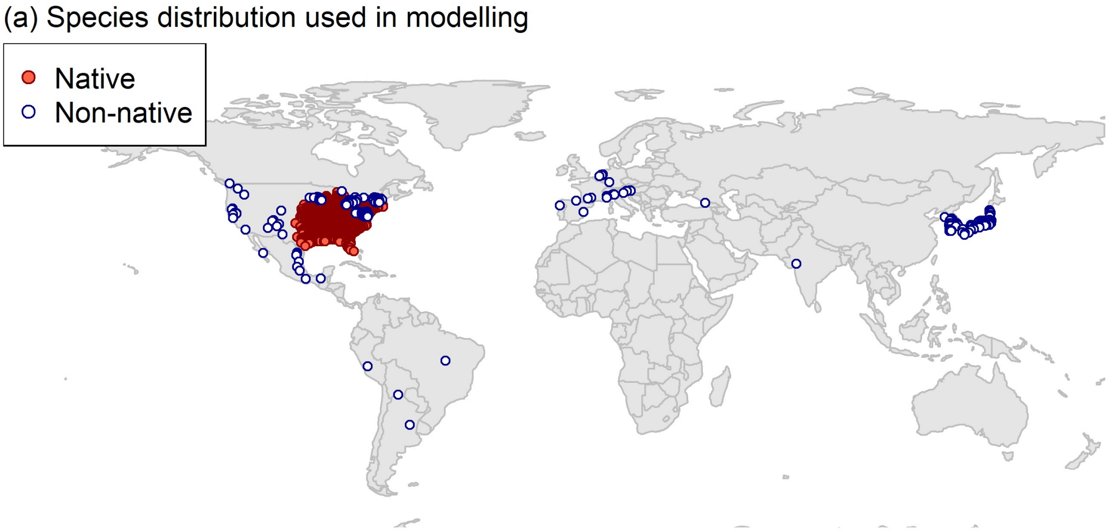
- <u>Growing degree days</u> (gdd10 °C) as a measure of growing season heat accumulation with a base temperature of 10 °C. The species needs warm summer temperatures for germination, sprouting and growth (Bassett & Munro, 1986; Follak & Strauss, 2010; Miyazaki, Ito, & Urakawa, 2005).
- <u>Mean minimum temperature of the coldest month</u> (bio6 °C), since frost kills above and below ground parts of the plants. Deep roots allow perennation through very cold winter conditions but there is likely to be a limit to this cold avoidance strategy (Bassett & Munro, 1986).
- <u>Annual precipitation</u> (bio12 kgm^{-2}), which was natural log transformed for modelling. *S. carolinense* is drought tolerant due to deeply penetrating roots (Bassett & Munro, 1986), but there is likely to be a level of drought stress detrimental to persistence since the species is largely absent from arid areas such as central southern USA (Follak & Strauss, 2010).
- <u>Precipitation seasonality</u> (bio15 kgm^{-2}) since highly seasonal precipitation regimes might involve periods of high drought stress.
- <u>Artifical surfaces proportion cover</u>, as *S. carolinense* may have a preference for urban areas (Bassett & Munro, 1986).
- <u>Croplands proportion cover</u> as *S. carolinense* can act as a crop weed and seed contaminant (Bassett & Munro, 1986).
- <u>Grasslands proportion cover</u> as pasture is a preferred habitat of the species (Bassett & Munro, 1986).

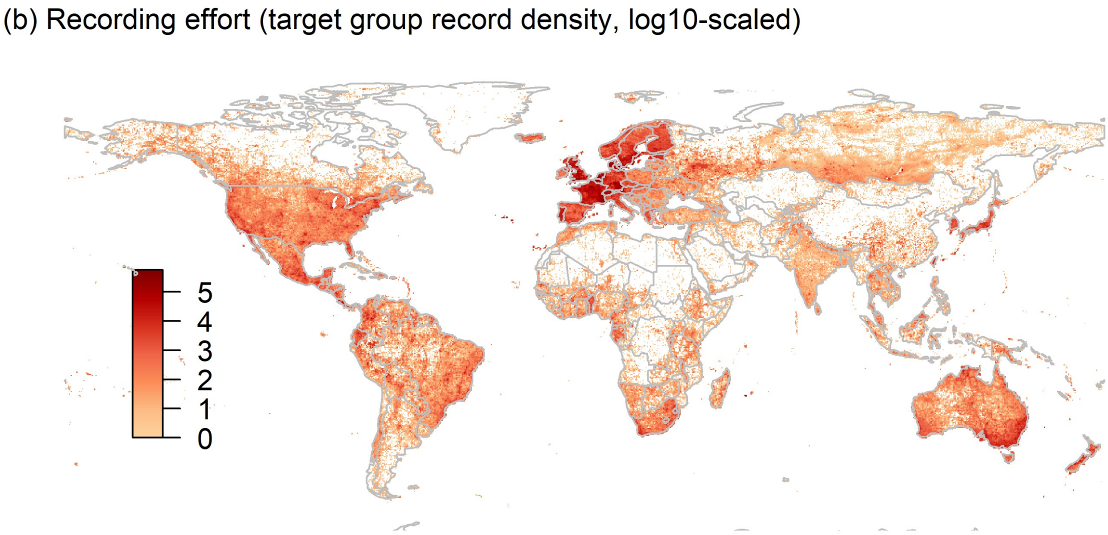
To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for 2041-2070 were obtained for two IPCC Coupled Model Intercomparison Project 6 (CMIP6) scenarios or Shared Socioeconomic Pathways (SSPs) (IPCC, 2021):

- SSP1-2.6 is an optimistic low-emissions scenario in which atmospheric CO_2 concentration peaks below 450 ppm in the mid-21st century and then falls slightly. The estimated warming by around 2050 is 1.7 °C.
- SSP3-7.0 is a high emissions scenario for a world that fails to act to limit warming. Atmospheric CO_2 concentrations rise to approximately 850 ppm by 2100. The estimated warming by around 2050 is 2.1 °C.

