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

# Pest Risk Analysis for

# *Celastrus orbiculatus*

Zigmantas Gudzinskas – EPPO Global Database (EPPO Code: CELOR)

EPPO Technical Document No. 1084
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The risk assessment follows EPPO standard PM 5/5(1) *Decision-Support Scheme for an Express Pest Risk Analysis* (available at http://archives.eppo.int/EPPOStandards/pra.htm), as recommended by the Panel on Phytosanitary Measures. Pest risk management (detailed in appendix 1) was conducted according to the EPPO Decision-support scheme for quarantine pests PM 5/3(5). The risk assessment uses the terminology defined in ISPM 5 *Glossary of Phytosanitary Terms* (available at https://www.ippc.int/index.php).

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**Based on this PRA, *Celastrus orbiculatus* was added to the EPPO A2 List of pests recommended for regulation as quarantine pests in 2021. The following measures are recommended: prohibit the import of plants for planting (including seed and bonsai).**

# Pest Risk Analysis for *Celastrus orbiculatus*

**PRA area:** EPPO region
**Prepared by:** EWG on ***Celastrus orbiculatus***

**Date:** 18 - 21 January and 2 – 4 February 2021
Further reviewed and amended by EPPO core members and Panel on Invasive Alien Plants

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

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

Ratings of likelihoods and levels of uncertainties were made during the meeting. These ratings are based on evidence provided in the PRA and on discussions in the group. Each EWG member provided a rating and a level of uncertainty anonymously and proposals were then discussed together to reach a final decision. Such a procedure is known as the Delphi technique (Schrader et al., 2010).

Following the EWG, the PRA was further reviewed by the following core members: Ms Petter (EPPO), Mr Picard (EPPO) and Ms Suffert (EPPO).

The PRA was reviewed and amended by the EPPO Panel on Invasive Alien Plants on 2021-05. EPPO Working Party on Phytosanitary Regulation and Council agreed that *C. orbiculatus* should be added to the A2 Lists of pests recommended for regulation as quarantine pests in 2021.

**Contents**

**Summary** of the Express Pest Risk Analysis for *Celastrus orbiculatus*

**PRA area:** EPPO region in 2021 (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 that the endangered area is predominantly woodland and forest habitats in central, eastern and northern Europe (excluding the far north), and a smaller suitable region in Georgia and southern Russia. In addition, coastal habitats, grassland and heathland in the vicinity of woodland or forests colonised by *C. orbiculatus* are also endangered and the impact on biodiversity may be larger due to the endangered status of areas within these habitats. The EWG considered the species distribution modelling conducted as part of this PRA (see Appendix 2) to be a realistic projection of the potential occurrence of *C. orbiculatus* in the EPPO region.

**Main conclusions**

Although the likelihood of entry of *C. orbiculatus* into the EPPO region via imported plants for planting is low with a high uncertainty, *C. orbiculatus* is already produced and widely available in trade within the EPPO region and occurs in parks and gardens throughout the EPPO region.

*Celastrus orbiculatus* is established in limited areas of the EPPO region. Potential habitats that *C. orbiculatus* can invade are widespread and include disturbed or managed habitats (e.g. harvested forests), transportation networks (e.g. verge of railway tracks, roadsides and habitats under powerlines) and natural habitats (e.g. forests and woodlands and adjacent grassland and heathland). Further establishment is likely because the species can tolerate a wide range of climatic and other abiotic factors. Where conditions are suitable, the likelihood of further establishment outdoors is very high with low uncertainty. Likelihood of establishment in protected conditions is very low with a low uncertainty, as management practices within protected conditions would prevent establishment. The potential for spread within the EPPO region is high with a moderate uncertainty. *C. orbiculatus* can spread both naturally (e.g. seed via mammals and birds) and with human assistance.

The magnitude of impact in the current area of distribution is moderate with a moderate uncertainty. In North America, *C. orbiculatus* threatens natural habitats, and the species can act locally as an ecosystem engineer by transforming the structure of habitats and supressing native species with its dense thickets. *C. orbiculatus* can reduce tree growth and regeneration which can have a negative impact on timber production in forests. The EWG consider that potential impact in the PRA area will be largely the same as in the current area of distribution but with an increased uncertainty. Direct impact studies and/or comparative studies are lacking, however, taking a precautionary approach, the increased uncertainty indicates the risk may be higher than that of the current area of distribution.

Due to the wide availability of the species in the EPPO region already, the overall risk of the species is not strongly influenced by further entry.

| | | | |
|---|---|---|---|
| **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 ☐ | **Moderate** X | Low ☐ |
| **Level of uncertainty of assessment**<br>(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:***

The EWG recommend the following aspects for consideration:

- Perform surveys to determine the extent of occurrences in the EPPO region,
- Include *C. orbiculatus* as a species to be surveyed in citizen science programmes (Good identification guides must be provided to avoid misidentifying specimens (see 2.2.1)),
- Suggest alternatives to key stakeholders for decoration and planting (e.g. *Euonymus europaeus* and *Euonymus verrucosus, Ilex aquifolium),*
- Inform RPPOs and/or specific countries where *C. orbiculatus* has the potential to have negative impacts outside of the EPPO region,
- Conduct additional research on impacts in different habitats,
- Conduct additional research on patterns of monoecy vs dioecy within the EPPO region, Conduct research on biological control options.

**EPPO Pest Risk Analysis:**

# *Celastrus orbiculatus* Thunb.

## Stage 1. Initiation

**Reason for performing the PRA:**

In the USA, *Celastrus orbiculatus* is considered a significant weed where it negatively impacts native species, natural vegetation succession and forest regeneration (Fike & Niering, 2009). In the EPPO region *Celastrus orbiculatus* was first observed in in 1863 in horticulture in the Netherlands. The first records of the species in the natural environment were recorded in Germany in the 1950's (Stadler & Walther, 1970). It is now recorded as established in 15 EPPO countries (EPPO, 2020). In the EPPO region, *C. orbiculatus* has shown an increase in occurrence in the last 30 years where it is recorded as occurring in the natural environment (Gudžinskas *et al*., 2020; Alberternst & Nawrath, 2018). Tanner *et al*. (2017) prioritised 37 alien plant species including *C. orbiculatus* for risk assessment in the European Union (EU). The conclusion was that *C. orbiculatus* was a priority for a risk assessment (RA) based on the high spread potential, potential for establishment (up to 77 % of the EU) and potential for negative impacts (high potential for impacts on native plant species and a potential medium impact on ecosystem functions and services). The Netherlands conducted a RA on the species for the EU where the total risk score was medium (Beringen *et al*., 2017). In 2020, the EPPO Panel on Invasive Alien Plants prioritised *C. orbiculatus* for an EPPO pest risk analysis (PRA). The Panel considered that *C. orbiculatus* has the potential for further spread within the EPPO region, and therefore there is potential for wider impacts on biodiversity and ecosystem services. The Panel also noted that *C. orbiculatus* remains available for sale within the EPPO region.

