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

Pest Risk Analysis for

Ageratina adenophora

G. Fried - EPPO Global Database (EPPO Code: EUPAD) - *Ageratina adenophora*

EPPO Technical Document No. 1090
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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 https://www.eppo.int/RESOURCES/eppo_standards/pm5_pra), as recommended by the Panel on Phytosanitary Measures. Pest risk management (detailed in Section 3) 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, *Ageratina adenophora* was added to the EPPO A2 List of pests recommended for regulation as quarantine pests in 2023. Import prohibition of plants for planting (horticulture use) is recommended.

Pest Risk Analysis for *Ageratina adenophora* (Sprengel) King & Robinson

PRA area: EPPO region
Prepared by: EWG on *Ageratina adenophora*
Date: 13-16 February 2023. Further reviewed and amended by EPPO core members and Panel on Invasive Alien Plants (2023-05, see below).

Composition of the Expert Working Group (EWG)

BRUNDU Giuseppe (Mr)	University of Sassari, Department of Agricultural Sciences, Italy
CHAPMAN Daniel (Mr)	University of Stirling, Scotland
DATTA Arunava (Mr)	St Xavier's College, Ranchi, India
FOLLAK Swen (Mr)	Austrian Agency for Health and Food Safety (AGES), Institute for Sustainable Plant Production, Austria
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FROHLICH Danielle (Ms)	SWCA Environmental Consultants, United States
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The first draft of the PRA was prepared by Guillaume Fried & the EPPO Secretariat.

For the determination of ratings of likelihoods and uncertainties, experts were asked to provide a rating and level of uncertainty individually during the meeting, based on the evidence provided in the PRA and on the discussions in the group. Each EWG member provided anonymously a rating and level of uncertainty, 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 EPPO Core Members for PRA (Valerie Grimault, Alan MacLeod, Camille Picard, Gritta Schrader, Muriel Suffert). The PRA was then reviewed by the EPPO Panel on Invasive Alien Plants.

The PRA, in particular the section on risk management, was reviewed and amended by the EPPO Panel on Invasive Alien Plants on 2023-05. EPPO Working Party on Phytosanitary Regulation and Council agreed that *Ageratina adenophora* should be added to the A2 List of pests recommended for regulation as quarantine pests in 2023.

CONTENTS

Summary of the Express Pest Risk Analysis for *Ageratina adenophora*			
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).			
Describe the endangered area: The EWG consider the endangered area to be the coastal areas and frost-free inland areas of the Mediterranean (including humid parts of North Africa (Algeria, Morocco, Tunisia) and south Atlantic biogeographical regions, Macaronesia (Canary Islands, Azores and Madeira) and the east coast of the Black Sea (Georgia). Habitats at risk in the endangered area include river systems, pastureland, forests (coniferous forests, in particular pine forests, temperate Laurel forests, and oak forests). Appendix 2 gives the percentage of suitable areas in each EPPO country. The EWG considers the species distribution model conducted as part of this PRA (see Appendix 2) to be a realistic projection of the potential occurrence of the species in the EPPO region.			
Main conclusions ***Ageratina adenophora* presents a high phytosanitary risk for the endangered area with moderate uncertainty.** *Ageratina adenophora* is locally established in Algeria, Croatia, France (French Riviera, Corsica), Greece, Italy, Morocco, Portugal (including mainland, Azores and Madeira) and Spain (including mainland, Canary Islands). The overall likelihood of further entry of *A. adenophora* into the EPPO region is low with a moderate uncertainty. Several pathways were assessed in the PRA but there was no strong association with any pathways. The EWG note that the pathway plants for planting (horticultural use) is not currently active, however, this may change in the future. The likelihood of further establishment outdoors is very high with low uncertainty. Habitats are widespread within the EPPO region and further establishment is likely in regions where habitats and climatic conditions are conducive for establishment. Likelihood of establishment in protected conditions is very low with moderate uncertainty. Temperature within protected conditions would be suitable for the establishment however, other conditions, e.g., the intense crop management, are likely to reduce the likelihood of establishment. The potential for spread within the EPPO region is high with a moderate uncertainty. *Ageratina adenophora* can spread both naturally via wind dispersed seed, and plant fragments via waterways, and via human assisted spread (e.g. contaminant of travellers equipment). The magnitude of impact in the current area of distribution (excluding the EPPO region) is high with a moderate uncertainty. *A. adenophora* has negative impacts on native biodiversity, ecosystem services and has been shown to have socio-economic impacts on managed forests and crop yields. The EWG considered that the potential impact in the EPPO region is moderate with a moderate uncertainty. Similar types of impacts are expected though the moderate rating reflects the lower impact observed and the moderate uncertainty reflects the unknown severity in the EPPO region. Based on high likelihood of spread (moderate uncertainty) from existing established populations in EPPO region, and high impacts (mod uncertainty) the overall risk appears correct.			
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 (see Section 17 for the justification of the rating. Individual ratings of uncertainty of entry, establishment, spread and impact are provided in the document)	High ☐	Moderate X	Low ☐
Other recommendations: ● Scientific research should be conducted on the genetic variation of the species in the EPPO region, ● Studies should be conducted on the current distribution, spread and impacts in the EPPO region, ● The EWG recommend that EPPO-Q-Bank Plants develop look-alike factsheet to include *A. adenophora* and *A. altissima*, *A. riparia*.			

EPPO Pest Risk Analysis:
***Ageratina adenophora* (Sprengel) King & Robinson**

Prepared by: EPPO Expert Working Group
Date: 2023-02-13/16

Stage 1. Initiation

Reason for performing the PRA:

This Pest Risk Analysis (PRA) was conducted to determine the likelihood and extent of entry into, and establishment and spread within the EPPO region of *A. adenophora*, along with the magnitude of its impacts. In the EPPO region, *A. adenophora* is particularly a risk to riparian habitats and to a lesser extent to pastureland and wooded habitats. The species has many weedy traits that makes it highly competitive and difficult to control. It grows rapidly in a wide range of environments, produces many seeds and reproduces vegetatively from stem fragments. In 2022, the EPPO Panel on Invasive Alien Plants identified *A. adenophora* as a potential candidate for PRA based on a report of species behaviour in Southeast France (*A. adenophora* is locally invasive on the French Riviera). The EPPO Prioritization Process for Invasive Alien Plants concluded that the species is a priority for PRA. *Ageratina adenophora* is an invasive species in the Azores, the Canary Islands and Madeira. Additionally, *A. adenophora* is also established in Algeria, Croatia, Greece, Italy (mainland), Morocco, Portugal (mainland) and Spain (mainland). As it shows locally invasive behaviour with a limited distribution in the EPPO region, it can be considered as an emerging invasive plant.

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: *Magnoliophyta,* Class: *Angiospermae,* Order: *Asterales,* Family: *Asteraceae,* Tribe: Eupatorieae, Genus *Ageratina*, Species *Ageratina adenophora* (Spreng.) R.M.King & H.Rob Phytologia 19: 211 (1970).

EPPO code: EUPAD

Main synonyms:

Homotypic Synonyms:

Eupatorium adenophorum Spreng.

Heterotypic Synonyms:

Ageratina trapezoidea (Kunth) R.M.King & H.Rob.
Eupatorium glandulosum Kunth
Eupatorium pasadenense Parish
Eupatorium pascuarense J.Dix
Eupatorium trapezoideum Kunth

Common name:

English; Crofton weed, Mexican devil, sticky snakewort, sticky snakeroot, sticky eupatorium. French: agératine du Mexique, eupatoire blanc, Eupatoire glanduleuse. German: drüsentragender Wasserdost. Portuguese: abundáncia, inça-muito. Italy: Ageratina appiccicosa, Diavolo messicano. Russian: агератина железистая. Spanish: ageratina, espumilla, hediondo.

Plant type: Erect perennial herb (hemicryptophyte) or (sub)shrub (nanophanerophyte).

Related species in the EPPO region:

The genus *Ageratina* Spach is native to the Americas.

In the EPPO region, there are two related non-native species:

Ageratina altissima (L.) R. M. King & H. Rob. is a casual alien plant in several central European countries: Austria, Belgium, Czech Republic, Germany, Hungary, Italy and Poland (EPPO,2023).

Ageratina riparia (Regel) R. M. King & H. Rob. is naturalised on Canary Islands (Spain) and Madeira (Portugal) (Greuter, 2006+; Silva *et al.*, 2008).

2. Pest overview

2.1 Introduction

Ageratina adenophora is a perennial herb or a subshrub native to Mexico (Luis Villasenor, 2016; Catálogo Español de Especies Exóticas Invasoras, 2013). It is found in many countries of the world as an introduced invasive species (Section 6). The species has become a major weed of pastureland and wooded and disturbed habitats outside its original range (Lu *et al*., 2008; Fu *et al*., 2018; Wang & Niu, 2016). The species has several weedy attributes, including small wind carried cypselae (hereafter seeds), prolific propagule production, vegetative spread, rapid growth, and ability to grow in a variety of biotic and abiotic conditions (Poudel *et al*., 2019). *A. adenophora* was introduced into the EPPO region as an ornamental in the early 1800s (Auld & Martin, 1975).

2.2 Identification

The following description on morphology of *A. adenophora* was synthesised from the Flora of North America (Nesom, 1993+), Flora of Tropical East Africa (Beentje *et al*., 2005) and Flora of China (Wu & Raven, 1994).

Ageratina adenophora is a perennial herb or a (sub)shrub 30 to 220 cm high. The stem is erect, purplish when young, somewhat woody, with opposite branches. The stem is covered with short glandular hairs, becoming more densely pubescent towards the apex. The leaves are opposite with a petiole of 10-25 mm and triangular-ovate, or rhombic-ovate blades of (1.5–)2.5-7.5(–8)cm long and 1.5-3 cm wide; the base of the blade is truncate or slightly cordate. The synflorescences are terminal, somewhat leafy, up to 12 cm in diameter. The capitula are numerous, 40-50(72) flowered; they are borne on 5-12 mm long peduncles.
$2n = 3x = 51$.

See Appendix 1 for images.

Individuals from introduced ranges (e.g. China) have higher plant height, stem diameter, leaf length, leaf width and leaf area in comparison with individuals from native ranges (Feng *et al*., 2009).

2.2.1 Molecular identification

The complete chloroplast genome has been sequenced and published (Nie *et al*., 2012).

The Barcode of Life Data Systems (BOLD; https://www.boldsystems.org) contains eight sequences for *A. adenophora*. GenBank provides over 120 accessions of *A. adenophora* (NCBI, 2023).

2.3 Life cycle

Ageratina adenophora reproduces primarily by seeds which are produced apomictically by apomixis (clonal asexual reproduction through seeds), in particular by gametophytic diplosporous apomixis without fertilisation (Holmgren 1919; Parsons & Cuthbertson, 2001). Under favourable conditions, individual plants can produce 7,000 –10,000 seeds per year. The plant also reproduces vegetatively by stem and root fragments if the plants are broken (Parsons & Cuthbertson, 2001).

In Australia, seeds germinate between January and June (i.e. from summer to the end of autumn), with peak germination (>80% viable seeds) in February and March (i.e. from the end of summer to the beginning of autumn) (Auld & Martin, 1975). Seedlings grow rapidly and are fully established within 8 weeks of germination. In second year and older plants, new growth begins with the first heavy summer rains, usually in January. The growth rate of seedlings and mature plants remains high during the summer but decreases during the cooler winter months. Buds appear in late winter and flowering takes place from August to December (late winter to summer). Seeds ripen between October and mid-January (mid spring to mid-summer), with the lower leaves of the plant falling off after the seeds have dropped.

In India (Himalayas): The floral buds initiate in the late winter and flowers begin to bloom early in the February-March (spring). The seeds ripen rapidly in late spring and early summer. The seeds are dispersed readily by wind and animals. After the reproductive phase (i.e. after spring and early summer), the leaves of the mature plant senesces and many secondary and tertiary branches die off in April -May (summer). Later in the rainy season, the plant grows vigorously, producing plenty of new branches and leaves until autumn, forming a dense thicket. Large numbers of seeds germinate in July-August (the rainy season). The branches produce adventitious roots in moist soil during the rainy season, which further augments the lateral spread and vegetative propagation of the plant (Datta, 2018).

In the USA (California), this species flowers in the spring through late summer; from March through August, and sometimes as late as September (CALIPC, 2022). In Hawaii, flowers can be observed all year round. Seed germination corresponds with the rainy season and is dependent on the habitat (i.e. wet forest versus lava fields where the latter receives precipitation via moisture from clouds). Germination can occur all year round and appears to be primarily dependent on rainfall (D. Frohlich, pers. comm., 2023).

Throughout China, this species produces flowers from the end of February, followed by seed set in April and May. Most seeds germinate in the rainy season of the same year in which they are produced. The life span is 12 to 15 years (Sun *et al*., 2004; Sun *et al*., 2005).

There is no precise observation of the life cycle of the plant in the EPPO region (especially for the germination period) but the available evidence indicates a similar seasonal life cycle to that observed in Australia. In Mediterranean France, *A. adenophora* flowers early in spring (April) and seeds ripen from mid-May to later in the summer (Fried, 2023). In southern Spain, flowering starts in March.

Seed production of *A. adenophora* is very high and it forms a large seed bank in the soil. Dense populations can produce up to 60,000 viable seeds m^{-2} (Muniappan *et al*., 2009). Seed density is reported to be higher in the upper layer of the soil seed bank but this varies depending on the depth. Shen *et al*. (2006) details that seed density in the 0–10 cm soil layer varied from 47 to 13,806 seeds m^{-2}, and averaged 2,199 seeds m^{-2}. Fifty-seven percent of the seeds of *A. adenophora* were in the 0–2 cm soil layer, 24 % in the 2–5 cm layer and 19 % in the 5–10 cm layer.

Seed viability varies with the depth the seed is buried and time. The species forms a persistent seed bank. Shen *et al*. (2011) showed that 90 % of seed on the soil surface died. 40 % of seeds were viable at depths of 5 cm and 10 cm after 2 years, and 20% of seeds germinated after 3 years. After four years, survival rates at 5 and 10 cm decreased to less than 10%. Similar observations were made in India (Yadav & Tripathi, 1982).

2.4 Environmental requirements

Ageratina adenophora is highly ecologically adaptable: it can tolerate a wide range of biotic and abiotic conditions and has been shown to adapt to the habitats and areas where it has invaded.

Throughout the species invasive range, the plants are found in a diversity of habitats which can be facilitated by epigenetic variation as experimentally demonstrated in marginal populations from China (e.g. which show cold tolerance (see section 2.4.1) (Xie *et al*., 2015; Le Roux, 2022).

2.4.1 Temperature

In most of the area where, *A. adenophora* is invasive, it prefers to grow in warm, moist, frost-free regions. Cold temperatures are reportedly not required for seed stratification (Wang *et al.*, 2012). and low temperature (5-10 °C) has also been shown to limit germination (Lu *et al.*, 2006; Li & Feng, 2009).

Lu *et al*. (2006) conducted laboratory and greenhouse studies to determine the effect of several environmental factors on seed germination and seedling emergence. Seeds germinated over a range of 10–30 °C, with optimum germination at 25 °C. High temperature markedly restricted germination, with no germination occurring at 35 °C.

In China, the known localities of *A. adenophora* range from 4.4°C to 23.1°C for mean annual air temperature (Zhu *et al*., 2007). In South Africa, *A. adenophora* appears to prefer temperatures in the range of 10–25 °C and low temperature seasonality (Tererai & Wood, 2014).

Li *et al.* (2008) details that populations in China show different responses to low temperatures. Some populations can withstand low temperatures more than others where freezing injury was less in plants from Huangguoshu compared to other populations. The authors suggest that freezing-tolerant populations would have a greater chance to invade more north-eastern areas.

Marginal populations found at high elevations (~2500m a.s.l) in the Himalayas (India and Nepal, Datta *et al.*, 2017) and in Yunnan province (China) can experience freezing temperatures during the winter. One population in Lijiang Yunnan has been reported to experience the lowest temperature of -10 °C at elevation of 2600m (Xie *et al*., 2015). However, continuous exposure to sub-zero temperature damages the aerial parts of the plant and reduces the reproductive output drastically. Studies have indicated that epigenetic changes are responsible for conferring increased cold tolerance at high elevations (Xie *et al*., 2015).

In cultivation, *A. adenophora* can endure short periods of cold, at least immediately above freezing temperature by night (del Guacchio, 2013).

2.4.2 Precipitation

Precipitation of the driest month was the most important factor explaining *A. adenophora* distribution in southwest China (Zhang *et al*., 2022). The known localities of *A. adenophora* in China were distributed in areas with annual precipitation ranging from 698 mm to 2 254 mm (Zhu *et al*., 2007).

In a niche modelling study, Zhu *et al*. (2007) showed that the most likely areas for future invasion in China, were associated with increased levels of moisture-related variables, especially mean annual precipitation and precipitation in the driest month.