For both SSPs, the climate variables for modelling were obtained as averages of outputs of five Global Climate Models (NOAA's GFDL-ESM4, UK Met Office's UKESM1-0-LL, Max Planck Institute's MPI-ESM1-2-HR, Institut Pierre Simon Laplace's IPSL-CM6A-LR, and Meteorological Research Institute's MRI-ESM2-0), downscaled and calibrated against the Chelsa baseline.
Finally, the recording density of vascular plants (phylum Tracheophyta) on GBIF was obtained as a proxy for spatial recording effort bias (Figure 1b).

Figure 1. (a) Occurrence records obtained for *Solanum carolinense*, showing the native and non-native records used in the modelling. (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.





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, Pescott, Roy, & Tanner, 2019). This accounts for dispersal constraints on non-equilibrium invasive species' distributions (Elith, Kearney,

& Phillips, 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:

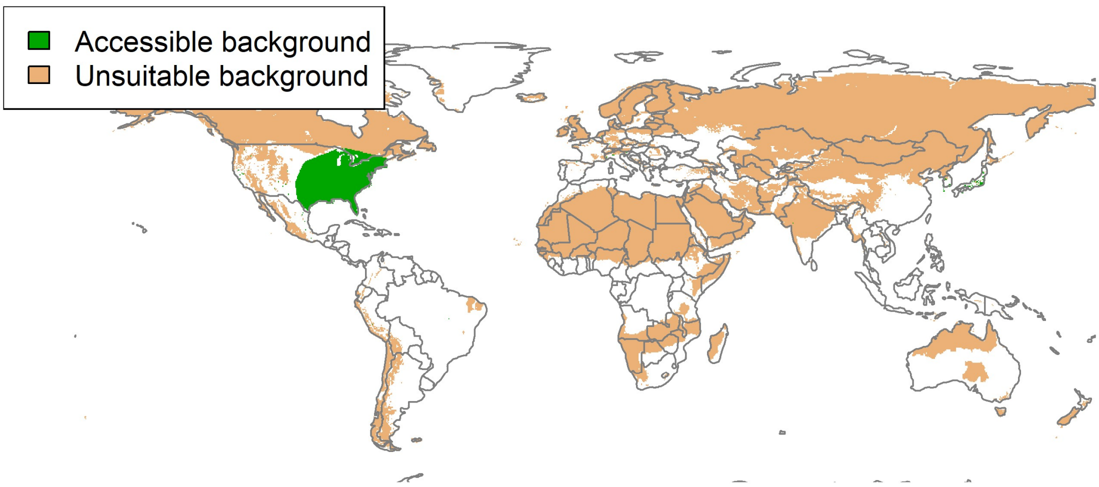
- An accessible background includes places close to *S. carolinense* populations, in which the species is likely to have had sufficient time to disperse and sample the range of environments. Based on potential for long-distance seed dispersal by animals, the accessible background was defined as a 200 km buffer around the native range (minimum convex polygon bounding native occurrences) and a 15 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. In previous testing of the model approach alternative buffer radii did not substantively affect the model projections (Chapman *et al.*, 2019).
- An unsuitable background includes places expected to be physiologically unsuitable for the species, so that absence will be irrespective of dispersal constraints. Little specific ecophysiological information was available so other than where stated extreme values of the predictors at the species occurrences were used to define unsuitability as:
    - Growing degree days (gdd10) < 900 °C, presumed too cold for growth or seed maturation; OR
    - Minimum temperature of the coldest month (bio6) < -15 °C, presumed too cold for root survival through winter; OR
    - Annual precipitation accumulation (bio12) < 200 kgm^{-2}, presumed too dry
    - Precipitation seasonality (bio15) > 100 kgm^{-2}, presumed to produce periods of severe drought stress

Of the 4272 occurrences, 12 (0.3%) fell in the unsuitable background.

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

- From the accessible background 4272 samples were drawn, which is the same number as the occurrences. Sampling was performed with realistic recording bias using the target group approach (S. J. Phillips, 2009) in which sampling was weighted by GBIF Tracheophyte 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. The accessible background is assumed to represent the range of environments the species has had chance to sample. 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 v3.4.6 (Thuiller, Georges, Engler, & Breiner, 2016; Thuiller, Lafourcade, Engler, & Araújo, 2009). 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) with linear and quadratic terms for each predictor

- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per predictor
- Multivariate adaptive regression splines (MARS)
- Artificial neural network (ANN)
- Random forest (RF)
- Maxent (Steven J Phillips, Dudík, Dudik, & Phillips, 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 maximum sum of sensitivity and specificity method, previously shown to perform well for presence-only models (Liu, White, & Newell, 2013).
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 and Discussion
The ensemble model suggested that suitability for *S. carolinense* at the global scale and resolution of the model was most strongly limited by climate rather than habitat variables (Table 1). The strongest limiting factor was excessively low or high growing degree days (gdd10). There was also relative strong limitation by very low winter temperature (bio6), and low or high precipitation (bio12) and highly seasonal precipitation regimes (bio15) (Figure 3). At the scale of the model, very weak preference for croplands was also modelled (Table 1, Figure 3).

Global projection of the ensemble model in current climatic conditions indicates that 96% of valid native and invaded records fell within regions predicted to have high suitability, i.e. above the threshold of 0.34 maximising the sum of sensitivity and specificity (Figure 4).

For the native region in North America, the model suggests little potential for further northwards range expansion (Figure 4) due to low summer temperatures (gdd10, Figure 6a). However, there are some clusters of records beyond the predicted northern limit, e.g. in Wisconsin, Minnesota and Michigan, suggesting the model might under-predict the northern extent of occurrence. The model bounds the western edge of the native distribution well (Figure 4) suggesting limitation due to low precipitation and lack of grassland habitat (Figure 6a).