**PRA area:**

EPPO region in 2021: 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 and nomenclature:

Kingdom: *Plantae,* Division: *Magnoliophyta,* Class: *Angiospermae,* Order: *Celastrales,* Family: *Celastraceae,* Genus: *Celastrus,* Species: *orbiculatus,* Authority: Thunb.

The valid name was published by Thunberg, Carl Peter in the Murray, Johan Andreas's book *Systema Vegetabilium*,14th Edition, at page 237, in 1784)[1]. For this reason, it can be indicated also as *Celastrus orbiculatus* C.P.Thunberg *ex* A.Murray.

**EPPO code:** CELOR

**Synonyms:**
According to PoWO (2020), the following names are synonyms: *Ilex leucantha* Hassk., *Catha articulata* (Thunb.) G.Don, *Celastrus articulatus* var. *orbiculatus* (Thunb.) C.H.Wang, *Celastrus crispulus* Regel, *Celastrus insularis* Koidz., *Celastrus jeholensis* Nakai, *Celastrus lancifolius* Nakai, *Celastrus strigillosus* Nakai, *Celastrus tatarinowii* Rupr., *Celastrus versicolor* Nakai. According to the Flora of China, the following names are synonyms *C. articulatus* var. *pubescens* Makino; *C. oblongifolius* Hayata

**Common name:**

English: Asian bittersweet, Asiatic bittersweet, climbing spindle berry, Chinese bittersweet, round-leaved bittersweet, staff vine, oriental bittersweet; Chinese: nán shé téng, 南蛇藤; Czech: jesenec okrouhlolistý; Dutch: boomwurger. French: bourreau des arbres, célastre orbiculaire; German: Rundblättriger Baumwürger; Hungarian: keleti fafojtó; Japanese: tsurûmemogoki, ツルウメモドキ; Korean: no bak deong gul, 노박덩굴; Russian: древогубец круглолистный; краснопузырник трубчатолистный; Slovak: zimokeř okrouhlolistý (EPPO, 2020).

**Plant type:** Deciduous woody vine (the form can vary between vine and shrub)

**Related species in the EPPO region:**
*Celastrus* L. is a genus of approximately 30 – 40 twining shrub species native to tropical and warm-temperate regions (Asia, Australia and North and South America).

The European Garden Flora (2011, Vol IV) lists a total of six *Celastrus* species that have been commonly traded in horticulture notably *C. angulatus, C. scandens, C. glaucophyllus, C. hypoleucus, C. orbiculatus, C. rosthornianus.* There is no additional information on *Celastrus* species in horticulture in the EPPO region. Excluding *C. orbiculatus*, only *C. scandens* is reported locally in the natural environment in the EPPO region.

### 2. Pest overview

### 2.1 Introduction

It should be noted that *C. orbiculatus* has been studied in detail in the USA (numerous references) and in a recent publication from Lithuania (Gudžinskas *et al*., 2020). Publications from these countries are used throughout the PRA and additional publications are referenced from other countries where available.

*Celastrus orbiculatus* is a deciduous woody vine that climbs by means of twining about a support. Cane-forming stems are located just above the ground and liana-forming stems are in the canopy layer where it climbs through the tree trunk and branches (Gudžinskas *et al*., 2020).

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[1] Murray's Syst. veg. ed. 14 was received in July 1784 and has priority over Thunberg's Flora Japonica, publ. 9 Aug 1784, "erhalten wir eben". Source: https://www.tropicos.org/home. In fact, Ding Hou (1955), in his revision on the genus *Celastrus*, erroneously considered as valid the name *C. orbiculatus* Thunb. Fl. Jap. pp. xlii, 97, 1784 (*errore* "*articulatus*").

## 2.2 Identification

### 2.2.1 Morphology of *Celastrus orbiculatus*

Appendix 1 includes images of the plant. Further images can be found in EPPO Global Database https://gd.eppo.int/taxon/CELOR.

Both Chinese and North American morphological descriptions have been given as the species could be imported from both regions.

The following information on morphology of *C. orbiculatus* has been taken from the Flora of China (efloras.org, 2020) and Hou (1955).

"Deciduous twining shrubs, up to 10 or 18 m tall; branchlets glabrous, gray- brown or brown, with sparse and inconspicuous lenticels; axillary buds small, ovate to elliptic, 1-3 mm. Petiole slender, 1-2 cm; leaf blade generally broadly ovate, suborbicular, or rectangular-elliptic, 5-13 × 3-9 cm, glabrous or abaxially sparsely pubescent on veins, base broadly cuneate to obtuse-orbicular, margin serrate, apex broadly rounded, muriculate, or shortly acuminate; secondary veins 3-5 pairs. Inflorescences (cymes) axillary, sometimes terminal, 1-3 cm, 1-7-flowered; pedicels jointed below middle or nearly to base. Male flowers: sepals obtuse-triangular; petals obovate-elliptic to rectangular, 3-4 × 2-2.5 mm; disk shallowly cupuliform, lobe shallow, apex rounded-obtuse; stamens 2-3 mm. Female flowers: corolla relatively shorter than that of male flower; disk slightly thick, carnose; staminodes very short; ovary approximately globose; styles ca. 1.5 mm; stigma deeply 3-lobed, lobe apex shallowly 2-lobed. Fruit (capsule) approximately globose, 8-13 mm wide, yellow, 3-valved. Seeds elliptic, slightly flat, 4-5 × 2.5-3 mm, reddish brown; aril orange-red. *Celastrus orbiculatus* has deep and spreading roots which can grow to 2 cm thick." (Hou, 1955)

The following paragraph is adapted from the Flora of North America.