In Italy, clones cultivated near Salerno show considerable drought resistance, up to three weeks. Even when the aerial parts were senesced, when watered, the plants readily produced young shoots from the base of the stem or the rootstocks (del Guacchio, 2013). However, plants did show drought stress after a week of no water.

The habitat in which the plant is growing affects how it collects water. Plants growing on volcanic lava fields with limited soil water retention capacity (e.g. in Hawaii), benefit from atmospheric moisture. On the other hand, plants growing in Mediterranean climates (e.g. France, Italy and South Africa), benefits from moisture from streams.

2.4.2 Soil

If water retention capacity is sufficient for growth, *A. adenophora* can develop on a large range of soil types regarding texture and pH ranging from dry sands to wetland clay soils (Queensland fact sheet, 2022). It can tolerate some salinity (CABI, 2022) and low nutrients (CABI, 2022).

2.4.3 Shading

Ageratina adenophora has some shade tolerance: in an experiment, Auld & Martin (1975) showed that seedlings display a degree of tolerance to shading to 10% daylight and they regard this as a useful attribute in the context of competition with other colonizing plants.

2.4.4 Irradiance

Light is essential for seed germination. Zheng *et al*. (2009) demonstrated plastic response of *A. adenophora* to irradiance with the light-saturated photosynthetic rate and root mass fraction (peaked at 40% irradiance) increasing but the leaf area to root mass ratio, leaf area ratio, and specific leaf area decreasing with the increase of irradiance, facilitating light capture and use, and water balance across irradiances.

2.5 Habitats

2.5.1 Native range

Herbario Nacional de México (MEXU, 2005) note that in its native range, *A. adenophora* occurs in several very diverse habitat types. For example, some northern records (Las Cebollitas) are located in "*Pinus, Quercus, Pseudotsuga, Picea*, and *Abies* mixed forest, on shallow stony soils"; more in the centre and close to coast (La Guaynera) on "Rocky, oak covered slopes cut small canyon". Close to the area of the Reserva de la Biósfera de Serra Gorda, the records are located in a riparian habitat (*Platanus* gallery forest) and in *Alnus* forest. In the area of Tehuacán, the records are located in "xerophytic shrubland", in Chiapas in "tropical sub-caducifolious forest" and in "tropical evergreen forest" close to the El Triunfo Biosphere Reserve. There is also high variability in the altitudinal data; for example, one sample collected in the municipality of "Donato Guerra" reports an altitude of 2980 m a.s.l. (Herbario Nacional de México (MEXU), Plantas Vasculares); more in general, this online herbarium database reports a total number of about 100 records with an altitudinal range of 169-2980 m a.s.l.

2.5.2 Non-native range

Information is included for countries where available.

USA

In ***California***, *A. adenophora* is found on "stream margins, ditches, road embankments, and hillsides" (Nesom, 1993+). For the same area, the Jepson eFlora listed also "disturbed places, streambanks, canyons, hillslopes" (Jepson Flora Project, 2022). It is also recorded in coastal scrub, riparian forests, riparian woodlands, riparian scrub including dry riverbeds, and coniferous forests (CALIPC, 2022).

Hawaii: In Hawaii, this species can be found in a variety of habitats, from relatively dry areas to wet forest, from around 600-2,000 meters elevation on the islands of O'ahu, Moloka'i, Lāna'i, and Maui. Invaded areas include lava fields on the slopes of Haleakalā volcano, the edges of mesic native forest, stream sides, fallow pastureland, and trail and roadsides (Wagner *et al*., 1999).

China

In the Flora of China, the description of the habitats of *A. adenophora* includes the main environments where the species is found: "wet places or roadsides on slopes, forest margins" between 900 and 2200 m (Wu & Raven, 1994). In more specific research articles, the species is noted in a variety of habitats. First, it is regularly recorded along linear habitats (corridors) such as roadsides (Lu *et al*., 2006; Zhao *et al*., 2013), riversides (Lu *et al*. 2006) or riverbanks (Zhao *et al*., 2013). Second, several works stated that it colonizes farmland (Lu *et al*. 2006; Lu *et al*., 2008; Zhao *et al*., 2013) where it became a "problem weed" in grassland, pastures, plantations, and in cultivated croplands" (Lu *et al*., 2008). Among other man-made habitats, it also colonized wastelands and rubbish dump edges (Zhao *et al*., 2013). Finally, it is found in various forest types: broad-leaf forest and pine forest (Lu *et al*., 2006; Wu *et al*., 2020), coniferous and broadleaf mixed forest (Wu *et al*., 2020), evergreen, broad-leaved-deciduous mixed forests (Niu *et al*., 2007; Wu *et al*., 2020). *Ageratina adenophora* also invades the understory of *Eucalyptus globulus* plantations (Yu *et al*., 2013).

Australia

In Australia, *A. adenophora* grows in wet shaded areas of fringing forest and along streams. It prefers south-facing damp slopes and is also found along roadsides and overgrazed pastures (Queensland Government, 2022). "This species is a weed of roadsides, railways, pastures, fence-lines, disturbed sites, waste areas and riparian zones (banks of watercourses) in subtropical and warmer temperate regions. It is also commonly found in urban open spaces, open woodlands, forest margins and rainforest clearings."

South Africa

In South Africa, *A. adenophora* is a "weed of waste places, particularly partly shaded and damp roadsides" (Flora of South Africa). In the Western Cape, it is restricted to riparian habitats (Meek *et al*. 2013) and along irrigation canals in urban areas (D.M. Richardson pers. obs.) In eastern South Africa, it is invasive in grasslands and forest margins, especially where these habitats are disturbed" (Tererai & Wood, 2014).

New Zealand

In New Zealand, it is present in lightly shaded frost-free areas, e.g. forest edges, shrublands, wetlands, banks of stream, open forest, inshore and offshore islands, gumlands (shrub-covered, flat to rolling land) in northern New Zealand which has deposits of *Agathis australis* (kauri), slips (land slip), alluvial flats, coast and estuaries (New Zealand Plant Conservation Network, 2023).

India

In the Western Himalayas, *A. adenophora* can be found at altitudes ranging from 400 m to 2300 m a.s.l. with a preferred altitude of 1300 m (Datta *et al*., 2017). In these areas, this species grows in moist regions along the slopes of hills or mountains and forest understory, but it can grow in diverse conditions ranging from the flat floodplains of the lower Himalaya to steep and dry rocky slopes, to ruderal habitats. It also grows along roads, streams, and gullies. In Nepal, this species can be found at altitudes up to 3280 metres in habitats similar to India, a.s.l. (Shrestha *et al*., 2018)

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

2.6 Existing PRAs

2.6.1 Outside the EPPO region

USA

Ageratina adenophora has been risk assessed by Cal-IPC with California as the risk assessment area. The conclusion of the risk assessment was 'moderate risk' with an overall score of 3.5 out of 5 (CALIPC, 2022).

South Africa

A risk assessment was conducted for South Africa where the risk summary was: *'Ageratina adenophora has naturalized in several provinces of South Africa (Limpopo, Mpumalanga, KwaZulu-Natal, Gauteng, Western Cape) and has climatically suitable regions that have not been occupied yet. Studies from other regions of the world show that A. adenophora has negative impacts on native biodiversity and forestry including allelopathic effects. It is also reported to be toxic to herbivores. Therefore, due to its likelihood of spread and its negative impacts, the species is a high risk'.* The risk assessment recommended that: '*Ageratina adenophora has a high risk and very little documented benefits. The existing populations should be controlled to ensure that it does not spread into new regions that are climatically suitable. Its current status as category 1b in NEM:BA listing should be maintained'* (SANBI unpublished). (NEM:BA category 1B are invasive species that may not be owned, imported into South Africa, grown, moved, sold, given as a gift or dumped in a waterway).

2.6.2 The EPPO region

Portugal
The species has been risk assessed using the Australian Weed Risk Assessment (Pheloung *et al*. 1999) with Portugal as the risk assessment area (Morais *et al*., 2017). The score of 28 (> 13) obtained indicated that there is a risk of the species having an invasive behaviour in the Portuguese territory.

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

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

5. Regulatory status of the pest

Outside the EPPO region

China: Quarantine pest since 2021 (EPPO, 2023).

United States of America: *Ageratina adenophora* is listed as a Federal noxious weed in the United States and is thus prohibited from import or interstate commerce unless under permit. It is listed as a noxious weed by Alabama, Florida, Hawaii, Minnesota, North Carolina, and Vermont, as a prohibited weed in Massachusetts, and as a plant pest in South Carolina (USDA NRCS, 2022). The species is a U.S. Federal noxious weed seed and is also a prohibited noxious weed seed in Hawaii (USDA/AMS, 2022).

South Africa: It is a category 1b plant prohibited from planting or commerce (NEM:BA listing).

Australia: New South Wales Class 4 - a locally controlled weed. This means that the "growth and spread of this species must be controlled according to the measures specified in a management plan published by the local control authority and the plant may not be sold, propagated or knowingly distributed (in a large number of local authority areas)" (Australian Government, 2014). Western Australia Prohibited - on the prohibited species list and not permitted entry into the state (Australian Government, 2014).

New Caledonia: Listed as potentially invasive in the Code de l'environnement de la province nord : Article 261-1 relatif aux espèces envahissantes (Délibération n° 2012-236/BPN du 12 octobre 2012) where it is not present.

EPPO region

Portugal: listed as invasive species in the Decreto-Lei nº 92/2019, 10 July.

Spain: listed as invasive species in the Real Decreto 630/2013, de 2 de agosto. The Regulation applies to the Canary Islands.

6. Distribution

Poudel *et al*. (2019) provide a summary of the historical global occurrence of *A. adenophora*.

'Ageratina adenophora was first introduced outside of its native range (Mexico) as an ornamental plant to the United Kingdom (Europe) in 1826 (Auld & Martin, 1975) and then to Hawai'i (USA) in 1860 (Muniappan et al., 2009) and Australia in 1875 (Auld & Martin, 1975). It is believed to have been introduced as a garden plant in India in 1924 (Tripathi et al., 2012), but herbarium specimens were collected as early as 1914 (based on digital image serial number 225216, deposited at Central National Herbarium, Calcutta). It has commonly been believed that the weed spread naturally to China during the 1940s from Myanmar along the international highway (Wang & Wang, 2006; Dong et al., 2008). It was first recorded from New Zealand in 1931 (Webb, 1987), Nepal in 1952 (Tiwari et al., 2005), South Africa in 1958 (Henderson, 2006) and recently Italy in 2013 (Del Guacchio, 2013)'.

Table 1 Global distribution of *Ageratina adenophora*

Region	**Distribution**	**Status**	**Reference**
Africa	Angola	Present	Goyder & Goncalves (2019); Rejmanek *et al*. (2016)
	Cape Verde	Present	POWO (2023), USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Kenya	Introduced	Witt & Luke (2017)
	South Africa (Eastern Cape, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga and Western Cape provinces)	Introduced	ARC LNR (2023); POWO (2023)
	Uganda	Present	USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Zambia	Present	Beentje et al. (2005); Mapaura & Timberlake (2004)
	Zimbabwe	Present	POWO (2023)
North America	Mexico (Colima, Hidalgo, Jalisco, México, Michoacán de Ocampo, Morelos, Oaxaca, Puebla, Querétaro)	Native	USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	USA (California)	Introduced	Nesom (1993+), POWO (2023); Di Tomaso *et al*., (2013)
	USA (Hawaii)	Introduced	Loope *et al*., 1992; USDA, Agricultural Research Service, National Plant Germplasm System (2023)

Central America and the Caribbean	Costa Rica	Present	POWO (2023)
	Jamaica	Present	POWO (2023)
	Trinidad and Tobago	Present	POWO (2023)
South America	Peru	Present	POWO (2023)
Asia	Bhutan	Introduced	APFISN (2012); USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Cambodia	Introduced	Rundel & Middleton (2017)
	China	Introduced	POWO (2023), Wu & Raven, 1994); FU *et al* (2017/18) Feng *et al*. (2007)
	India	Introduced	APFISN (2012); Datta *et al* (2017)
	Indonesia (Java)	Introduced	APFISN (2012); POWO (2023), Nyuanti *et al*., 2020
	Laos	Introduced	POWO (2023), USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Lebanon	Present	Euro+Med 2006+
	Myanmar	Introduced	USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Nepal	Introduced	Bishwakarma (2021); POWO (2023); Thapa *et al*. (2016)
	Philippines	Introduced	APFISN (2012); POWO (2023), USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Sri Lanka	Introduced	APFISN (2012)
	Thailand	Introduced	POWO (2023), USDA, Agricultural Research Service, National Plant Germplasm System (2023)
	Vietnam	Introduced	USDA, Agricultural Research Service, National Plant Germplasm System (2023)
EPPO region	Algeria	Introduced	Meddour *et al*. (2020), Euro+Med (2006+), POWO (2023)
	Croatia	Introduced	Euro+Med 2006+
	France (continental)	Introduced	Tison *et al*. (2014), Tison & de Foucault (2014)
	France (Corsica)	Introduced	Conrad (1961a/b)
	Germany	Transient: currently absent	Euro+Med 2006+; Buttler & Harms (1999)
	Greece	Introduced	Alien Plants of Greece (2023), Arianoutsou *et al*. (2010)

	Italy	Introduced	Del Guacchio (2013)
	Morocco	Introduced	Euro+Med (2006+); POWO (2023)
	Portugal (Azores, Madeira, mainland)	Introduced	Euro+Med 2006+
	Spain (Canary Islands, mainland)	Introduced	Euro+Med 2006+
Oceania	Australia (New South Wales, Norfolk Island, Queensland)	Introduced	Auld & Martin (1975); Parsons and Cuthbertson (2001); POWO (2023)
	New Zealand (New Zealand North)	Introduced	New Zealand Plant Conservation Network (2023)
	French Polynesia	Present	USDA, Agricultural Research Service, National Plant Germplasm System (2023)

Mexico (native range)
According to the web site efloramex.ib.unam.mx (Project "eFloraMEX: La flora electrónica de México" and the references cited therein) *Ageratina adenophora* is native in the following states of Mexico: Aguascalientes; Chiapas; Chihuahua; Colima; Distrito Federal; Durango; Guanajuato; Guerrero; Hidalgo; Jalisco; Michoacán de Ocampo; Morelos; México; Nayarit; Oaxaca; Puebla; Querétaro de Arteaga; San Luis Potosí; Sinaloa; Veracruz de Ignacio de la Llave; Zacatecas. It is reported as absent in five southern states of Mexico (Pruski and Robinson, 2018). According to Rzedowski *et al*. (2005, pages 789-790), in the "Valle de Mexico", in addition to the type locality, in the municipality of Epazoyucan, *Ageratina adenophora* has been collected from Huixquilucan to Tlalpan, between 2,300 and 2,400 m of altitude, in sites with disturbed vegetation, behaving as weeds in gardens, vacant lots, roadsides, sidewalks and roads. Outside the Valley it is known from Jalisco to Puebla.

Distribution records for Mexico are available also at the web site Sistema Nacional de Información sobre Biodiversidad de México (2023).

Doubtful records
USDA, Agricultural Research Service, National Plant Germplasm System (2023) indicates the presence of the plant in Austria, Belgium, Czech Republic, Hungary and Poland. However, *A. adenophora* is not cited in the Catalogue of neophytes in Belgium (1800-2005) (Verloove, 2006) nor in third version of the Catalogue of alien plants of the Czech Republic (Pyšek *et al*., 2022) and none of these countries are listed in the Euro+Med checklist (Euro+Med 2006+). Therefore, the EWG considers these occurrences as doubtful in the absence of more precise records. Actually, it seems that the European list of countries provided by USDA combined the ones where *A. adenophora* is present (France, Spain, Portugal) but also the ones where *Ageratina altissima* is present (see in section 1, *related species in the EPPO region*).

Specific details about the distribution in selected EPPO countries

Algeria
Ageratina adenophora appears in the seed catalogue of the Hamma garden in Algiers (Société générale algérienne, 1875), which suggests that the plant was cultivated in botanical gardens. The plant was considered naturalised as early as in the 1870s (Battandier & Trabut, 1878). It is also indicated in the flora of Battandier & Trabut (1902) as present in the ravines of Bab-el-Oued.