Beyond the native region, the currently invaded areas in Japan and South Korea are well defined in the model. The model also identifies substantial climatically suitable areas in temperate South America, eastern China, southeast Australia and New Zealand that are currently without records used in the modelling, but are listed in the PRA as countries where the species is introduced.

In the EPPO region, the model predicts a large climatically suitable area south of about 48°N across most of central, and southern Europe, and around the Black Sea coast into southern Russia (Figure 5). The currently invaded areas in France, Italy, Austria and Georgia are all projected as suitable, though the occurrence records from further north (Germany and the Nertherlands) are projected to be in marginally unsuitable climatic conditions. The model suggests the main limiting factor in northern Europe is low temperature (low gdd10), while drought stress (low bio12) is more important in unsuitable areas of southern Europe and North Africa (Figure 6b).

Predictions of the model for 2041-2070, under the moderate SSP1-2.6 climate change scenario (Figure 7) suggests a northwards expansion of the suitable area, especially in western Europe, Ukraine and southern Russia, driven by warmer summer temperatures. Similar but more pronounced patterns are projected for the more extreme SSP3-7.0 scenario (Figures 7 and 8). Note that these projections assume no change in land use of human influence.

These results are reflected in the suitability of different European Biogeographical Regions (Bundesamt fur Naturschutz (BfN), 2003) (Figure 9). Regions highly suitable for establishment in the current climate are the Pannonian, Black Sea, and Mediterranean, though we note pockets of high current suitability are in southern parts of the Atlantic and Continental regions. By 2041-2070, the Pannonian, Black Sea, Continental, Atlantic and Steppic regions all increase markedly in suitability. Overall suitability in the Mediterranean is little changed.

Table 2 provides a similar breakdown by EPPO member state, identifying many countries with substantial suitable areas.

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**						
			Growing degree days (gdd10)	**Minimum temperature of coldest month (bio6)**	**Annual precipitation (bio12)**	**Precipitation seasonality (bio15)**	**Artificial cover**	**Croplands cover**	**Grassland cover**
GBM	0.8656	yes	39%	15%	35%	6%	1%	2%	2%
GAM	0.8626	yes	46%	22%	15%	12%	0%	1%	3%
ANN	0.8622	yes	45%	27%	10%	16%	0%	1%	1%
MARS	0.8618	yes	37%	26%	21%	9%	0%	4%	3%
GLM	0.8610	yes	37%	28%	23%	6%	0%	2%	4%
MAXENT	0.8582	no	42%	23%	24%	8%	0%	2%	2%
RF	0.7776	no	24%	12%	24%	14%	7%	10%	8%
Ensemble	0.8654	-	41%	24%	21%	10%	0%	2%	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 are as in Table 1.

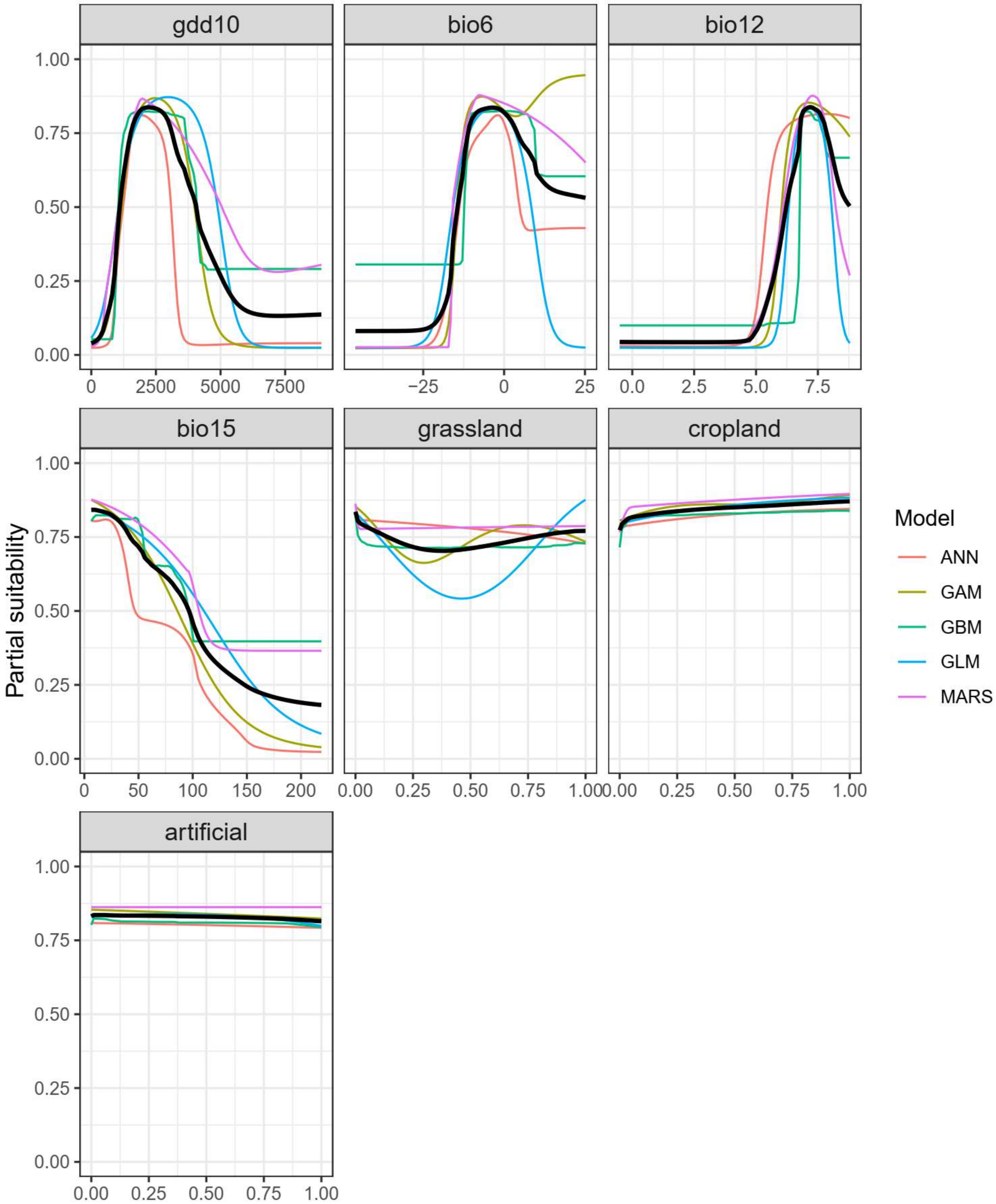


Figure 4. (a) Projected global suitability for *Solanum carolinense* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Red shading indicates suitability, according to the selected threshold. (b) Uncertainty in the suitability projections, expressed as the standard deviation of projections from different algorithms in the ensemble model.