"Vines 40+ m, twining, polygamodioecious. Branchlets terete. Leaves deciduous [persistent], alternate; stipules present; petiole present; blade margins denticulate; venation pinnate; blade suborbiculate to broadly oblong-obovate 4-6 x 3-5 cm, aestivation conduplicate. Inflorescences axillary cymes [racemes] 1-2 cm. Flowers bisexual and unisexual, radially symmetric; perianth and androecium hypogynous; hypanthium absent; sepals 5, distinct; petals 5, white or greenish white; nectary intrastaminal, fleshy. Bisexual flowers: stamens 5, free from and inserted under nectary; staminodes 0; pistil 3-carpellate; ovary superior, 3-locular; placentation axile; style 1; stigmas 3; ovules 2 per locule. Staminate flowers: stamens 5; free from and inserted under nectary; staminodes 0, pollen white; pistillode present. Pistillate flowers: staminodes 5, alternate with petals, undivided, not gland-tipped, minute; pistil 3-carpellate; ovary superior, 3-locular, placentation axile; style 1; stigmas 3; ovules 2 per locule. Fruits capsules yellow when mature, 3-locular, globose, 7-10 mm diam., glabrous, 3-lobed distally, apex not beaked. Seeds [1–]2 per locule, orange, ellipsoid, not winged; aril red, completely surrounding seed. x = 23. 2n = 46." (efloras.org, 2020)

Root surface is deep orange in colour (Bugwood, 2021) (also true of *C. scandens*).

Chromosome number is n=23 (Bowden, 1945).

### 2.2.2 Species with which *C. orbiculatus* can be confused

Misidentification between *C. orbiculatus* and *C. scandens* has occurred where the species grow together (e.g. USA) (Leicht-Young *et al*., 2007; Zaya *et al*., 2017). Leicht-Young *et al*. (2007) and Pavlovic *et al*. (2007) provide a thorough identification tool of *C. orbiculatus* and *C. scandens*. Both species are widely cultivated commercially for their colourful fruits (Hou, 1955; Cullen *et al*., 2011).

### 2.2.3 Molecular identification for the genus *Celastrus*

Molecular methods are available to identify species within the genus (Zhang et al., 2018, Mu et al., 2017).

A molecular analysis of combined nuclear and chloroplast DNA provides reference for molecular identification. This method was used to identify species within *Celastrus* and *Tripterygium* (Mu *et al*., 2017;

Zhang *et al*., 2018). Zaya *et al* (2017) used nuclear microsatellite DNA loci to compare the genetic identities of *C. orbiculatus* and *C. scandens.*

## 2.3 Hybridization

*Celastrus orbiculatus* has been shown to hybridize with *C. scandens* in the USA (Zaya *et al*., 2015). Hybrids show a reduced seed set and small, potentially inviable pollen. However, it should be noted that Pooler *et al.* (2002) crossed *C. scandens* (female parent) with *C. orbiculatus* and found classic hybrid vigour; the resulting plants had less seed dormancy and were more vigorous than progeny of *C. scandens* alone.

Hybrids are not widely reported in the natural environment in the USA. Zaya *et al.* (2015) surveyed *Celastrus* populations over the eastern USA and showed only 4.2 % of populations were identified as hybrids. Pollen flow comes primarily from *C. orbiculatus* because all the hybrids sampled had *C. scandens* as the maternal origin, which may increase decline in the native species by wasting already limited female reproductive effort (Zaya *et al*., 2015). The hybrid may have both lateral and terminal inflorescences but is otherwise difficult to distinguish morphologically from *C. orbiculatus.*

## 2.4 Life cycle

*Celastrus orbiculatus* is a deciduous twining woody vine with the leaves emerging in the spring. It flowers from April in its native range, and from May and June in the northeastern USA and from May and June in the EPPO region. Depending on the habitat, plants can flower after one or two years of growth (Pooler *et al*., 2002). Flowers are frequently functionally unisexual because of abortion or reduction of male or female parts, thus the plants are usually dioecious, sometimes monoecious, though plants develop both unisexual and perfect flowers: polygamo-dioecious (Brizicky, 1964; Gleason and Cronquist, 1991; Burnham and Santana, 2015).

In the USA, *C. orbiculatus* is, in most cases, functionally dioecious and, thus, may require cross pollination. Insect (Brizicky, 1964) and wind pollination (Wyman, 1950) have been documented for this species, suggesting that male and female plants may need to be relatively close for successful cross-pollination. Pollen is shed approximately 24 hours after flowers open (Pooler *et al*., 2002). Fruit and seed mature around late September in the USA with each fruit containing 3 to 6 seeds (Greenberg *et al*., 2001; Hou, 1955).

Gudžinskas *et al*. (2020) showed that only monoecious individuals were present from 12 sampled individuals at 4 populations in Lithuania. In other studies, Verloove (2013) showed that the species rarely flowers in Belgium.

Individual plants that do not reproduce sexually either due to age, plant size, or lack of light are dependent on vegetative reproduction for growth. All individuals have the potential to resprout from aerial buds on branches, basal buds on the root collar or stump, and subterranean buds that permit root suckering if above ground portions are removed (Pavlovic *et al.*, 2011). Small pieces of root left during clearing operations can resprout quickly and may form new plants (Dreyer *et al*., 1987; Ellsworth *et al*., 2004).

## 2.5 Growth rates

*Celastrus orbiculatus* can grow rapidly, possibly up to 3 m/yr (Patterson 1973; McNab and Meekers, 1987). In the USA, studies have shown that growth rates differ compared to the amount of sunlight the plant receives. Ellsworth *et al.* (2004) showed that aboveground biomass 1 year after transplanting was significantly lower in deep shade (2% of full sunlight: 0.3 g) than under 100% full sunlight (9.9 g) or 28% of full sunlight (14.4 g).

*Celastrus orbiculatus* can persist in forest understories in the USA for a number of years and following a disturbance in the canopy (i.e. tree or limb falls causing canopy gaps), rapid growth can occur (Patterson, 1973). *Celastrus orbiculatus* “uses a ‘sit and wait’ invasion strategy” (Greenberg *et al*., 2004).

In the USA, *C. orbiculatus* produces root suckers prolifically, and a single individual can expand to a dense thicket in a relatively short time (Dreyer *et al*., 1987; Ellsworth *et al.*, 2004). Stems may reach up to 5-10 cm in diameter and up to 18 m long (Hutchinson, 1992) (however, efloras.org (2020) indicate 40 m +). This vine may strangle host species, reduce host species' photosynthesis rates, and cause structural damage to the host (Dreyer *et al*., 1987).