France (mainland)

Ageratina adenophora has been cultivated in botanical gardens since the 19th century. It is mentioned in the Villa Thuret garden (Antibes Juan-les-Pins, Sauvagio, 1899), the Monte Carlo garden (Jeannel, 1890), the Montpellier botanical garden (L'Indépendant: journal du Midi, 1848), the Grenoble botanical garden (Verlot, 1857). It was also probably cultivated in private gardens since it is also mentioned in horticultural books with advice on cultivation and maintenance (e.g. Dupuis & Hérincq, 1884). The first dated mention goes back to 1846 where Rantonnet (1847) indicates that the plant perished during a harsh winter in Hyères. Sauvagio (1899) seems to say that at the end of the 19th century, it is much less cultivated in gardens "where it once had a good place" among cultivated species. However, he notes at the same time that it is already naturalized in some gardens in Nice (Sauvagio, 1899). The first record of the species outside a garden dates back to 1910. In his inventory of the Chateau de Nice hill, Mader (1910) lists *A. adenophora* among the naturalised species and indicates it as very common on the western side of the hill near the waterfalls. A few years later, Chevalier (1918) found it "abundantly naturalised on the grounds dominating the Pont Saint-Louis in Menton and in Monaco, along the ravine of Sainte-Dévote". In the 1930s, it was noted in a stone gutter in front of the railway station in Villefranche-sur-Mer (Muséum national d'Histoire naturelle, Paris (France), Collection: Plantes vasculaires (P), Specimen P04185072). In spite of these observations of the first naturalizations, it seems that the plant remained discreet and only known by local botanists, because the flora of France of the beginning of the XXth century. In the mid-1980s, Alziar (1984) noted that the species had developed considerably in recent years. He observed that it was now present everywhere between Menton and Monaco, on walls, unkempt stairs, abandoned gardens and rubble. He also observed that the plant is more vigorous in cooler places but that it also manages to establish very well in rocks. More recent records around the 2020s confirmed this expansion trend, with several new locations covering the area between Monaco and Nice (Cap-d'Ail, Beausoleil, Roquebrune-Cap-Martin, Eze, Beaulieu-sur-Mer, Saint-Jean-Cap-Ferrat, Nice). The species now occupies the entire Riviera coastline between Nice and Menton (Provence-Alpes-Côte d'Azur region) (Fried, 2023).

France (Corsica)

The plant was first discovered in 1952 in Lupino near Bastia. *Ageratina adenophora* was observed there on the banks and in the bed of the Lupino stream which flows between the lustrous schists near Bastia. At the time of its discovery, the species had already conquered a one kilometre long habitat (Conrad, 1961a). In 1961, Conrad (1961b) found it in Ajaccio where it invaded the banks of the Gravona canal near the "Château des Anglais" at Carrosaccia.

Greece

Alien Plants of Greece (2023) detail that *A. adenophora* is distributed in East Aegean Islands, Ionian Islands, Kiklades, Kriti and Karpathos north central and north east. The database mentions that the species is non-invasive.

Italy

Ageratina adenophora was first reported as present in Italy in 2013 by Del Guacchio (2013). The author details that two populations occur, one in Sorrento which has been present for seven years and one in Salerno which has been present for five years. Del Guacchio (2013) reports that both populations are established and cannot be considered as an ephemeral plant. In Italy, *A. adenophora* has a long history of being cultivated in botanical gardens where the first record of the species in cultivation was from the botanical garden of Palermo (Sicily) in 1858 and in the mainland of Italy at the botanical garden of Genova in 1890.

Portugal (mainland)

Plantas invasoras em Portugal (2020) detail that *A. adenophora* is distributed in Azores archipelago (islands of São Miguel, Terceira, S. Jorge, Pico, Faial), and Madeira archipelago (islands of Madeira, Porto Santo and Desertas islands).

Portugal (Madeira): "Introduced into Mad[eira]. scarcely before 1840, and first noticed on walls in Funchal below the house of a former British Consulate. In 1855 it had already spread in vast profusion over all the neighborhood of Funchal and elsewhere, even in the N[orth]. of the island, up to an elevation of 2000 or 3000 ft. or more; forming, in some places, hedges about cottage gardens, and in ravines (as up the Rib. de S ta Luzia almost to the foot of the great waterfall) thickly clothing the wet dripping perpendicular cliffs in many places as if perfectly indigenous. Unfortunately, it seems inapplicable to any use but litter, and is entirely unfit for fodder. The Portuguese have given it a very appropriate name, " Inqa muito,"—equivalent to Spread-much, or literally (as applied to insects) Swarm-much. It is originally from Mexico and was first brought to England in or about 1830."

Spain
The plant is known from Andalusia, where it was first mentioned near Malaga (Burton, 1979). It is well naturalized and abundant there along field ditches near Motril. More recently, it has been recorded near Huelva, again in ditches on the N-472 road, towards San Juan del Puerto (Sánchez Gullón *et al*., 2006). *Ageratina adenophora* has also been found in Galicia. The first mention dates back to the end of the 1980s (Rodríguez-Oubiña & Ortiz, 1989) in the locality of Redondela (Pontevedra). Later, Gómez Vigide *et al* (2005) mention it from Lourizán, in the same province. In both cases, the plant is reported in human-modified environments. More recently it has been found in A Pobra do Caramiñal, where it is relatively abundant and shows clearly invasive behaviour (González-Martínez, 2017). It is distributed over a stretch of about 800 m long, on slopes and ditches on both sides of a road (oriented N and S) and its immediate surroundings, in more or less human-modified environments, and especially in cool and shaded areas on wet soil.

7. Habitats at risk and their distribution in the PRA area

The table provides information on habitats the species may establish in and habitats which the species is currently established in the EPPO region (habitat classification based on EUNIS habitat types - https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification-1).

Table 2. Habitats at risk and their distribution in the PRA area

Habitats (EUNIS Habitat classification 2023)	**Presence**	**Status of habitat**	**Is the pest present in the habitat in the PRA area (Yes/No)**	**Comments (e.g. *major/minor habitats* in the PRA area)**	***Reference***
Q Wetlands	Periodically exposed shores (Q6): riverbanks, streambanks	Protected in part	Yes	Major	Tison *et al*. (2014), Plantas invasoras em Portugal (2020), Del Guacchio (2013), Catálogo Español de Especies Exóticas Invasoras (2013)
R Grasslands and lands dominated by forbs, mosses or lichens	Lowland moist or wet tall-herb and fern fringe (R55)	Protected in part	Yes	Major	Tison *et al*. (2014), Plantas invasoras em Portugal (2020), Del Guacchio (2013), Catálogo Español de Especies Exóticas Invasoras (2013)
	Mediterranean grasslands on alluvial river banks (R554): stream margins	Protected in part	Yes	Minor?	
S Heathland, scrub and tundra	Heaths, hygrophytic tree thickets and mesophytic tree thickets), scrubland	Protected in part	Yes (Canary Islands)	Major	Catálogo Español de Especies Exóticas Invasoras (2013)
T~~:~~ Forest and other wooded land	Mediterranean and Macaronesian riparian forest (T14)	Protected in part	Yes	Major	Catálogo Español de Especies Exóticas Invasoras (2013)
	Coniferous forests (T3)	Protected in part	No	Major	Lu *et al*., 2006; Wu *et al*., 2020
	Broad-leaved forests (T1-T2)	Protected in part	No	Major	Lu *et al*., 2006; Wu *et al*., 2020
	Eucalyptus plantations (T291)	Not protected	No	Major	Yu *et al*., 2014

Habitats (EUNIS Habitat classification 2023)	Presence	Status of habitat	Is the pest present in the habitat in the PRA area (Yes/No)	Comments (e.g. major/minor habitats in the PRA area)	Reference
U Inland habitats with no or little soil and mostly with sparse vegetation	Mediterranean wet inland cliffs (U3D1) : cliffs, wet or fresh rocks, wet rocky coast	Protected in part	Yes	Minor ?	Tison et al. (2014), Plantas invasoras em Portugal (2020), Del Guacchio (2013)
V Vegetated man-made habitats	Artificial grasslands and herb dominated habitats (V3): roadsides, old walls, rubble, urbanized areas, man-made green spaces, pastures Bare tilled, fallow or recently abandoned arable land (V15) Recently abandoned garden areas (V23)	Not protected Not protected Not protected	Yes No Yes	Major Minor Minor	Tison et al. (2014), Plantas invasoras em Portugal (2020), Catálogo Español de Especies Exóticas Invasoras (2013)

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

Importantly, Macaronesian laurel forests grow in deep soils at an altitude of 500 to 1,500 m in mountain cloud belts (orographic strata) that form under the influence of NE moisture-laden winds in the Canary Islands and Madeira, and SW winds in the Azores. They grow in conditions involving an average annual temperature of 13-19 ºC and precipitation between 500 and over 1,500 mm (up to 3,800 mm in the hyper-humid laurisilva of the Azores, according to Dias 2001) and under fog-drip, and are therefore not subject to climatic stress. They are a feature of the parts of the Canaries with the highest net primary production (Guimarães. & Olmeda 2008).

Specific details of habitats for EPPO countries are detailed below:

France
Tison *et al*. (2014) indicated the species on "wet or fresh rocks and old walls, rubble" but this species is most abundant on the banks of streams and in coastal wetland valleys (Fried, 2023).

Portugal
In mainland Portugal, *A. adenophora* is established on "cliffs, banks of water lines and roads, including disturbed and agricultural areas." (Plantas invasoras em Portugal, 2020).

Azores
Cliffs, water stream margins, roadsides, *Pittosporum* scrubland (non-native woodland dominated by *P. undulatum*), waste places (Silva *et al*., 2008).

Madeira
Rocky shores, cliffs, thermo-Mediterranean scrubland, heath substituting Apollonias laurel forest, heath substituting Ocotea laurel forest, Madeira olive micro forest, Apollonias laurel forest (Mediterranean laurel forest), Ocotea laurel forest (temperate laurel forest), riparian laurel forest (*Sambucus* woodland, *Persea* laurel forest, *Salix* woodland), Cultivated and human-modified vegetation, urban areas, abandoned land, degraded natural habitats (Silva *et al*., 2008).

Italy
It is found along wet rocky coasts or on riverbanks (Del Guacchio, 2013).

Spain
It is listed in riparian environments (artificial conduction systems, springs, seeps and other wet enclaves and ponds), moist montane "forests" (heaths, hygrophytic tree thickets and mesophytic tree thickets), scrubland, urbanised areas, cultivated land and man-made green spaces (Catálogo Español de Especies Exóticas Invasoras, 2013).

Canary Islands
Cultivated and human-modified vegetation, middle elevation scrubland, mountain humid woodland (hygrophytic, mesophytic, heaths and Morella scrubland), inland wetlands (water-springs, infiltration areas and other wetlands, ponds and reservoirs, ditches), urban areas (Silva *et al*., 2008).

8. Pathways for entry

Seed and grain should be understood in this PRA as defined in ISPM 5 (FAO, 2022):

- Seeds: seeds (in the botanical sense) for planting [ISPM, 1990; revised ICPM, 2001; CPM, 2016]

- Grain: Seeds (in the botanical sense) for processing or consumption, but not for planting [FAO, 1990; revised ICPM, 2001; CPM, 2016; CPM, 2021]

The following pathways for entry of *A. adenophora* are discussed in this PRA:

- **Plants for planting of *A. adenophora* (horticultural use),**
- **Contaminants of growing medium attached to plants for planting,**
- **Soil/growing medium,**
- **Contaminants of grains,**
- **Contaminants of seeds,**
- **Travellers,**
- **Conveyances, vehicles & equipment,**
- **Natural spread.**

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 prevent the introduction of the pest.

The EWG acknowledged that there is (1) a lack of information for all pathways of entry and (2) it is unlikely there are current active pathways. Therefore, the EWG considered a detailed analysis was not possible.

Some pathways are included below even though the EWG initially considered that the pathway is very unlikely (e.g. contaminant of grain). The reason for this is that the current literature details such pathways, even though such detailing may not be supported by any evidence. However, the EWG considered it was important to list all pathways for completeness.

The EWG provided individual rating for likelihood and uncertainty as well as a global rating for all pathways in the table at the end of section 8.

Plants for planting (horticulture use): There is no evidence that *A. adenophora* is currently sold within the EPPO region (a comprehensive review online did not find any information on trade, e.g. RHS Plant finder website). However, the pathway is cited throughout the literature (e.g. CALIPC, 2022; Wagner *et al*., 1999). During the 1800s and early 1900s, the species has been sold as an ornamental species and moved around the world for this purpose (see section 6: specific details about the distribution in selected EPPO countries). The California Department of Food and Agriculture, state: "California Interceptions: A seed sample of the species was intercepted in 2009 in a shipment from Hawaii and submitted to the CDFA Plant Pest Diagnostics Branch for identification (CDFA/PDR, 2021)." The most likely stage associated with the pathway would be seed though live plants could also be imported. The volume and frequency of movement along this pathway are unknown and likely to be currently very low. *Ageratina adenophora* could transfer from this pathway to a suitable habitat as plants for planting would be planted outside in a garden. Misidentification of *Ageratina* species may result in inadvertent introductions (e.g. *Ageratina altissima*: https://www.crocus.co.uk/). The EWG also considered planting of the species in botanical gardens. There is historic evidence that the species has been planted, and in one case, more recent evidence from France (where the species was collected in Thailand and grown in the botanical garden in Nancy Herbarium CJBN-NCY NCY021903). The EWG considers that the pathway is not currently active for horticulture, though it cannot be excluded that the species may be traded in the future. **The EWG consider the entry on the pathway plants for planting (horticulture use) has a low likelihood of entry with a moderate uncertainty.**

Contaminants of growing medium attached to plants for planting: There is no evidence that *A. adenophora* has been intercepted as a contaminant of plants for planting. However, as the seeds are light and can be moved by wind there is the potential for contamination of growing media. The most likely stage associated with the pathway would be seed. The small seeds may not be easily detected upon inspection. The volume and frequency of movement along this pathway are unknown and likely to be very low. Plants for planting imported from countries where *A. adenophora* is established may potentially increase the likelihood of entry. *Ageratina adenophora* could transfer from this pathway to a suitable habitat as propagules would be planted outside in a garden or other area. **The EWG consider the entry on the pathway contaminants of growing medium attached to plants for planting has a very low likelihood of entry with a moderate uncertainty.**

Soil/growing media: (see ISPM 40; FAO, 2017b): import of soil/growing media is prohibited in EU EPPO countries (e.g. importation of soil and growing medium as such is prohibited in the EU, and is regulated when associated with plants (Implementing Regulation (EU) 2019/2072, EC, 2019) and likely other non-EU EPPO countries. The most likely stage associated with the pathway would be seed. The small seeds may not be easily detected upon inspection. The volume and frequency of movement along this pathway are unknown and likely to be very low. **The EWG consider the entry on the pathway soil/growing media has a very low likelihood of entry with a moderate uncertainty.**

Contaminant of grain: The most likely stage associated with the pathway would be seed. Although CABI (2022) lists grain as a potential for movement of seed, there is no evidence that the species has been intercepted along this pathway ('seeds may also contaminate stockfeed [grain]' (CABI, 2022). It is unlikely that *A. adenophora* will persist in intensively managed agricultural areas that produce grain for export. *Ageratina adenophora* is reported to infest maize in China, however, the seed would be relatively easy to sort as a contaminant due to the size and colour difference. **The EWG consider the entry on the pathway contaminant of grain has a very low likelihood of entry with a low uncertainty.**

Contaminant of seed: The most likely stage associated with the pathway would be seed. The species is a US Federal noxious weed seed and is also a prohibited noxious weed seed in Hawaii (USDA/AMS, 2021). CABI (2022) details an important means of spread of *A. adenophora* is movement as an impurity in agricultural produce, mainly cereals, forage and other seeds….). This spread pathway could also be a pathway for entry. However, the species is not reported in major export crops (e.g., maize, wheat, soybean, …) so it is unlikely to be found as a seed contaminant in these crops. **The EWG consider the entry on the pathway contaminant of seed has a very low likelihood of entry with a low uncertainty.**

Travellers. In Hawaii, there is an association with *A. adenophora* and tourism, it is found growing along trails for recreation that are only used by hikers. *Ageratina adenophora* seed may be a contaminant of travellers and their equipment (e.g. shoes, clothes and leisure equipment (tents, bags, etc.)). The most likely stage associated with the pathway would be seed. Seeds spread by wind can become attached to equipment and the small seeds can become incorporated into the tread of shoes. Travellers arriving from where the species is established with equipment that has not been properly cleaned, could potentially introduce the species into habitats where the species could establish in the EPPO region. **The EWG consider the entry on the pathway travellers has a very low likelihood of entry with a low uncertainty.**

Conveyances, vehicles and equipment. Seed of *A. adenophora* 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 (Implementing Regulation (EU) 2019/2072)). The

EWG considered that due to the small size of *A. adenophora* seeds, cleaning procedures applied may not be fully effective. Agricultural and forest 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 entry on the pathway conveyance, vehicles and equipment a very low likelihood of entry with a low uncertainty.**

Natural spread. Taking into consideration the current area of distribution (see section 6), it is not possible that *A. adenophora* can naturally spread from outside into the PRA area.

The EWG conclude that the overall rating for entry of *A. adenophora* into the EPPO region is low with a moderate uncertainty, based on the worst-case scenario (plants for planting).