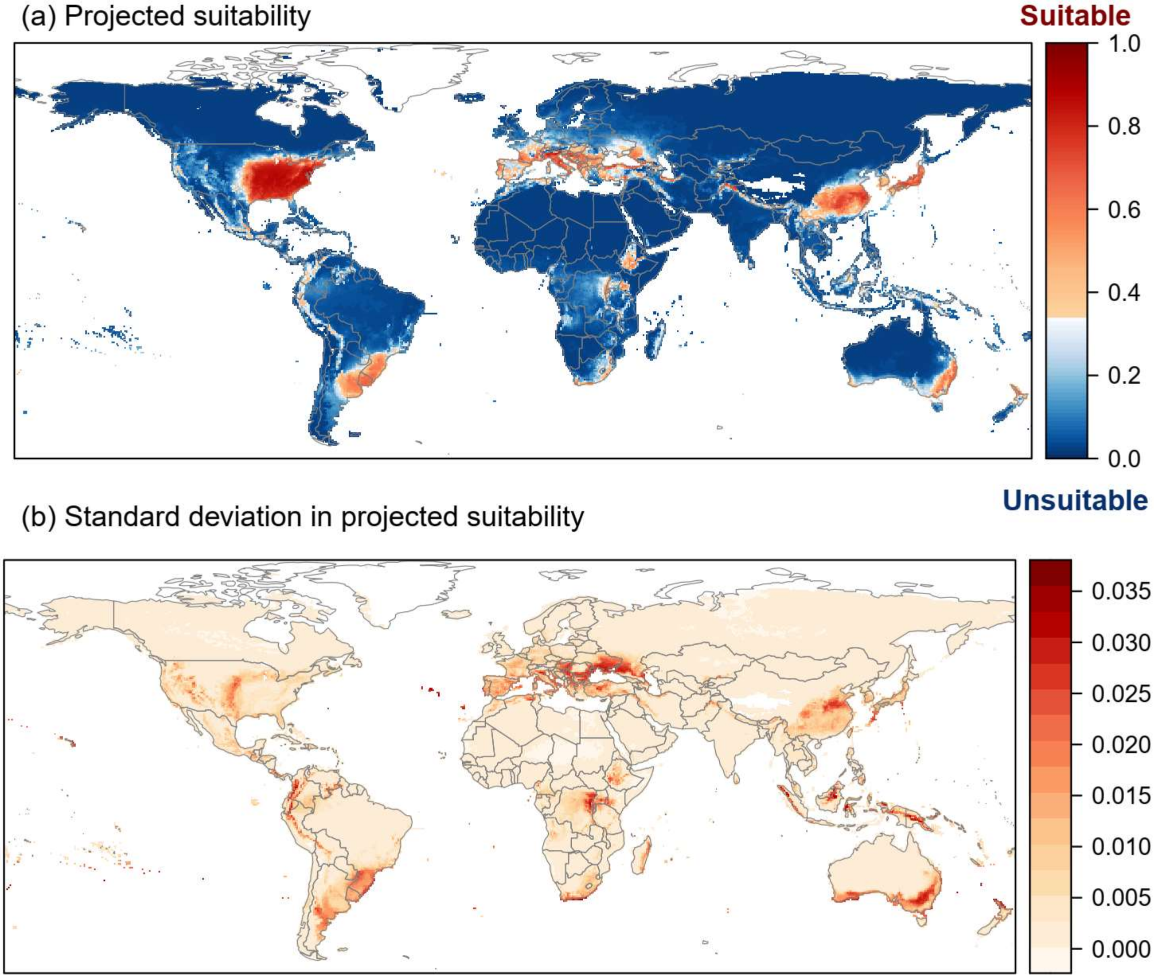


Figure 5. Projected current suitability for *Solanum carolinense* establishment in Europe and the Mediterranean region.