Clonal runners may grow up to 2 m/yr; searcher runners (those that seek a structure to attach too) grow less than 1 m/yr (Ichihashi & Tateno, 2015) with more rapid increases in growth likely under higher light conditions (Greenberg *et al*., 2001).

In Lithuania, shoots of *C. orbiculatus* have been recorded reaching the tree canopy layer where the height of the tallest individuals ranged from 10 to 18 m (Gudžinskas *et al*., 2020).

## 2.6 Seed production

Seed production may vary among habitats where open habitats, including canopy gaps, promote abundant fruiting (Webster *et al*., 2006). In 15 sites in Massachusetts, USA, *C. orbiculatus* seed rain averaged 168 seeds/m$^2$, but was highly variable with a range of 13-826 seeds/m$^2$ (Ellsworth *et al*., 2004). In the EPPO region, there is variation in fruit production between areas where the species occurs. This may be caused by functionally dioecious plants in the absence of the other gender.

*Celastrus orbiculatus* has no persistent seed bank (Van Clef & Stiles, 2001) or only a short-lived seed bank (Dreyer, 1994). Van Clef & Stiles (2001) conducted a study in the USA and found that during a 3-year seed bank persistence study of native and non-native congeneric plants, both *C. scandens* and *C. orbiculatus* had negligible germination after the first year. Seed longevity may be longer if seed is buried too deep to germinate under ideal conditions but may germinate later due to soil disturbance and subsequent exposure; such seed longevity has been documented with other invasive plants (Rebbeck & Joliff, 2018).

## 2.7 Seed germination and emergence of seedlings

The overall germination rate of seeds is high. Over 85% germination has been reported in the field and 95 % germination under laboratory conditions (Wendel *et al*., 2008; Dreyer, 1994). Most seeds germinate in the spring and summer months.

A number of sources detail that seed requires a period of cold stratification to aid germination (approx. 5 ºC) (e.g. Greenberg *et al*., 2001; Patterson, 1973). However, this may not be necessary in the natural environment. For example, in USA southern States (e.g. Louisiana), a period of cold may not be required to break seed dormancy but it remains uncertain and scientific studies would be required to confirm if seed production or vegetative growth is the main lifecycle strategy (pers. comm., C. Huebner, 2021).

Seeds can germinate under a wide range of light intensities and this is suggested to aid the species establishment under closed canopies (Greenberg *et al*., 2004). Greenhouse experiments showed no significant difference in germination under 20% sunlight to full sunlight (Greenberg *et al*., 2004). In other studies, germination has been shown to be better under low-light conditions in the greenhouse (Dreyer *et al*., 1987; Patterson 1973).

Seed germination has been shown to increase when seed has moved through the digestive tract of a bird. In a laboratory experiment, seeds ingested by birds, or which had the arils removed manually, had a higher germination rate compared to seeds with intact fruits (Greenberg *et al*., 2004). Similarly, germination rates of seed that had naturally fallen below the parent plant and seed that had been ingested by animals, showed a 51 % germination rate compared to 82 % rate, respectively (Greenberg *et al*., 2001).

In Lithuania, Gudžinskas *et al*. (2020) recorded a density of seedlings and saplings of 8.10 ± 1.94 individuals m$^{-2}$. However, in the Netherlands, in vicinity of a commercial grower of *C. orbiculatus* for cut branches, no seedlings were observed despite the potential high propagule pressure. Thus, sometimes other limiting factors for germination may occur (pers. comm. J van Valkenburg, 2021).

## 2.8 Seed dispersal

In the USA, it has been shown that approximately 24% of seed falls under or near parent plants (Greenberg *et al*. 2001). *Celastrus orbiculatus* seed can be dispersed by birds, mammals, water and humans (Dreyer *et al*., 1987).

The European starling (*Sturnus vulgaris*), which is invasive in North America and native to the EPPO region, disperses the seed of *C. orbiculatus* (La Fleur *et al*., 2009; Robinson *et al*., 1993). Additionally, in North America other frugivorous birds are reported to eat the fruit of *C. orbiculatus* including northern flickers (*Colaptes auratus*), yellow-rumped warblers (*Setophaga coronate*), American robins (*Turdus migratorius*) and other thrushes (Turdidae), mockingbirds and catbirds (Mimidae), and mynas (Sturnidae) (White & Stiles, 1992). Approximately 75% of seed was removed by birds in an oak forest in North Carolina (Greenberg *et al*., 2001).

## 2.9 Environmental requirements

*Celastrus orbiculatus* can tolerate a wide range of soil and other environmental conditions (Leicht-Young *et al*., 2007). Sinclair *et al*. (1987) highlights that the species does not grow well in waterlogged soils.

The species is able to grow slowly in forest understories, foraging for openings in the canopy, and grow rapidly in full sunlight (Leicht & Silander, 2006; Greenberg *et al.*, 2004).

*Celastrus orbiculatus* is recorded to grow from 400 – 2200 m a.s.l. (eflora.org). Others, e.g. Hou (1995) report an altitudinal range of 100-1400 m in the native range, which is supported by Yang *et al.* (2014).

## 2.10 Habitats

In the native range (in China), *C. orbiculatus* is reported to grow in mixed forests, forest margins, and in thickets on grassy slopes (eflora.org, 2021).

In the eastern USA, the following habitats where the species is found, but not limited to, include: mixed-hardwood forests (all successional stages), coniferous forests (all successional stages), forest edges, woodlands, shrublands, oldfields, dunelands-field, duneland, coastal beaches, and tidal freshwater and saltmarsh communities (Wells *et al*., 2000; Merhoff *et al*., 2003; Von Holle & Motzkin, 2007; Kearsley, 1999). Though found in forest systems, a thick litter layer may deter seedling establishment (McNab and Loftis, 2002).

The species clearly benefits from disturbance hence it being commonly found growing along roads and sites disturbed by logging and animal foraging (Ellsworth *et al*., 2004).

In Europe, *C. orbiculatus* has been found in areas close to urban environments and occupying disturbed habitats, but also in natural or semi-natural habitats (Alberternst & Nawrath, 2018; Gudžinskas *et al*., 2020). For example, in Lithuania, Gudžinskas *et al.* (2020) showed that the species invades dry dune woodlands, grasslands, pine, spruce, alluvial and riparian forests.