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

9. Likelihood of establishment outdoors in the PRA area

Ageratina adenophora is locally established in Algeria, Croatia, France (Corsica), Greece, Italy, Morocco, Portugal (including mainland, Azores and Madeira) and Spain (including mainland, Canary Islands).

Habitats which are suitable for *A. adenophora* 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.

Recent research suggests that temperature, precipitation, altitude, and human activity (urbanization, landuse change etc.) are key factors in determining the distribution of *A. adenophora* (Zhang *et al*., 2022).

9.1 Natural habitats

Ageratina adenophora is currently well established in natural habitats in a number of small areas (see Section 7) and is likely to establish further within the EPPO region.

Natural habitats in which it has established (e.g. riverbanks, ditches, wooded habitats or ruderal sites) are widespread. Establishment is more likely in disturbed habitats compared to stable intact natural habitats, where interspecies competition may limit establishment (Wan *et al*., 2010).

In Italy, *A. adenophora* has been established for at least 7 years in wet rocky coast with sparse vegetation (Sorrento) and 5 years along a riverbank among high-herbaceous vegetation (Salerno) (del Guacchio, 2013). In France, *A. adenophora* has been established since the 1910s (Mader, 1910; Chevalier, 1918). It colonises ruderal habitats and banks of streams in the coastal valleys on the French Riviera (Fried, 2023). In Macaronesia the species has established since the 19th century in scrubland, humid woodland and inland wetlands (Silva *et al*., 2008; Parada-Diaz *et al*., 2021). See Section 7 for further details on habitats.

In the EPPO region, there are natural areas where the environmental conditions are suitable for the establishment of the species but are currently absent from *A. adenophora*. Further establishment is likely in these areas with spread from existing populations.

9.2 Managed habitats

Managed habitats are often prone to disturbance which is favoured by *A. adenophora* as seeds require light for germination (Wang *et al*., 2012).

A. adenophora is established in the managed environment in the EPPO region (e.g. along roadsides, water channels, abandoned gardens which were previously managed) (Fried, 2023, González-Martínez 2017, Plantas invasoras em Portugal, 2023, Arévalo *et al*. 2005). It is likely that *A. adenophora* can further establish in the managed environment in the EPPO region. It is capable of rapidly invading disturbed areas due to its high seed production, dispersal ability and the formation of a persistent seed bank.

Throughout the invasive range outside the EPPO region, *A. adenophora* has been recorded growing along roads (Dong *et al*., 2008; Horvitz *et al*., 2014; Lu & Ma, 2006; Wang & Wang, 2006: Arevalo *et al*., 2005), railway embankments (Xian *et al.*, 2022), field ditches (Burton, 1979) and ruderal or degraded environments (González-Martínez, 2017). In South Africa, the species has established in managed environments (e.g. urban areas, irrigation canals) (D. M. Richardson pers. comm. 2023).

In the EPPO region, *A. adenophora* is reported as being present in agricultural and silvicultural systems (see Section 7 for further details).

It occurs in agricultural systems in Portugal (Plantas invasoras em Portugal 2023) and Spain (field ditches; Burton, 1979). However, no further information is given on the type of agricultural system. The EWG consider that the species may potentially establish in pastureland and in permanent perennial crops with low management, and where the environmental conditions are favourable. In silvicultural systems, *A. adenophora* was recorded in *Pinus* spp. plantations of Tenerife (Fernández-Lugo & Arévalo 2009). Bermúdez *et al*. (2007) reported establishment in a managed Laurel forest of La Palma island (Canary Islands, Spain Parada-Diaz *et al*., 2021).

In France, Italy, and other Mediterranean countries, the EWG considers that soil moisture) is not favourable for the establishment of the species in managed forests. However, in Spain and Portugal the moisture levels may be more suited to the establishment.

Outside the EPPO region *A. adenophora* is reported as established in agricultural and silvicultural systems in the non-native range. It is established in pastureland in Australia (Auld & Martin, 1975), and in managed forests and crops in China (Wu *et al*., 2020), India and Nepal (A. Datta, pers comm., 2023).

9.3 Other factors affecting establishment

9.3.1 Natural enemies

Generalist natural enemies will potentially attack the plant, but these are unlikely to cause enough damage to influence establishment. Biological control has been practised against the species in the EPPO region. The biological control agent, *Procecidochares utilis* (Diptera: Tephritidae) was released in Madeira in 1962 to control *A. adenophora* (Marchante *et al*., 2023). However, it has a negligible degree of control on the island (Vieira, 2002). *P. utilis* has also been accidentally introduced into the Canary Islands and also had a negligible degree of control.

Biological control has been used with varying degree of success in other regions where the species is invasive (see section 16.2; Winston *et al* 2014).

9.3.2 Climatic conditions

Establishment of *A. adenophora* depends on favourable climate conditions, especially limited frost and sufficient moisture (Wang *et al*., 2017, Changjun *et al*., 2021, Datta *et al.*, 2019). Niche expansion has been observed for *A. adenophora* globally (Xian *et al*., 2023; Datta *et al*., 2019) suggesting an ability to adapt to new climate conditions.

The species distribution model developed for this PRA (appendix 2) did not include the marginal populations in China (as detailed in Xie et al., 2015) where extreme temperatures (-10 °C) have been recorded as (1) confirmed records in the region were unavailable, (2) there is no information on the persistence of these populations in these regions and (3) there is conflicting data from the Himalayas where cold temperatures will kill the plant. As already stated, low temperature (5-10 °C) has also been shown to limit germination (Lu *et al.*, 2006; Li & Feng, 2009). The model used minimum temperature of the coldest month (bio6) < -2 °C, presumed too cold for survival through winter.

In the EPPO region, the species distribution model (see Appendix 2) predicts a climatically suitable area around most of the Mediterranean coast, except for the most arid parts (e.g. North Africa, southern Turkey, eastern Italy). Suitability is also predicted for frost-free parts of the Black Sea and Atlantic coastline, with pockets of marginal suitability as far north as southwest UK. Frost-free inland areas in Portugal, southern France, Italy (Sardinia and Sicily) are also predicted to be climatically suitable. The currently invaded islands of Macaronesia are also predicted to be highly suitable.

The model suggests the main limiting factor in inland Europe is low winter temperature (low bio6), while summer drought stress (low bio18) is more important in unsuitable areas of the Mediterranean, Middle East and North Africa. Low irradiance is predicted to limit suitability in northwest Europe.

Predictions of the model for 2041-2070, under the moderate SSP1-2.6 climate change scenario and the more extreme SSP3-7.0 scenario suggests that reduced frost allows a modest potential for range expansion in inland parts of western Europe (especially southern France, Italy, northwest Spain). These projections used current levels of ground-level solar radiation, so may underestimate the magnitude of northwards spread in western Europe should climate change cause increases in radiation. In addition, more severe summer drought is projected to reduce suitability around the Mediterranean coastline.

These results are reflected in the suitability of different European Biogeographical Regions. Regions highly suitable for establishment in the current climate are the Macaronesia and Mediterranean regions, with substantial suitable areas in the Atlantic and Black Sea regions. By 2041-2070, overall suitability in Macaronesia and Black Sea remain little changed, while the Mediterranean sees declining suitability and the Atlantic increases markedly in suitability.

9.3.3 Soil conditions

Soil conditions are suitable for the species in the EPPO region. *Ageratina adenophora* can develop on a large range of soil types regarding texture and pH ranging from dry sands to wetland clay soils (Queensland fact sheet). However, many articles indicate that it has a preference for sufficiently moist substrates, under which conditions its performance is greater (Alziar, 1984, Del Guacchio 2013, González-Martínez, 2017). It can tolerate some salinity and low nutrients.

It should be noted that *A. adenophora* has positive plant-soil feedback where once the species becomes established it can alter the soil biochemical properties to favour its establishment at a cost to other plant species in the near vicinity (Fang *et al*., 2019).

The EWG considered that the likelihood of *A. adenophora* establishing outdoors in the EPPO region is very high with a low uncertainty. The species is already established in the EPPO region, and these populations have persisted for at least 20 years.

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 in the PRA area

No evidence was found of the presence of *A. adenophora* under protected conditions in areas where the species occurs. 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 *A. adenophora*. 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 *A. adenophora* establishing in protected conditions in the EPPO region is very low with a low 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. Protected conditions themselves vary, with different intensities of management.

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

11. Spread in the PRA area

There is no information on the rate of spread of *A. adenophora* in the EPPO region. However, its spread has been studied in a number of regions where the species is invasive, in particular in China. In fact, Poudel *et al*. (2019) note the geographical bias in publications on this species with over 90 % of scientific papers coming from research conducted in China. Key information is summarised here.

In China, after a lag phase of 20 years (1940–60), *A. adenophora* has spread rapidly throughout the south and middle subtropical zones in Yunnan, Guizhou, Sichuan, and Guangxi, with an average expansion rate of 20 km per year. It spread relatively slowly in north subtropical areas, with an average expansion rate of

6.8 km per year. Although range expansion in Yunnan stopped after 1990, the continued expansion of its range into neighbouring provinces indicates that *A. adenophora* has not reached the full potential of its distribution and its range is still rapidly expanding within China (Wang & Wang, 2006).

Poudel *et al*. (2019) state: *'Multiple factors, such as the dispersal of tiny and light seeds by water, wind, animals and vehicles, removal of native/resident vegetation during construction works and a heterogeneous landscape with a mosaic of suitable microhabitats, contribute to the rapid spread of this species (Wang et al., 2011). These factors have contributed to upslope as well as downslope dispersal in hilly and mountain landscapes. In plains areas, flood also facilitates long-distance dispersal (Wang et al., 2011)'.*

In South Africa, *A. adenophora* has been observed to spread along the Eerste river (Stellenbosch, Western Cape) where the populations have been estimated to spread 15 km over a 20-year period (D.M. Richardson, pers. comm., 2023).

In Australia, it spread rapidly across the eastern coastal areas of Australia in the 1940s and 1950s, and colonised Lord Howe Island (600 km from the mainland) (Australian Government (2014).

In Sikkim (India), *A. adenophora* has spread rapidly from 1800 m to altitudes of 2700 m in 3 years (Verma *et al*., 2023).

11.1 Natural spread

Ageratina adenophora propagates by seed and stem or rhizome fragments. It can produce ca. 7 000– 10 000 seeds per plant (Parsons and Cuthbertson, 2001). Seeds are light with feathery hairs and are easily dispersed by wind. Seeds can float on water and can be spread with water movement. CABI (2022) notes that seed can attach to the hair, skin or feathers of animals with mud thus facilitating spread.

The establishment of stem fragments is assumed to be very successful, as the species can grow vegetatively from small cuttings (Wang *et al*., 2011). This may act to facilitate short distance spread and to increase density of the local population. Broken stem fragments can root when pieces are in contact with the soil. Wang *et al*. (2011) note: 'A large number of stem fragments or broken rhizomes can be produced and float downstream with a flood event. Flooding can act to amplify the vegetative dispersal ability of *A. adenophora*. Following the destruction or disturbance of other riparian vegetation, large openings are available and favourable for colonisation'.

Natural spread has been shown to benefit from transportation networks (roads and railways) and rivers in China that act as corridors to facilitate spread (Horvitz *et al*., 2014; Lu & Ma, 2006; Wang & Wang, 2006; Wang *et al*., 2011). Movement along these corridors has acted to increase the rate of spread in many countries where *A. adenophora* is invasive. The invasion of *A. adenophora* expressed as cover, abundance, and number of clusters has been shown to decline significantly with distance from the road and stream in Southwest China (Lu & Ma, 2006). When modelling the mechanisms for spread in China, Horvitz *et al*. (2014) estimate that rivers have played an important role in the rapid spread of the species over time. Its biological traits, favouring dispersal by water and wind coupled with local spatiotemporally heterogeneous geography and ecology, promote invasion downstream and upstream along river valleys, while other factors associated with human activities facilitate its invasion over high mountains and across river valleys, providing new scope for progressive invasions (Wang *et al*., 2011).

In the EPPO region, *A. adenophora* is present along riparian systems where it spreads, and on the banks of streams and rivers (Fried, 2023; Plantas invasoras em Portugal, 2020; Del Guacchio, 2013). In Corsica, when the plant was first discovered in 1952, it already occupied 1km along a riverbank (Conrad, 1961a). In Portugal, clusters of distribution along urban watercourses suggest spread by natural means (invasoras.pt). Although this does not allow us to deduce a rate of spread, it nevertheless shows that the species has a very good capacity to colonise along the river corridors. Therefore, there is the potential for spread of seed and rhizomes via water and this can act to spread the seed over long distances.

11.2 Human assisted spread

A number of pathways considered not likely for import were considered likely for spread. The species may be spread via the deliberate movement of seeds or plants for planting for horticulture use (CALIPC, 2022; CABI, 2022). Additionally, seeds can be spread as contaminants of soil attached to plants for planting.

The small seeds can be contaminants of soil which can facilitate the spread and potential establishment as soil may be placed in suitable conditions to facilitate seed germination.

Other potential means of spread detailed in the literature include via mud attached to clothes and equipment (e.g. agricultural workers as well as tourists, hikers, etc.), spread via contaminants of used machinery (CABI, 2022). Additionally, CABI (2022) states that seeds may also contaminate stockfeed [grain]. 'An important means of spread of *A. adenophora* is movement as an impurity in agricultural produce, mainly cereals, forage and other seeds, also in sand and gravel used for road making….'.

Disturbance of existing populations, through direct management or habitat restoration can act to spread seeds and stem fragments. Potentially, the dumping of contaminated garden waste can act to spread the plant if viable propagules are included.

11.3 Overall assessment of spread

For *A. adenophora* to spread successfully in the EPPO region, propagules will need to find a suitable habitat where the conditions are favourable for germination and growth. Potentially, seed is spread from the existing populations in the EPPO region, though because they land in habitats or conditions (both biotic and abiotic) that are not suitable, the invasive potential of the species is not currently realised.

With climate change, and the potential increase in established populations, spread may increase within the EPPO region. If climate change promotes establishment, populations may produce higher propagule pressure and the frequency of spread may be higher (see section 9).

The suitability map (appendix 2) shows a continuity of climatic suitability areas from Portugal to the Atlantic region which can aid the spread. Thus, there is the potential for further spread in the EPPO region.

The EWG considered the rating of magnitude of spread to be high. In the EPPO region, *A. adenophora* can spread by wind and human assisted means. Uncertainty is scored as moderate due to lack of information on the human assisted spread. Additionally, established populations have not shown significant spread to-date (except for the Canary Islands and Madeira).

Rating of the magnitude of spread in the PRA area	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 EPPO region)

In the current area of distribution, there is evidence of impacts on biodiversity as a result of the following impact mechanisms, allelopathic effect and competition.

12.1 Impacts on biodiversity

Where *A. adenophora* is invasive it can reduce the growth of native species by releasing allelopathic compounds (Darji *et al.*, 2021; Kaul & Bansal, 2002) which in addition may alter the soil microbial communities (Niu *et al*., 2007). Laboratory trials have shown that chemicals from the plant (such as cadinenes and β-sitosterol) can inhibit germination of crop seeds such as *Allium cepa*, *Raphanus sativus*, and *Cucumis sativus*.

The invasive behaviour of *A. adenophora* and its ability to change the composition of the soil microbes and chemicals enables the species to replacing other invasive weeds such as *Imperata cylindrica* (Poaceae) and *Lantana camara* (Verbenaceae) (Darji *et al.*, 2021; Kaul & Bansal, 2002).

Shresatha *et al* (2022) highlight that *A. adenophora* has similar impacts on soil biology to a number of invasive species including: *Chromolaena odorata*, *Lantana camara*, *Leucaena leucocephala*, *Mikania micrantha*, *Mimosa diplotricha* and *Parthenium hysterophorus*.

Species richness of soil fungi is lower in invaded soil compared to the uninvaded soil (Balami *et al.*, 2017). *Ageratina adenophora* also alters soil fungi species composition in invaded soil by replacing saprophytic fungi and accumulating pathogenic fungi (Balami *et al*., 2017). It has been found that infestation of *A adenophora* reduces species diversity, biomass and productivity of grasslands in Western Himalaya (Balami *et al*., 2017).

The soil invaded by *A. adenophora* had low pH and a high amount of organic matter, total nitrogen, phosphorus, and potassium than the uninvaded soil. The results indicate that the native Nepalese *Osbeckia stellata* and *Elsholtzia blanda* are affected by *A. adenophora* in the natural environment by leaching of allelochemicals and probably by reducing soil pH (Darji *et al*., 2021).

Competition

Once *A. adenophora* invades an area, it can develop into a single predominant plant community in a short period of time by displacing native plant species and altering local nutritional cycles and hydrological conditions. *Ageratina adenophora* can reduce biodiversity and endanger native plant species, particularly rare species, ultimately causing serious ecosystem degeneration and altering the local natural landscape (Wan *et al*., 2010).