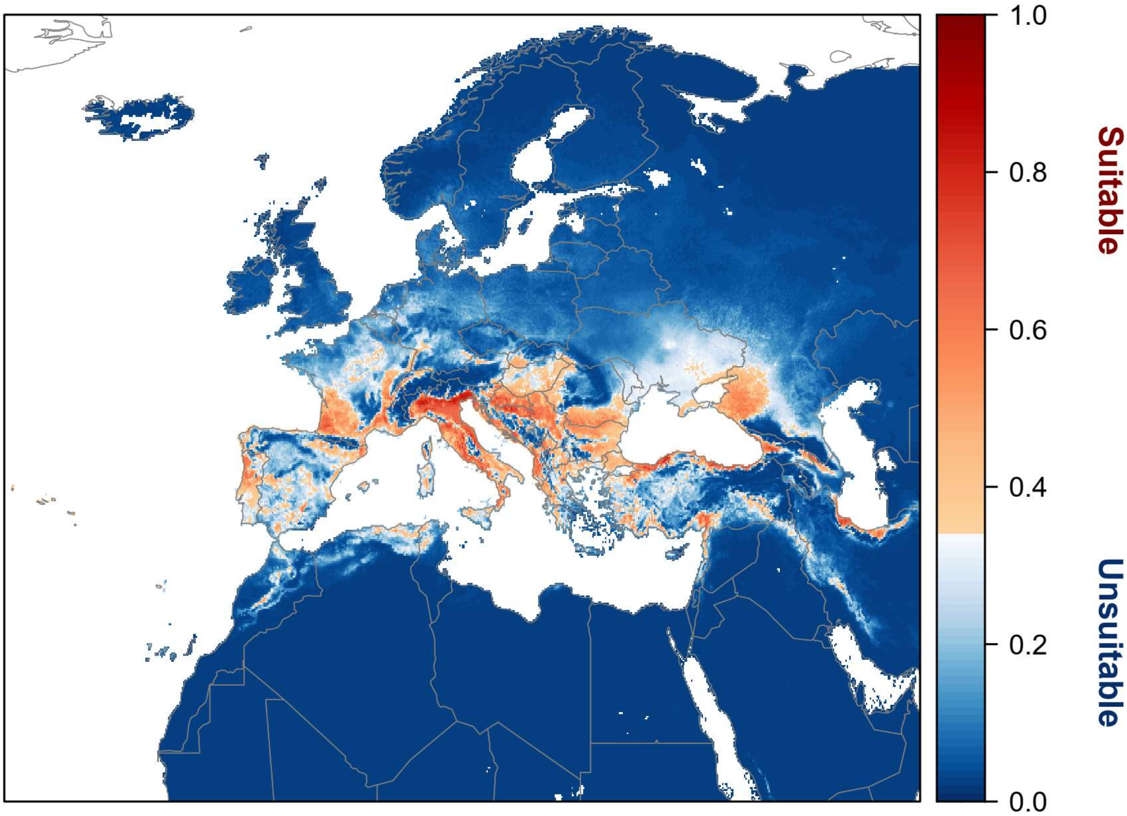
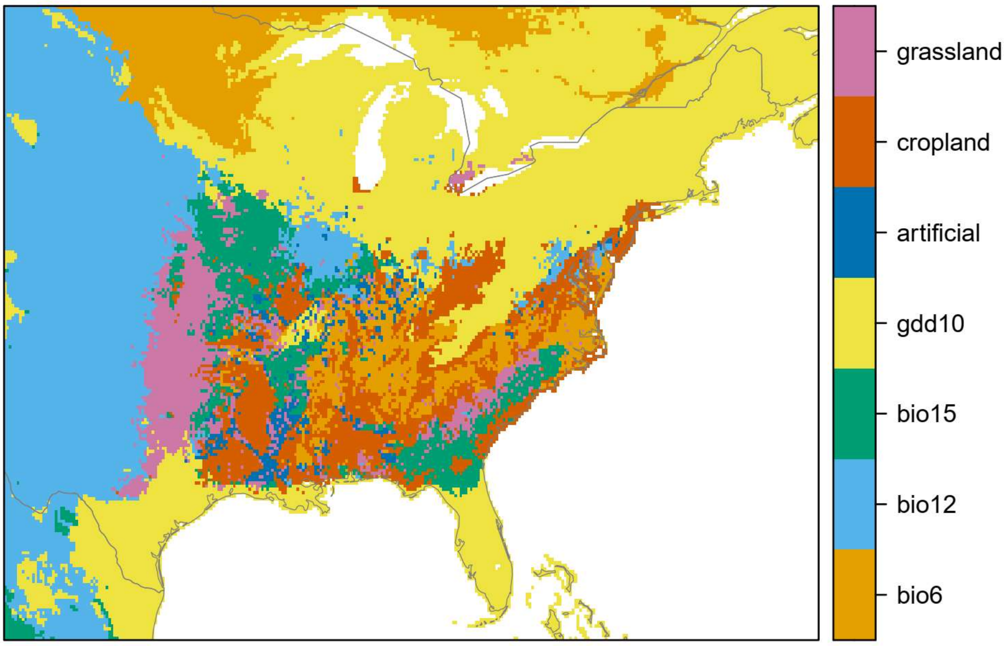


Figure 6. Limiting factor maps projected by the model for *Solanum carolinense* in (a) the native North American region and (b) Europe and the Mediterranean region, under the current climate and land use. Colours show the variable most strongly limiting suitability.

(a)



(b)

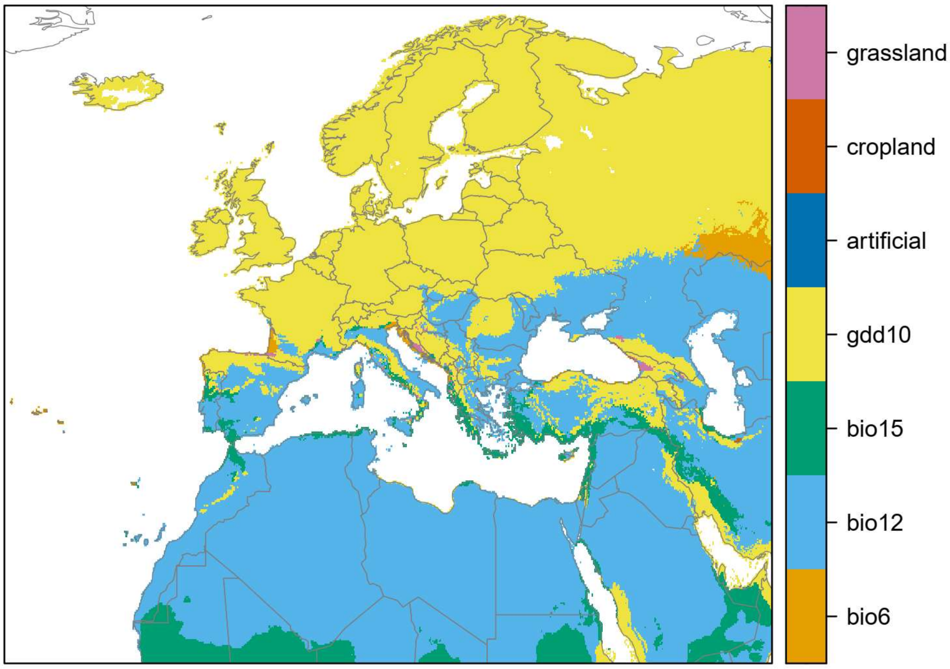


Figure 7. Projected suitability for *Solanum carolinense* establishment in Europe and the Mediterranean region for 2041-2070 under climate change scenario SSP1-2.6.