*Celastrus orbiculatus* uses trees and other vegetation for support for its climbing habit where it twines around support structures. The utilization of trees and other vegetation enables the species to inhabit the upper canopy. In North America, Putz (1995) estimated that *C. orbiculatus* successfully twines around trees with a 15 cm diameter and can infest larger tree by utilizing lower branches of the tree (Robertson *et al*., 1994) and other vegetation in the understory. It can also utilize its own stem as structural support to grow up trees with larger diameters (pers. comm. Z. Gudzinskas, 2021). Stems can also creep along the ground to increase surface area (Leicht & Silander 2006).

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

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

*Celastrus orbiculatus* has been recorded as an host for *Xylella fastidiosa* in North America (EFSA, 2015).

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

## 5. Regulatory status of the pest

In New Zealand *C. orbiculatus* has been regulated as a quarantine pest since 2001. It is included in the Official New Zealand Pest Register (Pest Register for Importing Commodities to New Zealand: https://pierpestregister.mpi.govt.nz/PestsRegister/ImportCommodity/.

In the USA *C. orbiculatus* is not regulated at the federal level although it is regulated in some states (USDA, 2020), specifically:

- Connecticut (invasive, banned noxious weed)
- Maine (prohibited invasive species)
- Massachusetts (prohibited noxious weed)
- New Hampshire (prohibited invasive species)
- New York (prohibited invasive species)
- North Carolina (Class C noxious weed)
- Rhode Island (listed as widespread and invasive, no legal authority)
- Vermont (Class B noxious weed)
- Virginia (Tier 3 noxious weed)

*Celastrus orbiculatus* is not currently regulated in the EPPO region. At the time of writing (February 2021), it is being considered for inclusion on the EU List of invasive alien species of Union concern (Regulation 1143/2014[2]).

### 5.1 **Existing PRAs**

### Europe

A risk assessment has been conducted by the Netherlands (Netherlands Centre of Expertise for Exotic Species (NEC-E) with the risk assessment area being the European Union (Beringen *et al*., 2017). *Celastrus orbiculatus* received a total risk score of *medium* and this score refers to the ecological risks in the EU using the Harmonia and ISEIA protocols (Beringen *et al*., 2017). In Germany, the German-Austrian Black List Information System (GABLIS) was applied and resulted in a classification of at least '*potentially* invasive' (Alberternst & Nawrath, 2018).

### United States of America

A risk assessment was conducted for Minnesota (Minnesota Department of Agriculture, 2016). The outcome of the risk assessment was that *C. orbiculatus* be recommended to list as a prohibited noxious weed and it should be included on the eradication list for Minnesota.

A risk assessment was conducted for Georgia. The outcome of the risk assessment was that the species should not be used in horticulture as it has a high risk of invasiveness (Plant Right, 2017).

Risk assessments were also conducted for the states of Indiana, Illinois, North Carolina, Ohio, and Wisconsin. In all cases *C. orbiculatus* was highlighted as invasive and restrictions should apply (e.g. see Ohio Invasive Plants Council, 2021; Casebere *et al.*, 2003; Trueblood, 2009).

## 6. Distribution

*Celastrus orbiculatus* is native to China. It is also recorded as native in the Korean Peninsula, Japan and the Russian Far East and Sakhalin Island.

*Celastrus orbiculatus* has been introduced into the EPPO region and New Zealand and North America.

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[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1417443504720&uri=CELEX:32014R1143

USDA (2020) record *C. orbiculatus* as present in 25 eastern states. However, 31 states document *C. orbiculatus* as present in at least one county according to EDDMapS (https://www.eddmaps.org/). The current US distribution of the species extends from Maine south to Georgia and west to Iowa (IPSAWG, 2019). Patterson (1973) stated that *C. orbiculatus* had spread to 33 US states, which included California and Washington (all 33 States are detailed in Table 2). POWO (2019) confirmed that the species is present in Washington State. *Celastrus orbiculatus* is also present in Canada in New Brunswick, Ontario, and Quebec (USDA, 2020) and Nova Scotia (CABI, 2020). The likely epicentre may be a plant nursery in Flushing, New York where the owner, Samual Parsons received seed in the 1870s (Del Tredici, 2014).

*Celastrus orbiculatus* was first introduced into New Zealand as a garden ornamental in 1905. Williams and Timmins (2003) detail that *C. orbiculatus* has a localised distribution in New Zealand but it is widely distributed in the northern areas of the North Island.

Beringen *et al.*, (2017) report that *C. orbiculatus* is present in 8 EU countries (Austria, Belgium, the Czech Republic, Germany, the Netherlands, Poland, Sweden, and the United Kingdom) and Gudžinskas *et al*. (2020) record the species in 13 European countries (adding Latvia, Lithuania, Norway, European Russia, and Ukraine to the previous list).