Studies carried out in Yunnan province and Sichuan province in China showed that an invasion of *A. adenophora* caused a significant decline of richness index in all the habitats involved. Plant communities dominated by annual herbs showed a more significant declining trend than those with perennial herbs (Ding *et al*., 2007).

Ageratina adenophora has been reported as having a negative impact on the composition and structure of understory communities and on *Pinus yunnanensis* seedling growth under pine stands in Yunnan (Fu *et al*., 2018). Fu *et al*. (2018) showed that *A. adenophora* altered species and functional diversity by changing the species composition and abundance in the understory community because of its higher specific leaf area, leaf nitrogen concentration, and leaf phosphorus concentration compared with native species.

In Nepal, it is locally known as the forest killer plant (pers. comm. A. Datta) due to its negative impacts on the forest and Thapa *et al*. (2016) showed that seedlings of the indigenous tree species *Schima wallichii* had reduced root length and dry weight when grown with leaf litter of *A. adenophora*.

In Hawaii, *A. adenophora* has spread quickly since its introduction in the late 1800's, coming to dominate large areas by 1913, forming monotypic stands up to 1.5 meters tall, and crowding out desirable plants and overtaking pasturelands (Loope *et al*., 1992). Despite the release of the biological control agent (*Procecidochares utilis*) the species remains along streams, in native-dominated forests where, along with a suite of other introduced species, it has been found to inhibit the growth of native plants (Loope *et al*., 1992).

Impact at higher trophic levels

Gu *et al*. (2006) studied the impact of *A. adenophora* on Carabidae (Coleoptera) in Yunnan Province (China) and showed that their abundance was lower under stands of *A. adenophora* compared to native grassland, but species richness was higher. According to this study, the invasion of *A. adenophora* altered the structure of carabid communities, but did not necessarily reduce the alpha-diversity of carabid assemblages.

12.2 Impacts on ecosystem services

The impact of *A. adenophora* on ecosystem services in the current area of distribution is high with impacts on provisioning, regulating, supporting and cultural ecosystem services. In China, the main negative impact of the species is the impact on the ecosystem function of grassland (Xu *et al*., 2006).

Some impacts detailed in this section are also detailed in section 12.3. However, only one score is given for impact in the current area of distribution and therefore the impacts are not double counted.

Ecosystem service (ES)	Impact on ES	Short description of impact	Reference
Provisioning	Yes	Reduction in productivity of pastureland/ reduced yields in crops (maize, rice, eggplant and banana) in China/ negative impacts on forest regeneration in China and Nepal; reduction in natural flow of water along streams and water bodies in India. *Ageratina adenophora* is toxic to horses.	Lu *et al*., (2008); Fu *et al*. (2018); Malla *et al*., (2021); Datta (2018)
Regulating	Yes	Can increase the potential for natural fires by increasing the amount of fuel material	Wang & Niu (2016)
Supporting	Yes	Modification of nutrient cycling in soils	Poudel *et al*. (2019)
Cultural	Yes	Loss of land for amenities. In Australia for example, it has become problematic along the eastern coast invading habitats such as public reserves (State forests, national parks and nature reserves).	Department of Primary Industries, Australia (2022)

12.3 Socio-economic impacts

Impacts on crop yield

Ageratina adenophora is a serious weed in agriculture, especially in pastureland where it often replaces either the more-desirable vegetation or native species (Bess & Haramoto, 1958), but also in forests (Sharma & Chhetri, 1977).

Zhihong *et al.* (2004) detail that for the Tianlin county (Guangxi, China) yield losses of 18 % in maize and 9 % in rice have been reported per year. Zhihong *et al*. (2004) also detail that banana plants can have two to three less leaves and a reduction in height of 4 - 8 % (potentially reducing yield). The EWG note that the methodology in Zhihong *et al.* (2004) to obtain yield losses is unclear.

In Australia, *A. adenophora* is an important agricultural weed, and although no economic studies of its importance have been undertaken, it has been reported to reduce crop yield (with no mention of the specific crop species) (Parsons and Cuthbertson, 2001).

Further data from China documented effects of various densities of *Ageratina adenophora* in cotton (*Gossypium hirsutum* L.) and eggplant (*Solanum melongena* L.). AoCheng *et al*. (2013) showed that fruit branches and bolls per plant were decreased by 22 % and 57 % at a density of 60 plants/m^2 of *A. adenophora* compared to the untreated control, and loss of lint yield was up to 57%. WenDa *et al*. (2011) demonstrated that height, fruit number and yield of S. *melongena* were not affected when the densities of *A. adenophora* ranged from 1-2 plants/m^2, while these parameters decreased significantly when the density was > 5 plants/m^2.

When *A. adenophora* grows near -rice fields it may release leachates through rainwater which can be mixed into the paddy field. Shrestha *et al.* (2021) studied the impact of leaf extracts of *A. adenophora* on the growth and development of rice (rice variety: Khumal-11). In controlled studies, fresh and dry leaf extracts of *A. adenophora* were shown to have a negative impact on root shoot growth and the number of roots of rice.

Impact on pastureland

In Australia, it can reduce the value of bush land (Department of Primary Industries, Australia, 2022) and reduce animal carrying capacity and restrict livestock movement (Parsons and Cuthbertson 2001).

Xu *et al*. (2006) detail that *A. adenophora* and *Eupatorium odoratum* are the two main invasive alien species in China that threaten grassland ecosystem function. Wan *et al*. (2010) detail that *A. adenophora* has caused 989-million-yuan (133 million Euros) losses to livestock production and 2.6 billion yuan (338 million Euros) annual losses to the production of grassland in China. "These high figures are supported by data that suggest that "each hectare of grassland invaded by this toxic species produces no more than 1 kg of grass and 78,000 kg of croftonweed" (Lu *et al.*, 2008). According to Sun *et al*. (2004) only three years after invading a natural pasture, the coverage of *A. adenophora* can reach 85 % to 95 % and reduce yield by 70% to 79%.

Impacts on forestry

Economic losses in forests have been reported at 5 % per year in China (Zhihong *et al*. 2004). Sections 12.1 and 12.2 detail effects of *A. adenophora* on biodiversity and soils in forest systems, respectively. *Ageratina adenophora* has been shown to have a negative effect on the growth of *Pinus yunnanensis* seedling under pine stands (Fu *et al*.,2018). In Nepal, *A. adenophora* invades plantation forests *(Pinus roxburghii, P. wallichiana* and *P. patula*) regenerated by seed. When it is present with other invasive plants (*Chromolaena odorata*, *Lantana camara* and *Mikania micrantha*), there is a negative impact on forest regeneration and a cost for the management of the suite of invasive plants (Malla *et al*., 2021).

Impacts on livestock

Ageratina adenophora has a poisonous effect on domestic animals, such as horses and cattle (Ren *et al*., 2021). The plant is more toxic in its flowering stage compared to its juvenile stages (O'Sullivan, 1985). It is known to cause respiratory disease in horses and may result in death, if horses continue to feed upon it for prolonged periods (O'Sullivan, 1979). It causes the "blowing disease" in Hawaii and "Numinbah disease" or "Tollebudgera horse disease" in Australia. Symptoms such as coughing, difficulty in breathing, and violent blowing after exertion are the result of acute lung edema leading to hemorrhage (O'Sullivan, 1985). Verma *et al*. (1987) found that *A. adenophora* reduced digestive function and photosensitive reaction in cattle.

Health hazards to humans have not been reported.

Other impacts

Zhihong *et al*. (2004) detail that *A. adenophora* can have impacts on infrastructure where it can block drainage ditches which can have a negative effect on irrigation. The authors estimate it can cost around 450 - 1200 RMB (61 - 162 Euros) per hectare in management costs in China. In Australia, it can restrict movement of equipment (Parsons and Cuthbertson, 2001).

The EWG considers the impact in the current area of distribution to be high based on the known impacts on biodiversity, ecosystem impacts and socio-economic impacts. Uncertainty: some areas such as California, Australia and New Zealand, with widespread populations have little evidence of impacts and impacts are difficult to control. Uncertainty on data from publications on reduced crop yields.

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

13. Potential impact in the PRA area

Will impacts be largely the same as in the current area of distribution? **In part: the type of impacts will be similar (i.e. effect on biodiversity, ecosystem services and socio-economic impacts) though the severity of impacts is likely to be lower in the PRA area.**

Ageratina. *adenophora* has a very high likelihood of establishment outdoors in the EPPO region, see section 9), it is established in a variety of habitats, both natural and agricultural (see section 7). There is ample evidence that the species is already abundant in natural or semi-natural habitats (e.g. Conrad 1961, Gonzalez-Martinez 2017, Fried 2023) and the EWG consider it is almost certain that impacts on local biodiversity have already occurred where *A. adenophora* forms dense stands.

13.1 Potential impacts on biodiversity in the PRA area

In areas that are climatically suitable and have favourable micro-habitats for the optimal growth and reproduction of *A. adenophora*, there is the potential for impacts on biological diversity. The species has the potential to compete with native species for resources (space, light and nutrients). This may lead to a displacement of native biodiversity in areas where *A. adenophora* invades. The invasion of the species in natural areas may also have a negative impact on higher trophic levels.

Along streams in the French Riviera (Provence-Alpes-Cote-d'azur region, between Nice and Menton), *A. adenophora* forms dense monospecific stands in several wet ravines and valleys (Fried, 2023). It is likely to have negative impacts on native species characteristic of these habitats such as *Allium triquetrum*, *Carex pendula*, *Eupatorium cannabinum* subsp. *cannabinum*, *Hypericum androsaemum*, *Oloptum miliaceum*, *Parietaria judaica*, *Sambucus nigra*, *Samolus valerandi*, *Sanicula europaea* (Fried, 2023). In one site, it has been found co-occurring with *Symphytum bulbosum*, a nationally protected species (Conservatoire botanique national méditerranéen, 2023). In drier ruderal habitats (roadsides) or on old walls and cliffs, populations are sparser and impacts less likely (Fried, 2023).

Based on recent sightings supported by images (Invas.pt), the EWG observe dense stands along the banks of large rivers through urban areas in Portugal (Leirea, Lisbon and Coimbra). Thus, indicting a suppression of native vegetation.

One of the most threatened habitats within the EPPO Region is likely to be the Macaronesian laurel forest [Macaronesian laurel forests, Laurus, Ocotea, 9360, according to the habitat classification of the Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora]. The Macaronesian laurel forests, also called laurisilva, are humid to hyper-humid evergreen forests of the cloud belt of the Macaronesian islands (Guimarães & Olmeda, 2008). Tree species with laurel-shaped leaves are predominant, forming a dense canopy up to 40 m high that can be hardly trespassed by light, which results in scant vegetation in the understory. This habitat is closely associated with another habitat typical of the Macaronesian region, the endemic Macaronesian heaths (*4050). Both communities have similar species composition, are generally intermixed in their distribution areas and often subject to common conservation measures (Guimarães & Olmeda,2008). A number of papers document the presence and the potential or actual impacts of *Ageratina adenophora* in the Macaronesian laurel forest, both in managed or unmanaged sites (e.g. Parada-Díaz *et al*., 2021), and in relation with disturbance (e.g. road density, see Arévalo *et al*., 2008). For example, according to Sanz Elorza *et al.* (2004), in Spain the presence of *Ageratina adenophora* is particularly concerning in the National Park of Caldera de Taburiente, on the island of La Palma (Canary Islands), where it has been estimated that it has invaded 80% of its surface, although it does not appear above 1,800 m altitude. It is located also in the Garajonay National Park, in La Gomera, where it invades the native pine forests (*Pinus canariensis*) and degraded Macaronesian laurel forest plants communities such as Myrico-Ericetum, Lauro-Perseetum, and Visneo-Arbutetum. In the National Park of the Caldera de Taburiente, at the beginning of the decade of the 1990s, a control plan for *A. adenophora* was adopted, uprooting the plants and after repopulating with native taxa for three years in a row. However, after two years, the areas where the control operations were carried out were colonized again by *A. adenophora*, reason for which this type of control was stopped. According to García Gallo *et al*. (2008) *A. adenophora*, on Canary Islands, contributes to modify the structure of the potential vegetation and competes for space with endemic and native species typical of laurel forest communities, affecting numerous protected natural spaces and the Natura 2000 Network, in which it would be necessary to carry out control and eradication plans. The need to control *A. adenophora* in Macaronesian laurel forest is remarked also by Herrero & Zavala (2015). Control of *A. adenophora* was included, between 2013-2017 in EU-funded LIFE project "Macaronesian Sparrowhawk" carried out by the Portuguese Society for the Study of Birds in partnership with the Institute of Forestry and Nature Conservation (IFCN), Spanish Ornithological Society (SEO/BirdLife). To restorate bird habitats, 12 different invasive plant species (including *A. adenophora*) needed to be controlled in an area of almost 46.5 hectares - Assumadouros and Ginjas, in Santana and São Vicente. Of these plant species, *A. adanophora* was one of the 9 that demanded an increased effort because of their abundance in these places[1].

Furthermore, a specific sub-type of the laurisilva forest, i.e. the riparian formations classed as Rubo-Salicetum canariensis associations (a type of oligospecific forest dominated by the Canarian willow (*Salix*

[1] http://life-furabardos.spea.pt/fotos/editor2/layman_final_2jun.pdf

canarienis), and to a lesser extent by *Myrica faya*, is often invaded by *Ageratina adenophora* and *Arundo donax*, competing with native species for space (Action Plant for the Biosphere Reserve “Macizo de Anaga”)[2]. In this habitat *Ageratina adenophora* can compete also with the endangered fern *Christella dentata* (Forsskal) Brownsey & Jermy (Bañares *et al*., 2004).

Historically, Lowe (1868) describes its behaviour as invasive: “spread in vast profusion”, “forming, in some places, hedges […], and in ravines, thickly clothing the wet dripping perpendicular cliffs in many places as if perfectly indigenous”.

In the coast of Eastern Andalusia *Ageratina adenophora* invades riparian environments and ruderal habitats, but it is also present in the Natural Park of the Sierras de Tejeda and Almijara.

In Northwest Spain (A Pobra do Caramiñal), *A. adenophora* is relatively abundant and shows clearly invasive behaviour (González-Martínez, 2017).

In Italy, del Guacchio (2013) notes that in Campania, *A. adenophora* may compete against native species both in stillicidious rocky coasts and along rivers in warm climate. In Sorrento several endemic entities were observed to grow together with *A. adenophora*, and it is able to compete against endemic plants which usually disappear in sites where the ecological conditions are favourable alien competitors. *Ageratina adenophora* can outcompete *Helichrysum litoreum* and *Centaurea tenorei* growing in the same locations and depriving them of space and light.

There are no studies on allelopathic effects of *A. adenophora*, and effects on the soil microbiota in the EPPO region. However, the EWG consider similar effects to that seen in other regions where the species is established will occur in the EPPO region.

13.2 Potential impact on ecosystem services in the PRA area

There is the potential for impacts on ecosystem services where *A. adenophora* invades in the EPPO region. The species can potentially impact on cultural ecosystem services by invading riverbanks and wooded habitats and reducing access to sites.

In the EPPO region, *A. adenophora* has invaded rivers (e.g., in Spain, Italy, France and the Macaronesia Islands). Therefore, the EWG consider there is the potential for *A. adenophora* to reduce the natural flow of water along streams and water bodies.

13.3 Potential socio-economic impact in the PRA area

There are no studies and few monetary figures on the economic impact of *A. adenophora* in the EPPO region. The only known figures are from Andreu *et al*. (2009) who detail management costs in Spain to be 23 109 euros (though no other details to justify the costs are given).

As stated in section 9, the EWG consider that *A. adenophora* can potentially establish in permanent perennial crops (e.g. fruit tree orchards) with low management, where the environmental conditions are favourable in the EPPO region. Although a negative impact on yield is unlikely, there may be increased costs for management.

Economic impacts could occur if the species spreads and establishes in grassland and pasture areas in the EPPO region. However, there is a limited area of pastureland under the climatic conditions suitable for the

[2] https://reservabiosfera.tenerife.es/wp-content/uploads/pdf/Memoria_y_plan_de_accion.pdf

establishment of *A. adenophora* (see section 9) and therefore it is unlikely that economic impacts as seen in Asia and Australia will be replicated in the EPPO region.

There is the potential for further negative impacts in managed forests in mainland Spain and Portugal (where moisture levels may be more suited to its establishment).

Socio-economic impacts due to the toxicity of the plant for livestock has not been reported in the EPPO region, however, if the species spreads and forms monospecific stands such impacts may occur.

Any action targeting control of this species will generate additional production costs (cost of weeding practices).