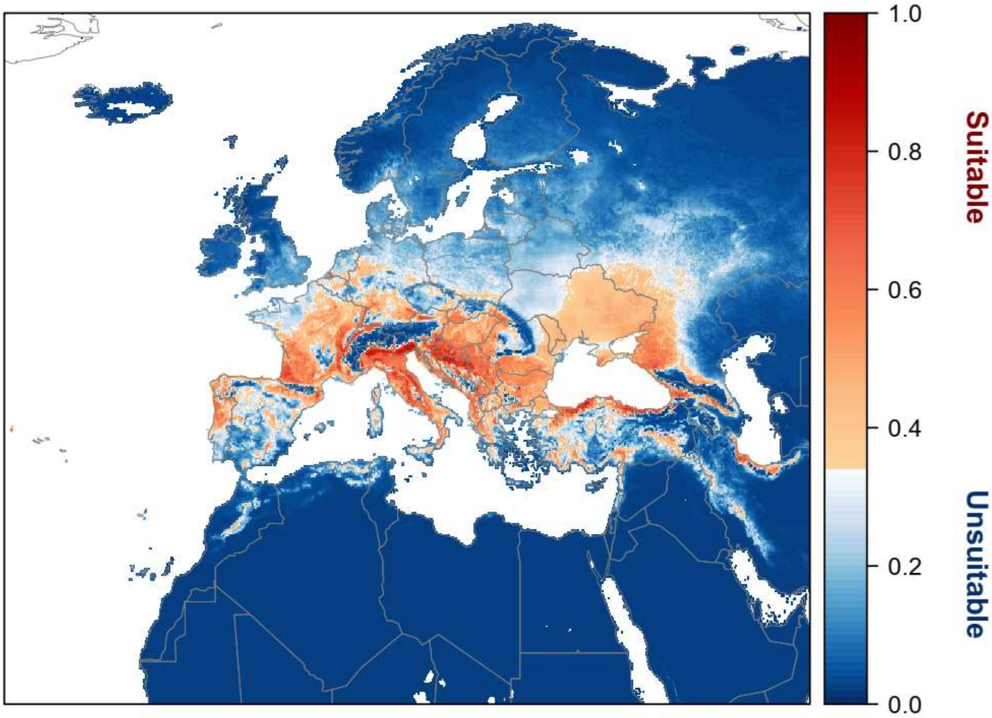


Figure 8. Projected suitability for *Solanum carolinense* establishment in Europe and the Mediterranean region for 2041-2070 under climate change scenario SSP3-7.0.

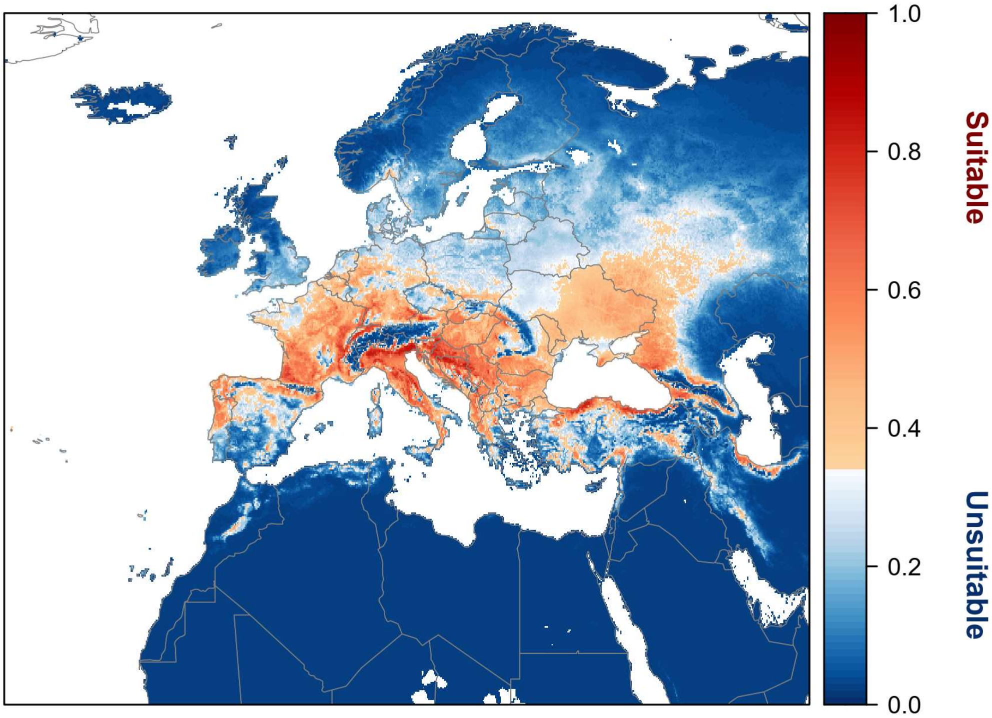
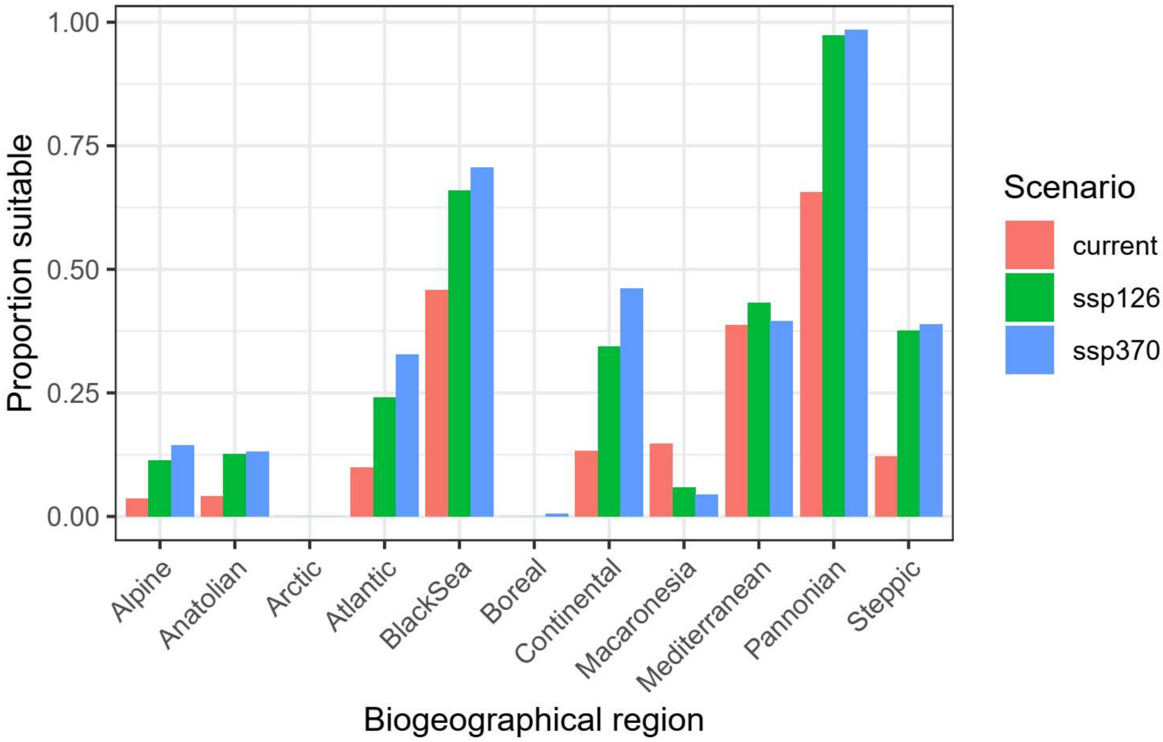