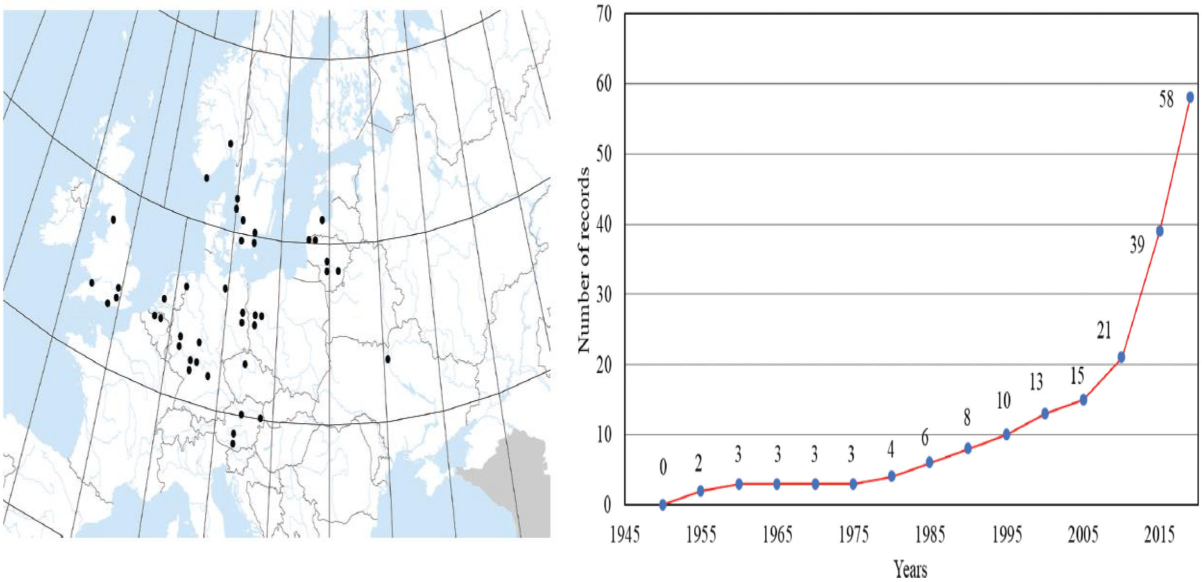

Figure 1: Distribution of *Celastrus orbiculatus* in Europe mapped to the grid of the Atlas Florae Europeae number (left) and the cumulative curve of records for *Celastrus orbiculatus* recorded in Europe (right).

Gudžinskas *et al*. (2020) report that *C. orbiculatus* is present in 58 sites in Europe. The number of records has increased in the EPPO region in recent years (> 2005; Figure 1).

In the EPPO region, *C. orbiculatus* is presently recorded in 15 countries (Table 2). Note that the species may be present in other countries, but then only cultivated, the list of 14 countries includes those where the species has at least been observed as an escaped from cultivation.

An updated distribution map of *C. orbiculatus* is available in Global Database (EPPO, 2021).

**Table 2. Global distribution of *Celastrus orbiculatus***

| Region | Distribution | Status | References and comments |
|---|---|---|---|
| **North America** | | | |
| Canada | New Brunswick | Introduced | USDA (2020) |
| | Nova Scotia | Introduced | USDA (2020) |
| | Ontario | Introduced | USDA (2020) |
| | Québec | Introduced | USDA (2020) |

| **Region** | **Distribution** | **Status** | **References and comments** |
|---|---|---|---|
| United States of America | Alabama | Introduced | EDDMapS (2021) |
| | Arkansas | Introduced | USDA (2020) |
| | Connecticut | Introduced | USDA (2020) |
| | Delaware | Introduced | USDA (2020) |
| | Georgia | Introduced | USDA (2020) |
| | Illinois | Introduced | USDA (2020) |
| | Indiana | Introduced | USDA (2020) |
| | Iowa | Introduced | USDA (2020) |
| | Kansas | Introduced | EDDMapS (2021); Patterson (1973) |
| | Kentucky | Introduced | USDA (2020) |
| | Louisiana | Introduced | EDDMapS (2021); Patterson (1973) |
| | Maine | Introduced | USDA (2020) |
| | Maryland | Introduced | USDA (2020) |
| | Massachusetts | Introduced | USDA (2020) |
| | Michigan | Introduced | USDA (2020) |
| | Missouri | Introduced | EDDMapS (2021); Patterson (1973) |
| | Minnesota | Introduced | EDDMapS (2021); Patterson (1973) |
| | Mississippi | Introduced | EDDMapS (2021); Patterson (1973) |
| | New Hampshire | Introduced | USDA (2020) |
| | New Jersey | Introduced | USDA (2020) |
| | New York | Introduced | USDA (2020) |
| | North Carolina | Introduced | USDA (2020) |
| | Ohio | Introduced | USDA (2020) |
| | Pennsylvania | Introduced | USDA (2020) |
| | Rhode Island | Introduced | USDA (2020) |
| | Tennessee | Introduced | USDA (2020) |
| | South Carolina | Introduced | USDA (2020) |
| | Vermont | Introduced | USDA (2020) |
| | Virginia | Introduced | USDA (2020) |
| | Washington | Introduced | EDDMapS (2021); Patterson (1973) |
| | West Virginia | Introduced | USDA (2020) |
| | Wisconsin | Introduced | USDA (2020) |
| **Asia** | | | |
| China | Anhui | Native | efloras.org (2020) |
| | Gansu | Native | efloras.org (2020) |
| | Heilongjiang | Native | efloras.org (2020) |
| | Henan | Native | efloras.org (2020) |
| | Hubei | Native | efloras.org (2020) |
| | Jiangsu | Native | efloras.org (2020) |
| | Jiangxi | Native | efloras.org (2020) |
| | Jilin | Native | efloras.org (2020) |
| | Liaoning | Native | efloras.org (2020) |

| Region | Distribution | Status | References and comments |
|---|---|---|---|
| | Nei Mongol | Native | efloras.org (2020) |
| | Shaanxi | Native | efloras.org (2020) |
| | Shandong | Native | efloras.org (2020) |
| | Shanxi | Native | efloras.org (2020) |
| | Sichuan | Native | efloras.org (2020) |
| | Zhejiang | Native | efloras.org (2020) |
| Japan | | Native | efloras.org (2020) |
| Korea Dem. People's Republic | | Native | efloras.org (2020) |
| Korea, Republic | | Native | efloras.org (2020) |
| **EPPO region** | Austria | Introduced | **Locally established**: Heber & Zernig (2013) Gudžinskas *et al*. (2020) |
| | Belgium | Introduced | **Locally established:** Tokarska-Guzik *et al.* (2012) |
| | Czech Republic | Introduced | **Transient under management:** J. Sadlo (pers comm. 2021), Pyšek *et al.* (2012) |
| | Denmark | Introduced | **Locally established**: Hartvig (2015) |
| | Germany | Introduced | **Locally established:** Adolphi (2015); Alberternst & Nawrath (2018) |
| | Latvia | Introduced | **Present:** Gudžinskas *et al*. (2020) |
| | Lithuania | Introduced | **Established:** Gudžinskas *et al*. (2020) |
| | Netherlands | Introduced | **Locally established:** Beringen *et al*. (2017) |
| | Norway | Introduced | **Present:** Gederaas et al. (2012) |
| | Poland | Introduced | **Established** Purcel (2010,11) |
| | Russia: European Russia | Introduced | **Transient:** Morozova (2013) |
| | Russia far east | Native | Beringen *et al*. (2017), Gudžinskas *et al*. (2020) |
| | Sweden | Introduced | **Locally established:** Gudžinskas *et al*. (2020) |
| | Switzerland | Introduced | **Transient eradicated**: Mangili *et al*. (2020) |
| | Ukraine | Introduced | **Locally established:** Gudžinskas *et al*. (2020) |
| | United Kingdom | Introduced | **Locally established**: BSBI (2020) |
| **Oceania** | New Zealand | Introduced | Williams & Timmins (2003), Beringen *et al*. (2017)<br>Localised distribution in New Zealand but it is widely distributed in the northern areas of the North Island |

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

### Austria

*Celastrus orbiculatus* is cultivated as an ornamental liana and occasionally wild populations can be observed. Such populations are known from the western shore of Lake Ossiach in Carinthia (Strudl, 2013), Graz in Styria (Heber & Zernig, 2013) and Tribuswinkel in Lower Austria (Sauberer & Till, 2015) as well as more recently from St. Johann im Walde in East Tyrol (Stöhr, 2019). It occurs in abandoned gardens and as a part of the riparian vegetation.