Rating of potential impact in the PRA area	Very low ☐	Low ☐	Moderate X	High ☐	Very high ☐
Rating of uncertainty			Low ☐	Moderate X	High ☐

14. Identification of the endangered area

The EWG consider the endangered area to be the coastal areas and frost-free inland areas of the Mediterranean (including humid parts of North Africa (Algeria, Morocco, Tunisia) and south Atlantic biogeographical regions, Macaronesia (Canary Islands, Azores and Madeira) and the east coast of the Black Sea (Georgia). Habitats at risk in the endangered area include river systems, pastureland, forests (coniferous forests, in particular pine forests, temperate Laurel forests, and oak forests). Appendix 2 gives the percentage of suitable areas in each EPPO country. The EWG consider the species distribution model conducted as part of this PRA (see Appendix 2) to be a realistic projection of the potential establishment of the species in the EPPO region.

15. Overall assessment of risk

Ageratina adenophora is locally established in Algeria, Croatia, France (French Riviera, Corsica), Greece, Italy, Morocco, Portugal (including mainland, Azores and Madeira) and Spain (including mainland, Canary Islands).The overall likelihood of further entry of *A. adenophora* into the EPPO region is low with a moderate uncertainty. Several pathways were assessed in the PRA but there was no strong association with any pathways. The EWG note that the pathway plants for planting (horticultural use) is not currently active, however, this may change in the future. The likelihood of further establishment outdoors is very high with low uncertainty. Habitats are widespread within the EPPO region and further establishment is likely in regions where habitats and climatic conditions are conducive for establishment. Likelihood of establishment in protected conditions is very low with moderate uncertainty. Temperature within protected conditions would be suitable for the establishment however, other conditions, e.g., the intense crop management , are likely to reduce the likelihood of establishment. The potential for spread within the EPPO region is high with a moderate uncertainty. *Ageratina adenophora* can spread both naturally via wind dispersed seed, and plant fragments via waterways, and via human assisted spread (e.g. contaminant of travellers equipment). The magnitude of impact in the current area of distribution (excluding the EPPO region) is high with a moderate uncertainty. *Ageratina adenophora* has negative impacts on native biodiversity, ecosystem services and has been shown to have socio-economic impacts on managed forests and crop yields. The EWG considered that the potential impact in the EPPO region is moderate with a moderate uncertainty.

Similar types of impacts are expected though the moderate rating reflects the lower impact observed and the moderate uncertainty reflects the unknown severity in the EPPO region. Based on high likelihood of spread (moderate uncertainty) from existing established populations in EPPO region, and high impacts (mod uncertainty) the overall risk appears correct.

Category	Likelihood	Uncertainty
Entry	Low	Moderate
Plants for planting	Low	Moderate
Contaminant of plants for planting	Very low	Moderate
Soil or other growing media	Very low	Moderate
Grain	Very low	Moderate
Seed	Very low	Moderate
Travellers and their equipment	Very low	Moderate
Used machinery and equipment	Very low	Moderate
Establishment		
Establishment outdoors	Very high	Low
Establishment protected conditions	Very Low	Moderate
Spread	High	Moderate
Impact in the current area of distribution	High	Moderate
Potential impact in the PRA area	Moderate	High

Stage 3. Pest risk management

16. Phytosanitary measures

The results of the risk assessment show that *Ageratina adenophora* has a high phytosanitary risk to the endangered area with a moderate uncertainty.

Several pathways were assessed in the PRA but there was no strong association with any pathways.

Recommendations by the EWG are the following:

- ***Ageratina adenophora* should be recommended for regulation as a quarantine pest,**
- ***Ageratina adenophora* should be banned for sale in the EPPO region.**

Possible pathways *(in order of importance)*	**Measures identified**
Plants for planting (horticulture use)	Prohibition of import into the EPPO region

The Expert Working Group recommends that the PRA is reviewed every ten years (e.g. especially to conduct a pathway analysis to assess if historic pathways become active or if new pathways open).

16.2 Eradication and containment

16.2.1 National measures

Early detection is important to identify new occurrences of the species. *Ageratina adenophora* 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 can help to monitor populations and subsequently prevent spread from existing populations in areas and/or countries at high risk.

16.2.2 Eradication

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

Eradication is only considered to be possible for *A. adenophora* in case of early detection of newly established populations in, e.g. forest areas, or when detected in the natural environment, 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.

16.2.3 Containment

A pro-active and integrated weed management strategy is required to effectively manage *A. adenophora*. It should be noted that in natural environments, management practices should be tailored to the habitat invaded. During the management of populations, care should be taken to avoid fragmenting roots and stems. Management should take place before flowering.

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 and mechanical control techniques.

Prevention: Unintentional dispersal of *A. adenophora* seed through the movement of travellers and their equipment should be avoided. This could be achieved with awareness campaigns. Equipment and machinery should be cleaned to remove seed and plant fragments before moving to an uninfested area (see ISPM 41: International movement of used vehicles, machinery and equipment; FAO, 2017).

Biological control: A number of biological control agents have been released against *A. adenophora* worldwide with varying success (Poudel *et al.*, 2019). *Procecidochares utilis* Stone, a gallfly was first introduced to Hawaii in 1945 and Madeira (Portugal) in 1962. A leaf spot fungus *Passalora ageratinae* Crous & A.R. Wood has been introduced into several countries and has established (Moris, 1989). The rust fungus *Baeodromus eupatorii* (Arthur) is a native of Mexico and was released in Australia in 2014. *Xanthaciura connexionis* (Diptera) Benjamin is native to Mexico and was released in Hawaii in 1955. Further research is needed in the EPPO region, particularly continental Europe to assess if any of the biological control agents are suitable for release. This research should include host range studies along with climate matching.

Mechanical control: Mechanical control can be applied where the plant is accessible. This can include digging plants out. However, plants often grow on steep slopes making hand removal difficult. Cutting a plant may not control it, but over time it will reduce the seedbank and reduce the population.

Chemical control: A number of herbicides can be effective in controlling *A. adenophora.* Chemical control of *A. adenophora* can be performed by spraying herbicides such as glyphosate, fluroxypyr, 2,4-D amine, picloram + 2,4-D, picloram + triclopyr, dicamba + MCPA and metsulfuron methyl (Parsons & Cuthbertson, 2001; Di Tomaso *et al*., 2013). They are most effective when the plant is in the vegetative stage and growing actively.

17. Uncertainty

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

- **Biology** – lack of studies on the biology of the species in the EPPO region (lifecycle and genetic variation, cold tolerance),
- **Pathways** – lack of evidence for current pathways,
- **Impact** – In the EPPO region no clear scientific replicated studies have assessed impact on biodiversity, ecosystem services.
- **Impact-** Outside the PRA area, magnitude of impact in agricultural systems
- **Efficacy of biological control agents** – varying impacts of BCA in different regions makes predicting success in the EPPO region difficult.

18. Remarks

- Scientific research should be conducted on the genetic variation of the species in the EPPO region,
- Studies should be conducted on the current distribution, spread and impacts in the EPPO region,
- The EWG recommend that EPPO-Q-Bank Plants develop look-alike factsheet to include *A. adenophora* and *A. altissima*, *A. riparia*.

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Appendix 1. Images of *Ageratina adenophora*

Figure 1. *Ageratina adenophora* in flower (France)

Figure 2. *Ageratina adenophora* invading riparian system in France

Figure 3. *Ageratina adenophora* invading riparian system in France

Figure 4 and 5. *Ageratina adenophora* achenes (4) lacking pappus and (5) with pappus

Figure 6: Drawing of *Ageratina adenophora* plant and seed (taken from *Tripathi et al*., 2006)

Appendix 2: Climatic suitability modelling for *Ageratina adenophora* establishment in the EPPO region

Aim

To project the climatic suitability for potential establishment of *Ageratina adenophora* in the EPPO 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), Atlas of Living Australia, Integrated Digitized Biocollections (iDigBio), published records (Del Guacchio, 2013) and additional records provided by the Expert Working Group performing the risk assessment, notably for India (western Himalayas) and China. 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, co-located with herbaria or botanic gardens, country or province centroids), including use of R package CoordinateCleaner (Zizka *et al.*, 2019). In the EPPO region, records from Netherlands and most of mainland France were considered casual and excluded from the modelling.

The native range of the species was determined as the whole of Mexico.

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 1360 grid cells containing valid records of *A. adenophora* (Figure 1a), which is a sufficient number for distribution modelling.

Predictor variables were selected based on the life history and habitat requirements of *A. adenophora* and likely limiting factors for establishment in Europe. Predictors included bioclimatic variables 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 *et al.*, 2014):

- Mean minimum temperature of the coldest month (bio6 °C), since *A. adenophora* is highly sensitive to frost. Previous studies demonstrated mortality at temperatures of -5 °C (Li *et al*, 2008) and found this to limit upper elevational distributions (Datta *et al.*, 2017). Cold temperatures are reportedly not required for seed stratification (Wang *et al.*, 2012). and low temperature (5-10 °C) has also been shown to limit germination (Lu *et al.*, 2006; Li & Feng, 2009).
- Mean temperature of the warmest quarter (bio10 °C), as a measure of growing season thermal regime. Previous studies found optimal temperatures for growth and physiological processes around 25 C with reduced performance at both lower and higher temperature (Lu *et al*, 2007; Chen *et al*, 2016). Additionally germination failure at very high temperature has been shown to limit lower elevational limits in Asia (Datta *et al.*, 2017) supporting experimental studies showing inhibition of germination at 35 C and 5 C (Lu *et al.*, 2006).
- Mean monthly surface solar radiation (MJ m^{-2} d^{-1}), as the average monthly surface downwelling shortwave flux in air. Low irradiance has been shown to reduce growth of *A. ageratina* (Feng *et al.*, 2007), and this was hypothesised to be a possible factor limiting colonisation of higher latitudes.
- Precipitation of the warmest quarter (bio18 kgm^{-2}, log(x+1) transformed) as a measure of growing season moisture availability.
- Precipitation of the coldest quarter (bio19 kgm^{-2}, log(x+1) transformed) as a measure of growing moisture availability during winter, when *A. ageratina* seedlings are establishing.
- Precipitation of the driest month (bio14 kgm^{-2}, log(x+1) transformed) as a measure of maximal drought stress.
- Artifical surfaces proportion cover, as *A. adenophora* may have a preference for urban areas and transport infrastructure
- Grasslands proportion cover as pasture is a preferred habitat of the species.
- Forests proportion cover as a preferred habitat.

- River length inside the grid cell (km, log(x+1) transformed) derived from the hydroRIVERS dataset (Lehner & Grill, 2013) as riverbanks are a preferred habitat. This database includes all global rivers with a catchment area ≥10 km^2 or average river flow ≥0.1 m^3/sec, so misses some smaller rivers and streams which provide habitat for *A. ageratina* in Europe.
- Road density (m km^{-2}, log(x+1) transformed) derived from The Global Roads Inventory Project (GRIP) dataset (Meijer *et al.*, 2018) as disturbed roadsides are a preferred habitat.
- Standard deviation of elevation (topo_sd, log(x+1) transformed) as a measure of the availability of microclimates such as warm valley floors in an on overall very cold grid cell. It was expected that the species might occur in seemingly unsuitable grid cells where there was a lot of topographic variability, such as around the Himalayas.

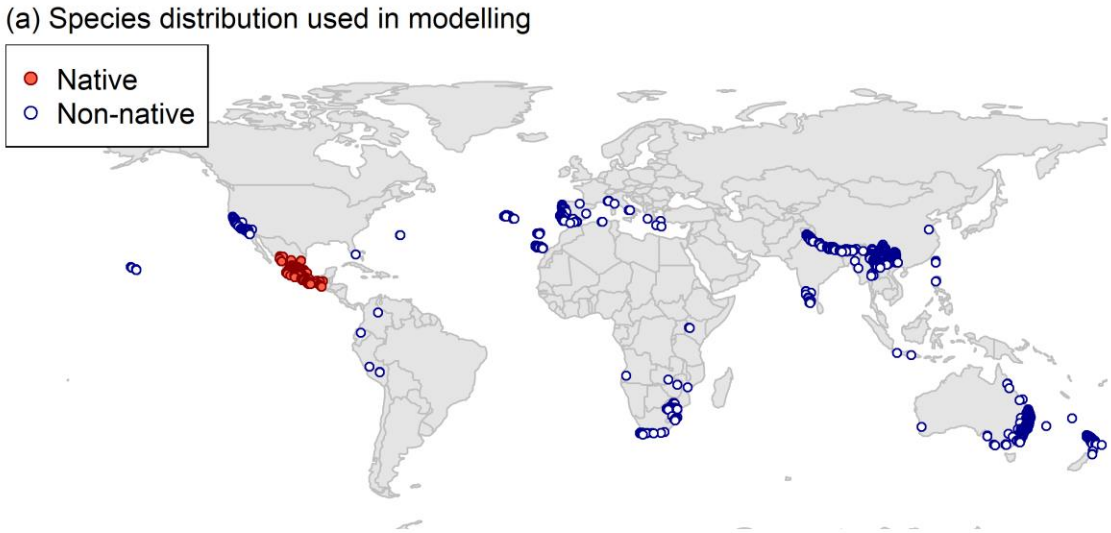
To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for 2041-2070 were obtained for two IPCC Coupled Model Intercomparison Project 6 (CMIP6) scenarios or Shared Socioeconomic Pathways (SSPs) (IPCC, 2021):

- 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.

However, future projections for solar radiation were not available so current levels were used in the model predictions. While the amount of incoming solar radiation will not change, changes in cloud cover and other factors may affect the ground-level irradiance.

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



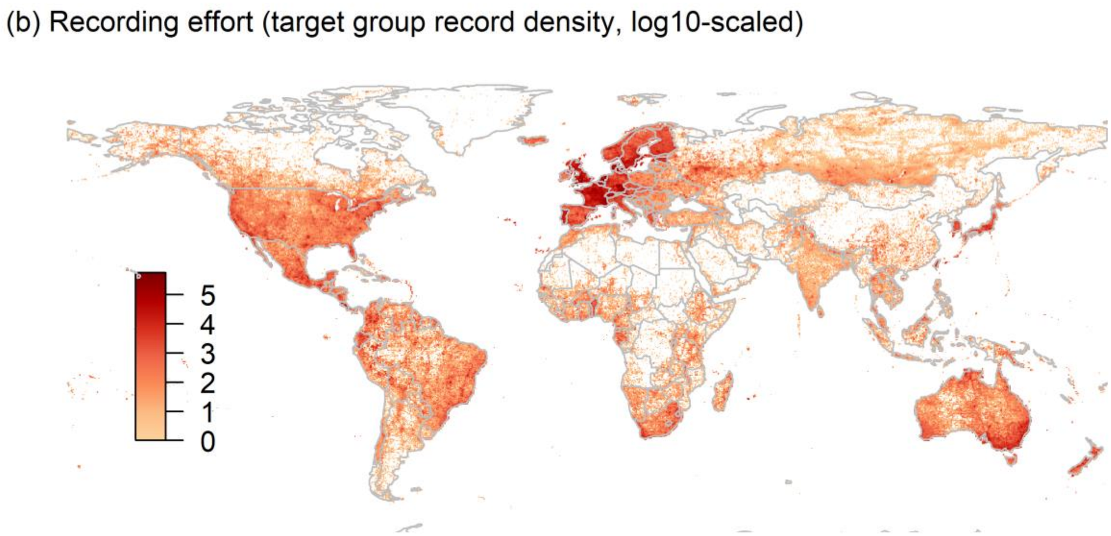


Figure 1. (a) Occurrence records used for modelling *Ageratina adenophora*, showing the native and non-native records. (b) A proxy for recording effort – the number of post-1970 vascular plant records held by the Global Biodiversity Information Facility, displayed on a $\log_{10}$ scale.

Species distribution model

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

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

- An **<u>accessible background</u>** includes places close to *A. adenophora* 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 **<u>unsuitable background</u>** 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:
    - Minimum temperature of the coldest month (bio6) < -2 °C, presumed too cold for survival through winter; OR
    - Minimum temperature of the coldest month (bio6) > 20 °C, presumed too warm for seed germination in the subsequent spring; OR
    - Mean temperature of the warmest quarter (bio10) < 10 °C, presumed too cold for growth or seed germination; OR
    - Mean monthly solar radiation < 11 MJ m-2 d-1, presumed too low irradiance; OR
    - Precipitation of the warmest quarter (bio18) < 6 kgm^{-2}, presumed too dry; OR
    - Precipitation of the coldest quarter (bio19) <16 kg m^{-2}, presumed too dry

Of the 1360 occurrences, 49 (3.6%) fell in the unsuitable background, which is quite high but mainly reflected records in grid cells with very high topographical variability.

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

- From the **accessible background** 1360 samples were drawn, which is the same number as the occurrences. Sampling was performed with realistic recording bias using the target group approach (Phillips, 2009) in which sampling was weighted by GBIF 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 and balanced the presences and background points within the main environmental range of the samples.

- 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.