Figure 9. Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). Bar plots show the proportion of grid cells in each region classified as suitable in the current climate (1981-2010) and projected climate for 2041-2070 under scenarios SSP1-2.6 and SSP3-7.0. The coverage of each region is shown in the map below.



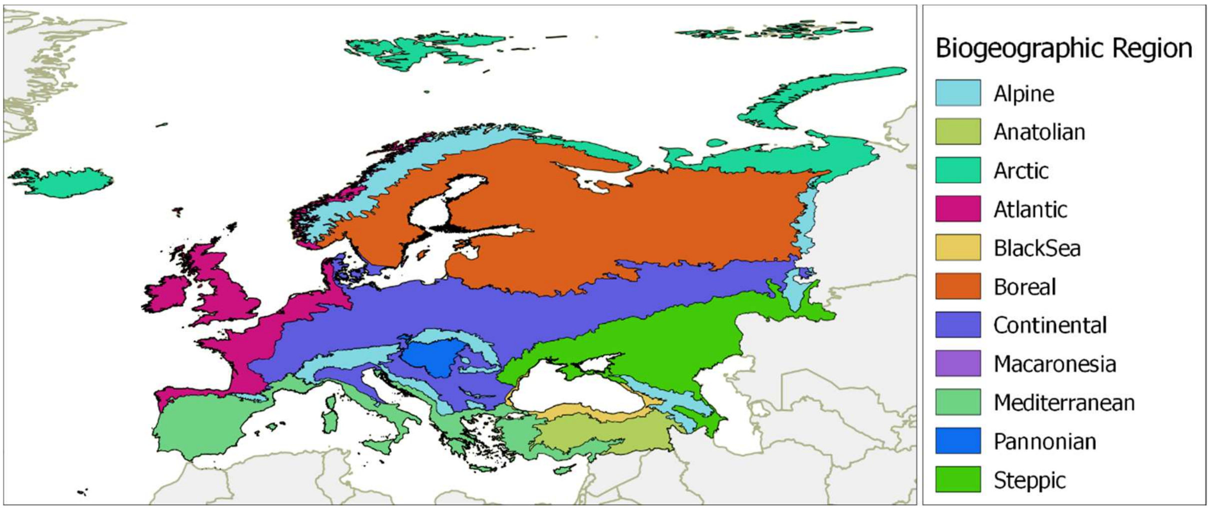

Biogeographic Region
Alpine
Anatolian
Arctic
Atlantic
BlackSea
Boreal
Continental
Macaronesia
Mediterranean
Pannonian
Steppic

Table 2. Projected % suitability among EPPO member countries, sorted from high to low in the current climate. Values are the % of grid cells in each country classified as suitable in the current climate (1981-2010) and projected climate for 2041-2070 under scenarios SSP1-2.6 and SSP3-7.0.

EPPO country (ISO3)	Current	SSP1-2.6	SSP3-7.0	EPPO country (ISO3)	Current	SSP1-2.6	SSP3-7.0
HRV	85%	96%	98%	MDA	1%	95%	100%
SRB	77%	93%	97%	DZA	1%	0%	0%
BGR	69%	90%	91%	RUS	1%	1%	2%
ITA	64%	67%	66%	UZB	0%	0%	1%
ALB	63%	87%	89%	KAZ	0%	0%	0%
HUN	56%	97%	98%	BEL	0%	31%	72%
PRT	54%	50%	45%	BLR	0%	0%	3%
BIH	52%	82%	90%	CYP	0%	0%	0%
SVN	50%	82%	88%	CZE	0%	16%	27%
MKD	45%	72%	73%	DNK	0%	0%	1%
ROU	35%	58%	63%	EST	0%	0%	0%
GRC	34%	40%	34%	FIN	0%	0%	0%
FRA	29%	65%	78%	GBR	0%	0%	0%
GEO	26%	42%	48%	GGY	0%	0%	0%
TUR	20%	30%	28%	IRL	0%	0%	0%
SVK	20%	53%	60%	ISR	0%	0%	0%
ESP	20%	28%	28%	JEY	0%	0%	0%
CHE	20%	36%	40%	JOR	0%	0%	0%
MNE	17%	39%	57%	LTU	0%	0%	6%
AZE	12%	16%	15%	LUX	0%	11%	42%
AUT	7%	33%	41%	LVA	0%	0%	0%
UKR	5%	65%	69%	MLT	0%	0%	0%
TUN	4%	1%	0%	NLD	0%	25%	38%
DEU	2%	33%	52%	NOR	0%	0%	1%
KGZ	2%	4%	5%	POL	0%	6%	13%
MAR	1%	1%	1%	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:

- There was some uncertainty about the limits of the native distribution, especially on its northern edge.
- There is uncertainty as to the main climate factor determining the northern range limit and therefore the projected extent of establishment in the EPPO region. The model estimated cool summer temperature (gdd10) to be limiting in the north, which could reflect limitation on seed germination and/or by the length of growing season for seed ripening. Since summers are cool in northern Europe the model therefore predicted unsuitability. However, a previous CLIMEX model for the species used low winter temperature to define the northern range limits and therefore predicted more potential for establishment in northern Europe (e.g. in Netherlands, Germany and Poland) (Follak & Strauss, 2010). As such, there is uncertainty about which projection is more correct which cannot be resolved without additional information.
- There is also some uncertainty about the extent of predicted occurrence in very dry areas of the Mediterranean, where summer precipitation amounts are lower than in the native range. The speies is deep rooted and considered drought tolerant, but if growing season precipitation (especially early in the season) is more important for the species than was represented in the model then establishment potential in the Mediterranean region might be lower than was estimated.

- The models were constructed using convenient climate and habitat layers, which may not be the most appropriate for *S. carolinense*. Specific predictors layers capturing requirements for different stages of the life cycle (e.g. precipitation in spring) may have improved the predictions.
- 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 6. Consideration of pest risk management options

The table below summarizes the consideration of possible measures for the pathways **Grain (for animal feed mixtures, human consumption and processing purposes)**

For measures, grains are considered for crops in which *S. carolinense* 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.

Option	**Grains of** ***Glycine max, Zea mays, Triticum aestivum***
Existing measures in EPPO countries	Partly, see Section 8.
Visual inspection at place of production	Yes, in combination* (for measures marked with '*', see after the table). The place/site of production when inspected at pre-harvest should be free from any *S. carolinense* plants. Detection by visual inspection is unlikely to be completely effective at the place of production in plants used to produce grains and needs to be used within a systems approach.
Testing at place of production	No There are no known molecular tests for the identification of *Solanum carolinense.*
Treatment of crop	Yes, in combination* No weed management strategy is considered to be 100% effective against *S. carolinense*.
Resistant cultivars	No, not relevant for invasive alien plants
Growing the crop in glasshouses/ screenhouses	Not relevant for grain production.
Specified age/size of plant, growth stage or time of year of harvest	No, When *S. carolinense* is present in the field, it will produce fruit with seeds during the harvesting period.
Produced in a certification scheme	No, not relevant for grains
Pest free production site	yes Pest free production site could be established for a time period before planting of grain production. For example, 1-2 years and then recognised as a pest free production site. To establish and maintain the PFPS, detailed surveys and monitoring should be conducted in the area and continued every year. Pest free production site will not be able to be formed where *S. carolinense* has been reported in the last four years.

Option	Grains of *Glycine max, Zea mays, Triticum aestivum*
	A buffer zone could be established where any *S. carolinense* plants are eradicated. Conditions in the buffer zone would include no presence of *S. carolinensis* and cleaning of machinery and equipment. 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 *S. carolinense* is present.
Pest free place of production	yes same as for Pest free production site
Pest-free area	Yes (but difficult to maintain) 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 *S. carolinense*, the PFA should not include any area where the species has been reported in the last 5 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 *S. carolinense*, 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.
Treatment of the consignment: sorting	Yes, in combination* 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. Checking could be done afterwards by an examination (e.g. a purity/noxious weed examination), as is performed for certified seeds. The efficiency of screening depends on the sorting methodology used (e.g. type of screens) and the seed size of grain and weeds. The efficiency of screening could be checked by inspecting the consignment (see below).
Treatment of the consignment: devitalization	Yes Note: Technically feasible (e.g. heat treatment) but economically unrealistic for large bulk quantities.
Inspection of consignment and confirmation by testing	Yes (and in combination) Tests allow to detect the weed seeds in mixed grains/seeds. After having performed a purity/noxious weed examination, *Solanum* 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 *Solanum* seeds, they will not be equally distributed in the seed/grain commodity – take samples from the bottom of the sample.

Option	Grains of *Glycine max, Zea mays, Triticum aestivum*
	Remark: this may not be cost-effective.
Pre or Post-entry quarantine	Not relevant for grain.
Limited distribution of consignments in time and/or space or limited use	Not relevant. The use of grains cannot be limited to reduce the probability of introduction: processing grain could be partially or totally destructive but seeds of *S. carolinense* may be spread during storage and transportation. Soybean are often packaged and the risk can be reduced if it remains packaged until the processing facility.
Only surveillance and eradication in the importing country	No. Eradication is difficult.

*The EWG considered whether the measures identified above as 'Yes in combination' (listed below) could be combined to achieve a suitable level of security. The EWG thought that a PFPS/PFPP + Treatment of consignment: sorting could achieve a suitable level of security.

Grains of *Glycine max, Zea mays, Triticum aestivum*
Visual inspection at place of production
Treatment of crop
Pest free production site
Pest free place of production
Treatment of consignment: sorting
Inspection of consignment and confirmation by testing