### Belgium

*Celastrus orbiculatus* was discovered in 2004 on the edge of a nature reserve in Berchem-Antwerpen (Wolvenberg). The population is very persistent despite the regular use of herbicides. It very locally climbs in native as well as planted shrubs and trees (in half-shade). In 2005, it was recorded in the valley of river

Schelde in Berlare (Paardebroek; a single specimen, ca. 6m tall) and in 2013 in Lommel (Den Tip), probably as a relic of former cultivation but regenerating (Veloove, 2020).

**Germany**

In Germany, *C. orbiculatus* is recorded rarely, mainly from the Southern part of the country. It is considered established or almost established (Hand & Thieme, 2020). The first record dates from the 1950s (Stadler & Walther, 1970). It was found in Northern Bavaria in a forest where it was assumed to have been introduced by birds from a nearby park. The species is now widely available in shops and online commerce (pers. obs. U. Starfinger, 2021), so it can be assumed that undetected populations exist (Adolphi, 2015). A detailed survey in Hessen (Alberternst & Nawrath, 2018; 2019) recorded dominant stands with vegetative and generative regeneration and spread. Because of its occurrence in habitats of high nature conservation value and its potential impacts, the author considers the species as at least potentially invasive.

**Latvia**

*Celastrus orbiculatus* has been grown in Salaspils botanical garden. Since 1990s, in one research plot it has shown high tendency to persist (mainly vegetatively), and it has been observed to be very competitive compared with other plants.

**Lithuania**

Currently, *C. orbiculatus* occurs in 8 localities in southeastern (Paneriai and Visoriai, Vilnius city), central (Vandžiai, Raseiniai distr. and Girionys, Kaunas distr.) and western (Babrungėnai, Plungė distr. and environs of Palanga city) parts of Lithuania (pers. comm. Z. Gudžinskas, 2021).

**Netherlands**

*Celastrus orbiculatus* is currently recorded in four locations in the Netherlands spanning the length of the country (https://www.verspreidingsatlas.nl/8152). Beringen *et al.* (2017) states that 'the first record of naturalized *C. orbiculatus* in the Netherlands dates from 2014. One specimen was recorded near Gasselte in the province of Drenthe.'

**Poland**

*Celastrus orbiculatus* is currently recorded in the central segment of the Międzyrzecz Reinforced Region and its spread has been observed near Panzerwerkes (Purcel, 2010, 2011). In areas where *C. orbiculatus* has been monitored it has become established and continues to spread further into natural communities (Purcel, 2010, 2011).

**Russia**

*Celastrus orbiculatus* is recorded in one region within European Russia, but is not considered invasive there. The species is native to the Russian Far East (Beringen *et al*., 2017 citing Morozova, 2014).

**Switzerland**

In the Canton of Ticino, *C. orbiculatus* was found in two locations: (1) Orselina, near a private garden in 2015 and (2) Croglio, growing in an alluvial forest close to the river Tresa in 2017. The latter individual was removed as a precautionary measure (Mangili *et al*., 2020).

**United Kingdom**

*Celastrus orbiculatus* has been found locally in particular in the southern part of United Kingdom (BSBI, 2020). The Online Atlas of the British and Irish flora (https://www.brc.ac.uk/plantatlas/plant/celastrus-orbiculatus) states that *C. orbiculatus* is a "woody climber grown in gardens" and has been found established "on a wooded roadside at Shottermill (Surrey) and in a woodland near West Porlock".

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

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

| **Habitats** | **Presence** | **Status of habitat** | **Is the pest present in the habitat in the PRA area (Yes/No)** | **Comments (e.g. *major/minor habitats* in the PRA area)** | ***Reference*** |
|---|---|---|---|---|---|
| B: Coastal habitats | Coastal dunes and sandy shores (B.1) | Protected in part | Yes | Major habitat in the EPPO region | Mehrhoff *et al*. (2003); Whalley *et al*. (2012); Gudžinskas *et al*. (2020) |
| E: Grasslands and lands dominated by forbs, mosses or lichens* | *Ruderal environments: road networks (J4-2), rail networks (J4-3), hard surface areas of ports (J4.5) | Ruderal grasslands (none) | Yes** | Major habitat in the EPPO region | Wells *et al*. (2000); Adolphi *et al*. (2013); Alberternst and Nawrath (2018) |
| F: Heathland, scrub and tundra | Shrub-steppes and semi-steppe shrublands | Protected in part | Yes | Major habitat in the EPPO region | Von Holle and Motzkin (2007); Gudžinskas *et al*. (2020) |
| G: Woodland, forest and other wooded land | Broadleaved deciduous (G1), broadleaved evergreen (G2), mixed deciduous (G4), riparian woodland | Protected in part | Yes** | Major habitat in the EPPO region | Kearsley (1999); Greenberg *et al.* (2001); Gudžinskas *et al*. (2020) |
| I: Regularly or recently cultivated agricultural, horticultural and domestic habitats | Fallow or recently abandoned arable land (I1-5), | None | Yes | Major habitat in the EPPO region | Gudžinskas *et al*. (2020); Dreyer *et al*. (1987) |
| X: Habitat complexes | Areas with wooded land (X10 -X18)<br>Gardens of city and town centres (X22 – X25) | None | Yes | Major habitats in the EPPO region | Gudžinskas *et al*. (2020); Steward *et al*. (2003) |

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

** see Appendix 1 for images.

The habitats where the species occurs in the native range is described in section 2.10

In the eastern United States, *C. orbiculatus* is most abundant in mesic, mixed-hardwood forests and forest edges (Kearsley, 1999). It may also be common in coniferous forests (Greenberg *et al*., 2001) and in woodland (Swearingen, 2009), shrubland (Von Holle & Motzkin, 2007), old field (Roberson *et al*., 1993; Mehrhoff *et al*., 2003), duneland, coastal beach (Mehrhoff *et al*., 2003), tidal freshwater edges (Leck and Leck, 2005), and saltmarsh communities (Mehrhoff *et al*., 2003). Critical habitat characteristics include light post-germination that ensures future sexual reproduction and growth (additionally, a cold period may be needed to allow the seeds to stratify for germination) (Greenberg *et al*., 2001).