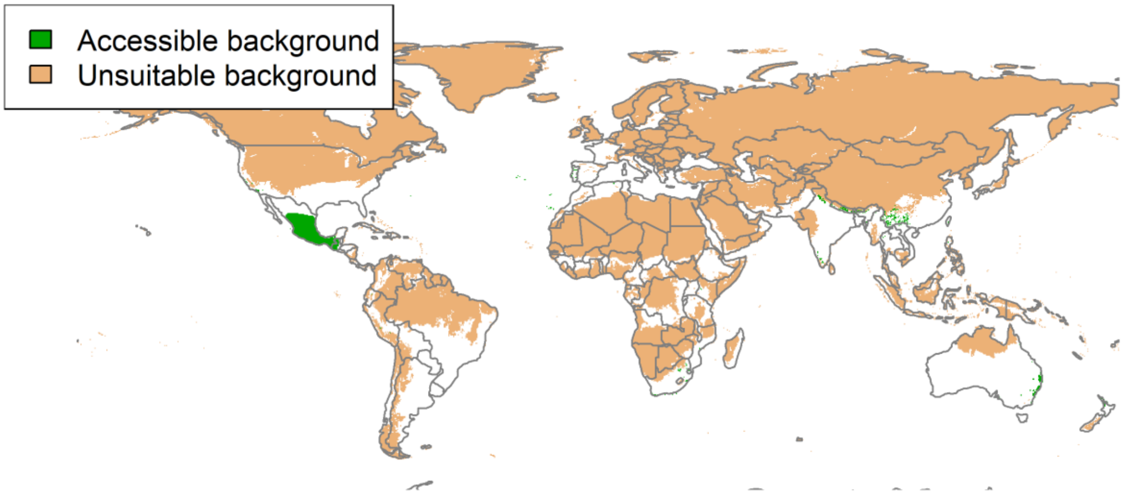


Figure 2. The background regions from which 'pseudo-absences' were sampled for modelling. The accessible background is assumed to represent the range of environments the species has had chance to sample. The unsuitable background is assumed to be environmentally unsuitable for the species.

Using these data, a presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.4.6 (Thuiller *et al.*, 2009, 2016). Each dataset (presences and the five individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, seven statistical algorithms were fitted with the default BIOMOD2 settings (except where specified below) and rescaled using logistic regression:

- Generalised linear model (GLM) 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)
- Maxnet, i.e. the implementation of Maxent (Phillips *et al.*, 2008) in the maxnet R package (Phillips, 2022).

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 $z < -1$ 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 a threshold that ensured a required sensitivity of 0.95 (i.e. predicting 95% of occurrence locations as suitable).

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 *A. adenophora* at the global scale and resolution of the model was most strongly limited by climate rather than by habitat variables (Table 1). The strongest limiting factor was winter minimum temperature (bio6) and there were also relatively strong contributions of solar radiation, summer precipitation (bio18), summer temperature (bio10) and winter precipitation (bio19) (Table 1, Figure 3). As expected topographic variability (topo_sd) increased suitability, though this effect appeared relatively weak.

Global projection of the ensemble model in current climatic conditions used a threshold suitability of 0.53 (giving sensitivity of 95%) and producing the map in Figure 4.

The native region in Mexico was well delineated, though with a prediction for some further occurrence in mountainous regions to the north and south of the known occurrences (Figure 4). The model suggested that the southern native distribution limit was mainly limited by high winter temperature (bio6), while high summer temperature limited the northern edge of the native range (Figure 6a).

Beyond the native region, the currently invaded areas in North America, Africa, Asia, Australia and New Zealand were well defined by the model (Figure 4). The model also predicted substantial climatically suitable areas in uninvaded areas of east Asia (China), South America (Brazil to Argentina), southeast USA and southern and eastern Africa (Figure 4).

In the EPPO region, the model predicts a climatically suitable area around most of the Mediterranean coast, except for the most arid parts (e.g. North Africa, southern Turkey, eastern Italy). Suitability is also predicted for frost-free parts of the Black Sea and Atlantic coastline, with pockets of marginal suitability as far north as southwest UK. Frost-free inland areas in Portugal, southern France, Italy (Sardinia and Siciliy) are also predicted to be climatically suitable. The currently invaded islands of Macaronesia are also predicted to be highly suitable.

The model suggests the main limiting factor in inland Europe is low winter temperature (low bio6), while summer drought stress (low bio18) is more important in unsuitable areas of the Mediterranean, Middle East and north Africa (Figure 6b). Low irradiance is predicted to limit suitability in northwest Europe.

Predictions of the model for 2041-2070, under the moderate SSP1-2.6 climate change scenario and the more extreme SSP3-7.0 scenario (Figures 7 and 8) suggests that reduced frost allows a modest potential for range expansion in inland parts of western Europe (especially southern France, Italy, northwest Spain). These projections used current levels of ground-level solar radiation, so may underestimate the magnitude of northwards spread in western Europe should climate change cause increases in radiation. In addition, more severe summer drought is projected to reduce suitability around the Mediterranean coastline (Figure 7 and 8).
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 Macaronesia and Mediterranean regions, with smaller suitable areas in the Atlantic and Black Sea regions. By 2041-2070, overall suitability slightly reduces in Macaronesia and Mediterranean, but increases in Atlantic and Black Sea regions (Figure 9).

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

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 in Mexico.
- Previous studies have made similar global projections using different modelling approaches and suites of predictor variables (Changjun *et al.*, 2021). Both that study and this one emphasised the importance of winter temperature. Nevertheless, there is uncertainty about which projection is more correct that cannot be resolved without additional information.
- It is possible that our model over-represents spread into northern Europe in current and future climates (e.g. coasts of UK and Ireland) (Changjun *et al.*, 2021). These areas are relatively frost free and have similar or slightly lower summer temperatures to the coolest locations where *A. adenophora* is well established (e.g. San Francisco, and high elevation occurrences in the Himalayas), according to the CHELSA database used in the modelling. However, the models ability to capture the low temperature niche response of the species might have been impeded by topographic heterogeneity in some of these areas and artefacts of coastal temperatures. Furthermore it is possible that other factors not considered in the modelling such as photoperiod, low solar radiation or edaphic factors might limit occurrence at higher latitudes.
- To determine the suitable area, a threshold was set to ensure 95% sensitivity (i.e. 95% of occurrences predicted as suitable). This threshold was chosen as it does not rely on the background pseudo-absences, but a choice of other threshold methods would have led to different predictions of the suitable area.
- To reduce the impact of spatial recording bias, the selection of the background sample was weighted by the density of vascular plant records on the Global Biodiversity Information Facility (GBIF). 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 occurrence data sources to GBIF were used.

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, normalised to sum to 100%.

Algorithm	**AUC**	**In the ensemble**	**Variable importance**											
			Minimum temperature of coldest month (bio6)	**Mean temperature of warmest quarter (bio10)**	**Mean solar radiation**	**Precipitation of warmest quarter (bio18)**	**Precipitation of coldest quarter (bio19)**	**Precipitation of driest month (bio14)**	**Artificial cover**	**Grassland cover**	**Forest cover**	**River length**	**Road density**	**Topographic variability**
GBM	0.9324	yes	67.7	10.4	10.2	3.3	7.2	0.2	0.0	0.1	0.1	0.0	0.1	0.7
MAXNET	0.9278	yes	57.0	1.9	16.0	6.2	8.1	3.7	0.6	1.3	0.7	1.7	0.3	2.6
GLM	0.9226	yes	44.1	9.7	11.8	11.1	11.3	5.1	0.7	0.5	1.3	2.0	0.9	1.6
MARS	0.9212	yes	73.2	4.0	5.6	6.9	2.9	3.4	0.1	0.0	0.5	1.5	0.0	1.9
GAM	0.9172	yes	46.8	8.2	16.8	11.3	4.2	3.4	1.3	0.8	0.6	2.2	3.8	0.6
ANN	0.8972	no	47.7	2.2	4.1	8.0	5.8	4.5	1.9	1.3	0.2	2.9	9.0	12.3
RF	0.8962	no	54.5	7.3	7.3	7.9	3.4	2.6	2.8	2.2	2.0	1.6	3.6	4.8
Ensemble	0.9282		56.4	6.9	12.4	8.1	6.8	3.3	0.6	0.6	0.7	1.6	1.1	1.5

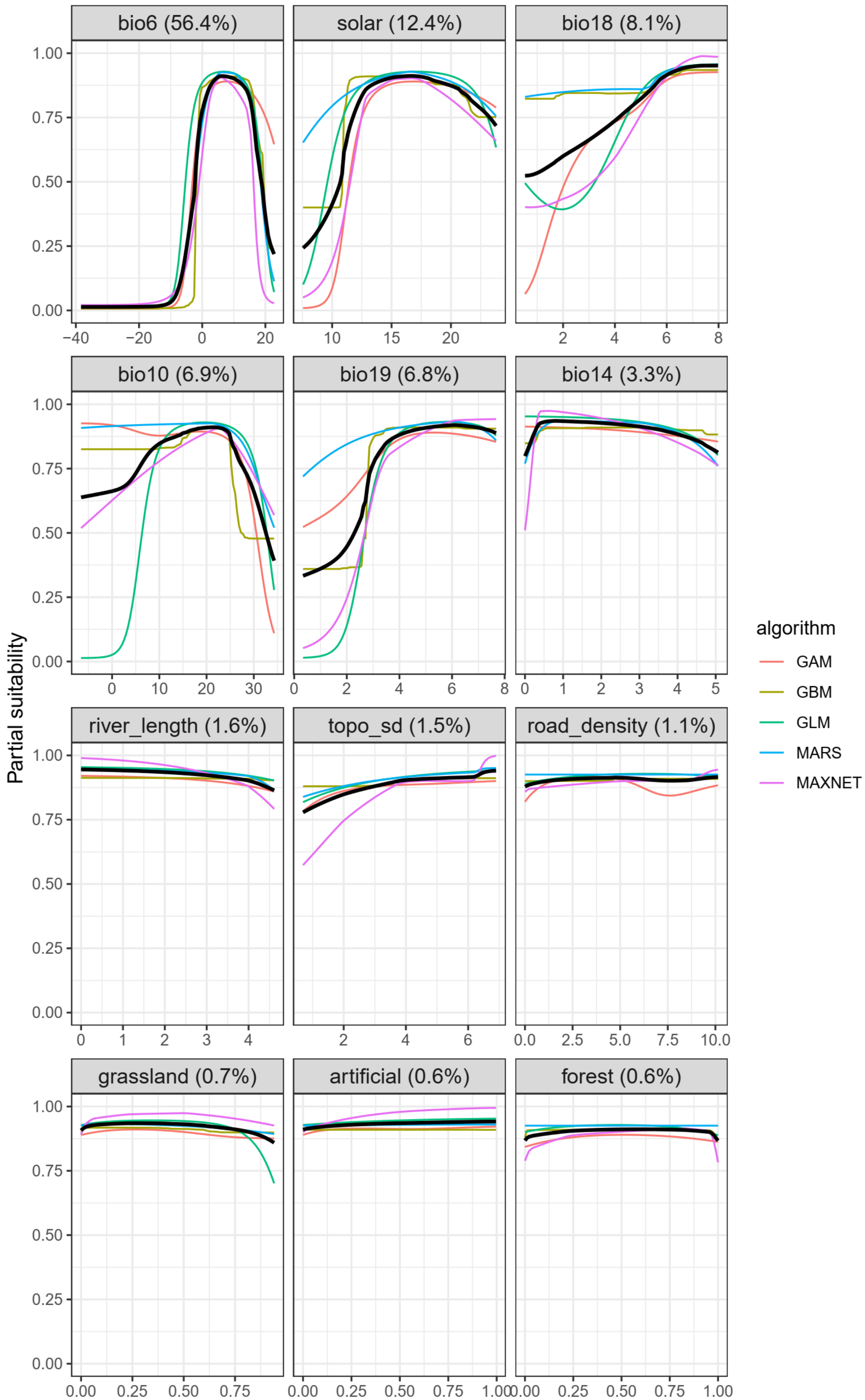


Figure 3. Partial response plots from the individual algorithms and ensemble model (thick black lines), ordered from most to least important. In each plot, other model variables are held at their median value in the training data. Variable codes are as in Table 1.

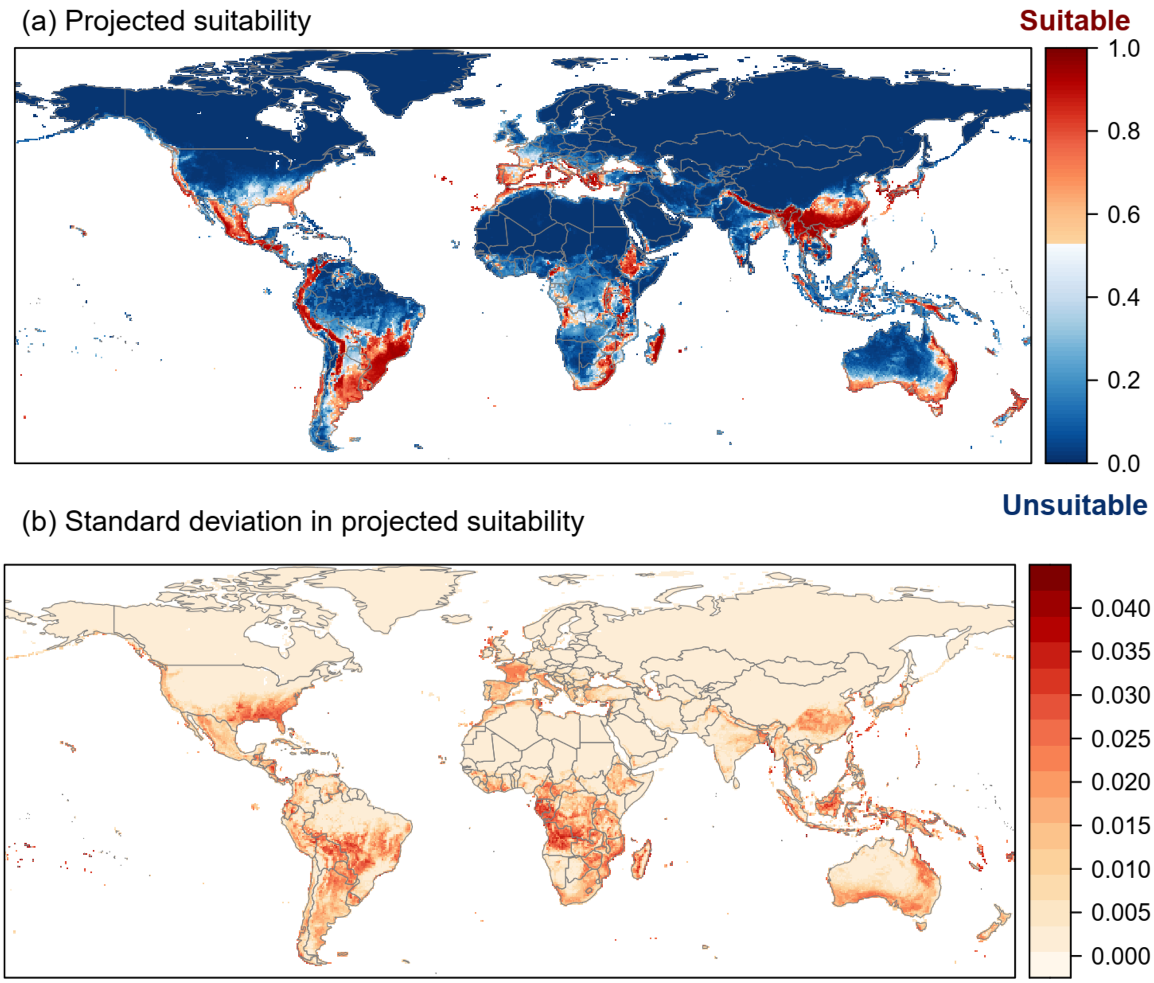


Figure 4. (a) Projected global suitability for *Ageratina adenophora* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Red shading indicates suitability, 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.

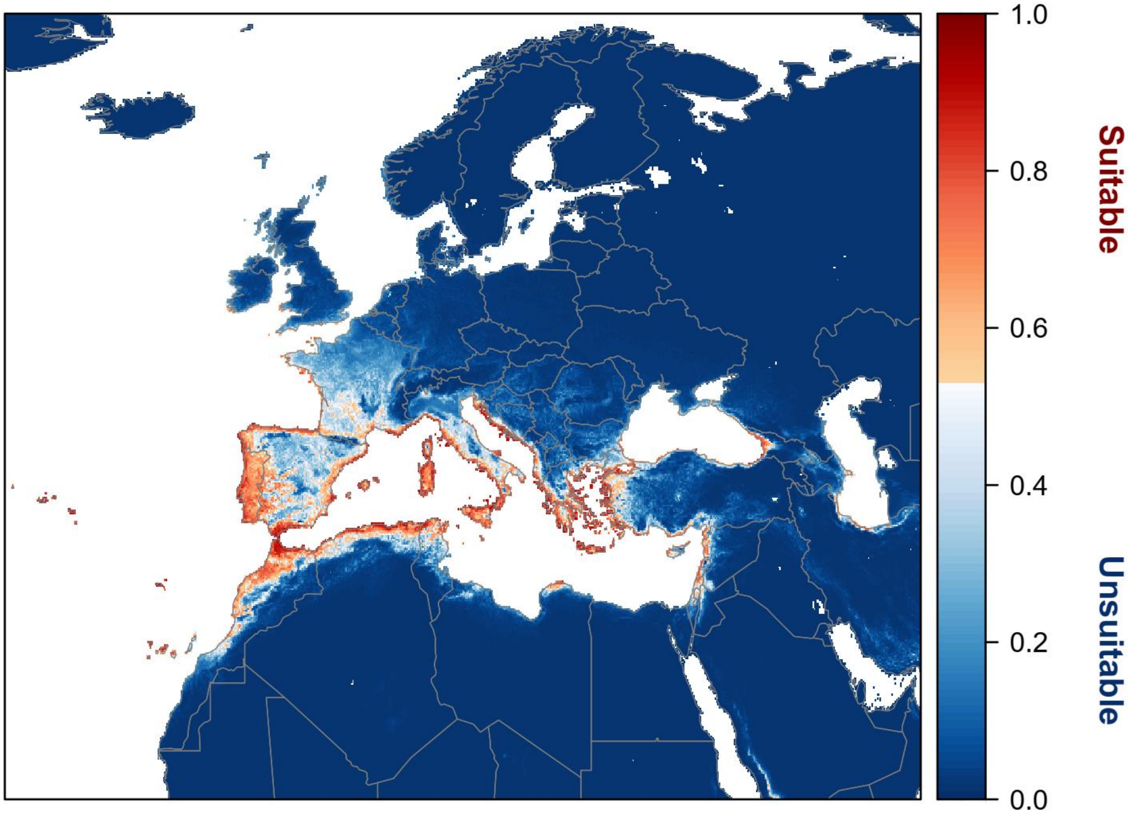


Figure 5. Projected current suitability for *Ageratina adenophora* establishment in Europe and the Mediterranean region. The white inland areas are areas with climate conditions beyond the ranges used in the model fitting, so no projections are made for those areas.

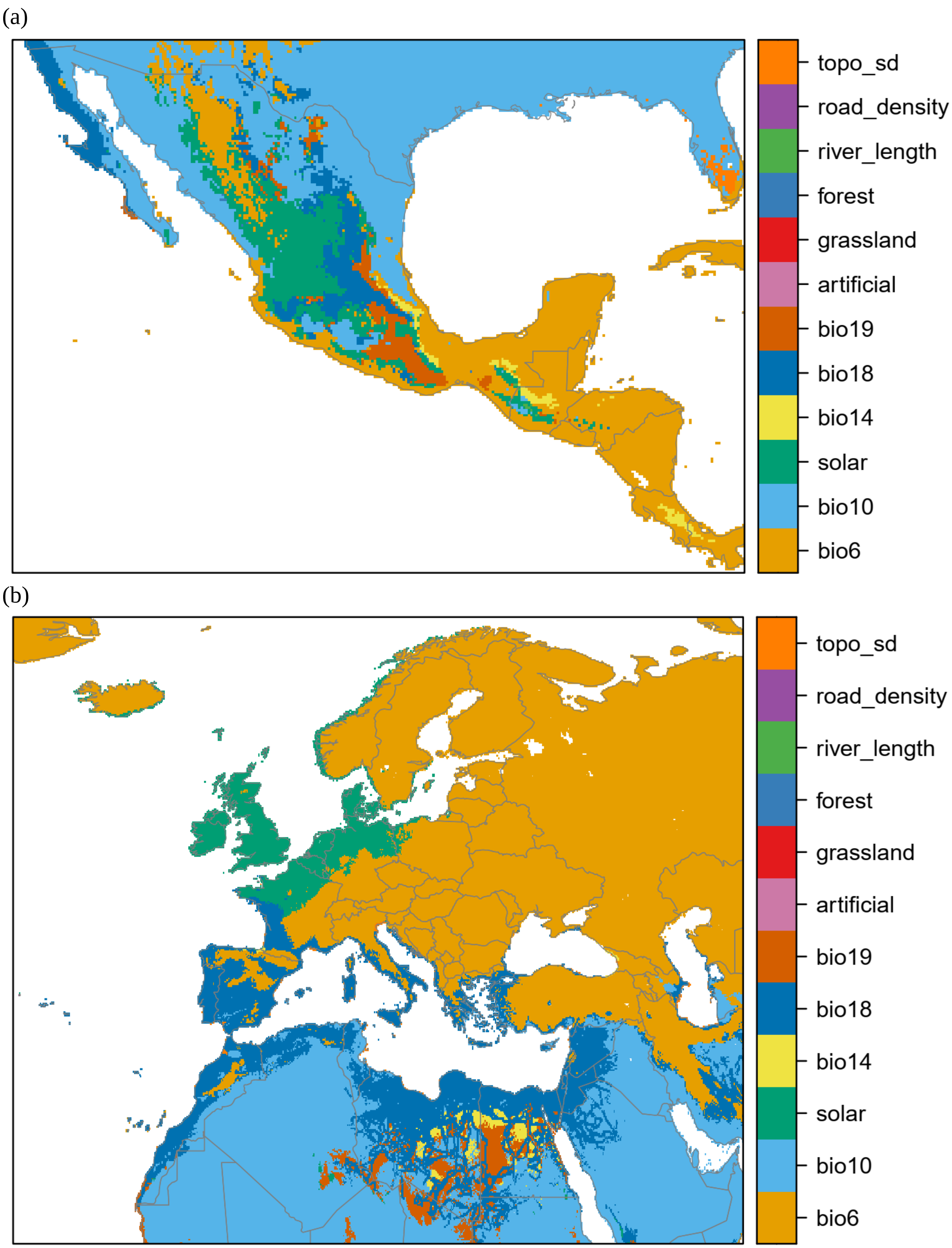


Figure 6. Limiting factor maps projected by the model for *Ageratina adenophora* in (a) the native North American region and (b) Europe and the Mediterranean region, under the current climate and land use. Colours show the variable most strongly limiting suitability.

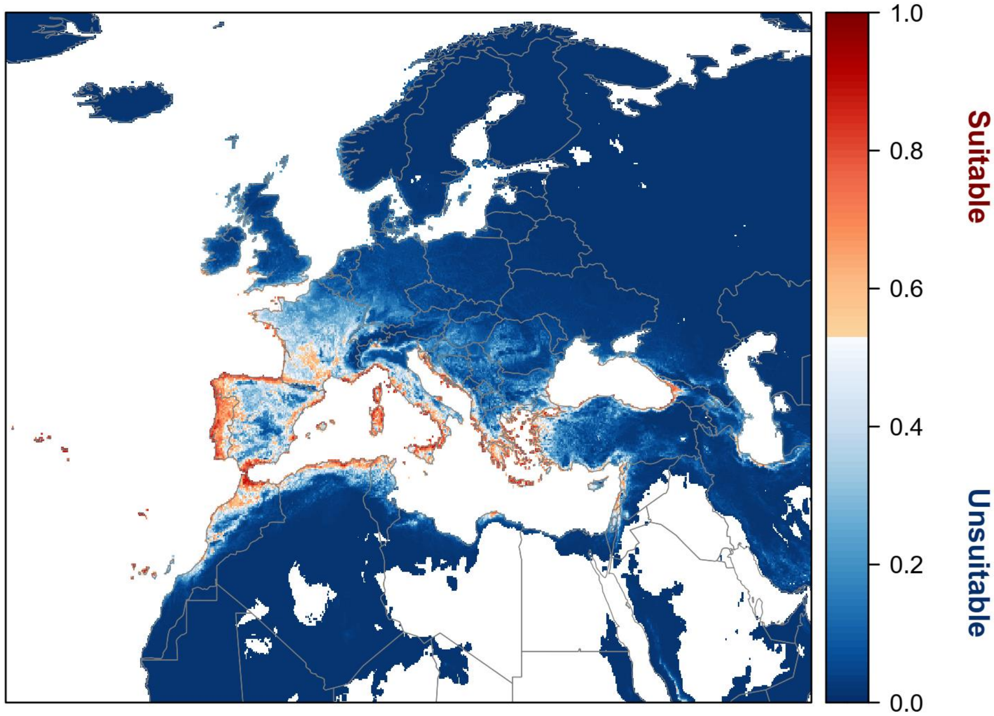


Figure 7. Projected suitability for *Ageratina adenophora* establishment in Europe and the Mediterranean region for 2041-2070 under climate change scenario SSP1-2.6.

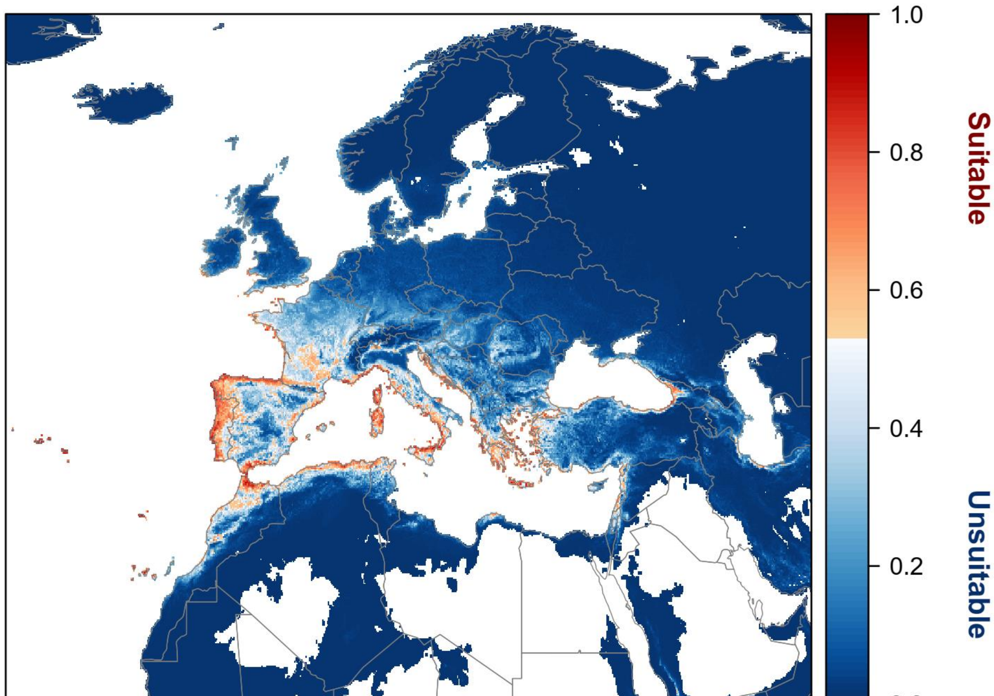


Figure 8. Projected suitability for *Ageratina adenophora* establishment in Europe and the Mediterranean region for 2041-2070 under climate change scenario SSP3-7.0.

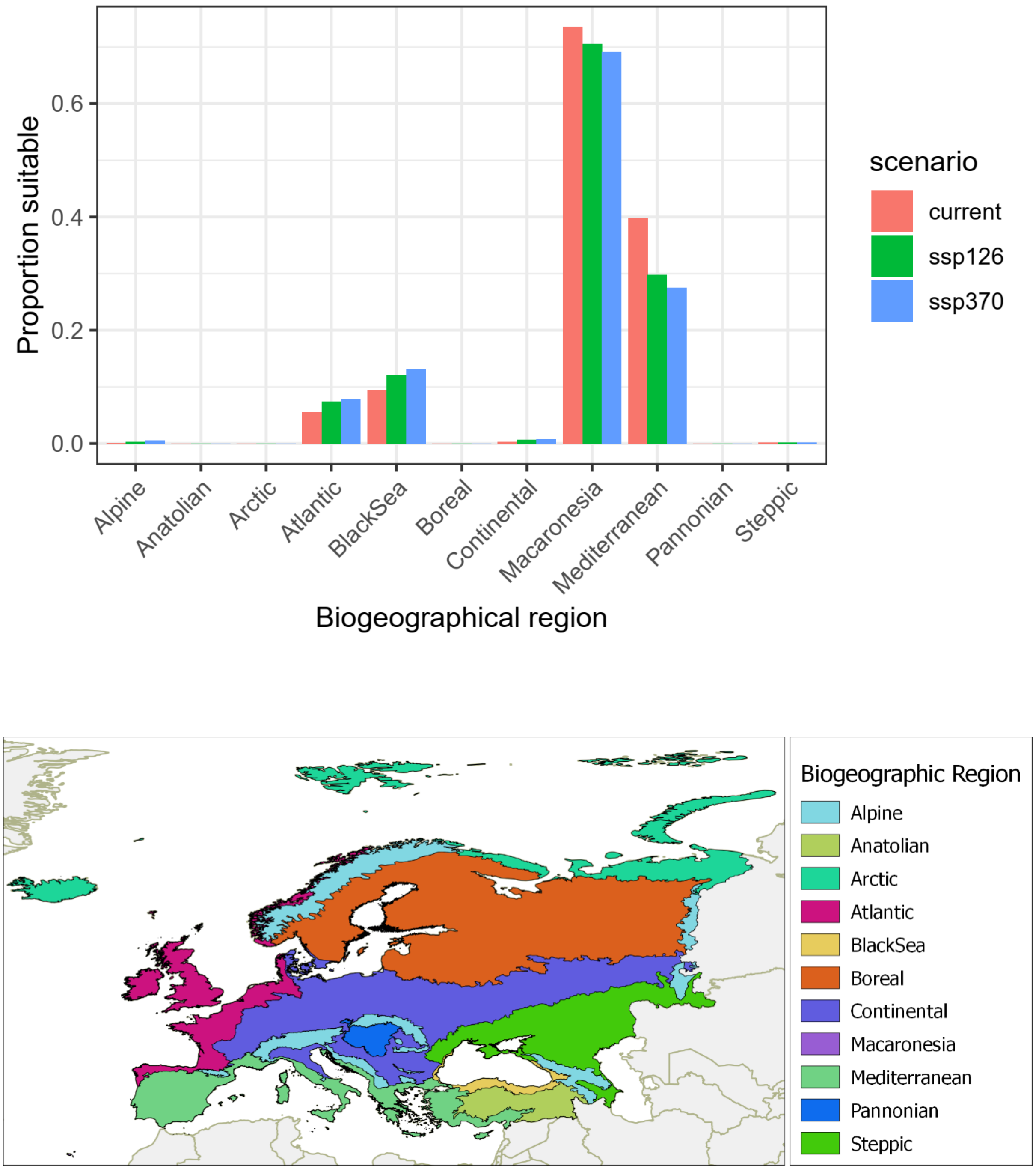


Figure 9. Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). Bar plots show the proportion of grid cells in each region classified as suitable in the current climate (1981-2010) and projected climate for 2041-2070 under scenarios SSP1-2.6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

Table 2. Projected % climatic 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
GGY	100%	100%	100%	AUT	0%	0%	0%
JEY	100%	100%	100%	BEL	0%	0%	0%
MLT	100%	0%	0%	BLR	0%	0%	0%
PRT	97%	83%	75%	CHE	0%	1%	2%
GRC	48%	40%	39%	CZE	0%	0%	0%
CYP	41%	12%	9%	DEU	0%	0%	0%
ESP	34%	25%	25%	DNK	0%	0%	0%
ITA	32%	27%	26%	EST	0%	0%	0%
ALB	23%	14%	11%	FIN	0%	0%	0%
MAR	19%	11%	9%	HUN	0%	0%	0%
HRV	16%	15%	16%	IRL	0%	0%	0%
ISR	15%	7%	3%	KAZ	0%	0%	0%
TUN	14%	8%	7%	KGZ	0%	0%	0%
GEO	12%	13%	13%	LTU	0%	0%	0%
MNE	9%	7%	9%	LUX	0%	0%	0%
FRA	9%	13%	14%	LVA	0%	0%	0%
TUR	7%	4%	4%	MDA	0%	0%	0%
DZA	3%	2%	2%	MKD	0%	0%	0%
AZE	2%	1%	0%	NLD	0%	0%	0%
BIH	2%	2%	2%	NOR	0%	0%	0%
SVN	2%	3%	3%	POL	0%	0%	0%
JOR	1%	0%	0%	ROU	0%	0%	0%
BGR	0%	0%	0%	SRB	0%	0%	0%
GBR	0%	0%	0%	SVK	0%	0%	0%
UKR	0%	0%	0%	SWE	0%	0%	0%
RUS	0%	0%	0%	UZB	0%	0%	0%