In the EPPO region, Beringen *et al*. (2017) state that the species is usually confined to habitats with a low or medium conservation value such as (peri)urban habitats but the species occasionally colonises high conservation value habitats such as riparian forests. Gudžinskas *et al*. (2020) recorded that in Lithuania, *C. orbiculatus* occurs in quite different types of forest habitats. The population in the environs of Palanga occupies a transitional area between a habitat of wooded dunes and grasslands. In Paneriai, this species occupies mature pine forest and the transitional zone to spruce forest (Fennoscandian herb-rich forests with *Picea abies*). In Visoriai, *C. orbiculatus* grows in stadial forest dominated by *Betula pendula*. In Vandžiai, *C. orbiculatus* has invaded a young *Betula pendula* stand situated in the transitional zone between alluvial forest (with *Alnus glutinosa* and *Fraxinus excelsior*) and broad-leaved forest (natural old broad-leaved deciduous forests) (Gudžinskas *et al*., 2020).

In the EPPO region, the potential habitats that *C. orbiculatus* can invade are numerous and include both transportation networks (e.g. railway track verges, roadsides and habitats under powerlines) and natural habitats (e.g. woodland, grassland). Beringen *et al*. (2017) detail that suitable habitats are most likely to be forests on moist, fertile, neutral soils, such as alluvial forest and riparian mixed forest (Natura 2000 codes[3] 91E0 and 91F0). The habitats detailed in table 2 are widespread within the EPPO region. *Celastrus orbiculatus* can occur in terrestrial habitats including: managed forests, plantations, orchards, managed grassland, disturbed pastures, disturbed areas, railway track verges or roadsides, and terrestrial natural or semi-natural habitats including forests, grasslands, riverbanks and coastal areas (Gudžinskas *et al*., 2020; Beringen *et al*., 2017; Purcel, 2010; 2011).

Beringen *et al*. (2017) scores the risk of *C. orbiculatus* colonising high conservation value habitats as medium (PRA area is the European Union).

It should be noted that Beringen *et al*. (2017) highlighted some uncertainty regarding the exact EU habitats where *C. orbiculatus* may establish within Europe. However, Beringen *et al*. (2017) does states: specifically, habitat types 91E0 “Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)” or 91F0 “Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)” are vulnerable’.

## 8. Pathways for entry

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

- **Plants for planting,**
- Cut branches,
- Travellers: footwear and leisure equipment,
- Used machinery and equipment,
- Natural spread.

### 8.1 Pathways studied

All the pathways are considered from areas where the pest has been reported to be present, into the EPPO region. Examples of prohibition or  import requirements 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 on the different pathways are not detailed in this PRA (although some were considered 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.

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[3] https://www.eea.europa.eu/data-and-maps/daviz/sds/list-of-species-with-natura/@@view

| **Pathway** | **Plants for planting** |
|---|---|
| **Coverage (short description why it is considered a pathway)** | This pathway covers the entry of *C. orbiculatus* into the EPPO region via plants for planting. The pathway includes both live plants and seeds. The pathway also includes the import of bonsai *C. orbiculatus.* As it is a temperate species, bonsais of this species are likely to be placed outdoors in the EPPO region.<br>*C. orbiculatus* has been utilized as a garden ornamental species in the EPPO region since 1860 (Gudžinskas *et al*., 2020). If plant material enters the EPPO region, it is likely that this material is used solely for the purpose of horticulture.<br>Costley (2006) and Fryer (2011) highlight that *C. orbiculatus* was historically utilized as a species for erosion control in the USA, for landscaping purposes and for wildlife food. These planting purposes are not likely to be practiced nowadays. In the EPPO region, *C. orbiculatus* is recommended as a species to plant for noise reduction along roads and railways or as a species for green walls (e.g. Eppel-Hotz 2012).<br>It should be noted that *C. orbiculatus* can be mistaken for *C. scandens* in horticultural trade and it is reported that many nurseries accidentally sell *C. orbiculatus* (Ritterskamp, 2018). Zaya *et al*. (2017) identified 34 plants from 11 vendors in the USA and found that 18 samples (53%) were mislabelled, and 7 out of the 11 vendors sold mislabelled plants.<br>Import of rooted plants (except as bonsais) is largely historical, though the import of seed via e-commerce is an active pathway. |
| **Pathway prohibited in the PRA area?** | No. The import of plant for planting of this species is not prohibited in the EPPO region. |
| **Pathway subject to a plant health inspection at import?** | Yes, partly in some EPPO countries.<br>All consignments of plants for planting other than seeds are subject to a phytosanitary certificate at import in the EU. |
| **Pest already intercepted?** | *Celastrus orbiculatus* is available from horticultural outlets and from online stores throughout the EPPO region. Seed can be purchased from the large online suppliers such as eBay and Amazon.<br>Beringen *et al*. (2017) detail that in the EU the species is available in trade in Belgium, Croatia, Czech Republic, Denmark, Estonia, Germany, Finland, France, Hungary, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Slovenia, Spain, Sweden, United Kingdom. |

| **Pathway** | **Plants for planting** |
|---|---|
| | Beringen *et al*. (2017) highlights that *C. orbiculatus* is traded internationally as a bonsai tree and there are several websites where bonsai trees can be purchased, e.g.<br>https://www.bonsai.de/celastrus-orbiculatus-p-23063.html?language=fr).<br>https://www.mistralbonsai.com/fr/tout-sur-le-bonsai/fiches-techniques-des-bonsais/bonsai-mediterraneen/celastrus/<br>https://www.crespibonsai.com/fr/shohin-bonsai/5134-celastrus-orbiculatus-27-cm.html<br>*Celastrus orbiculatus* is imported into the EPPO region as bonsai plants most likely from Asia. For example, https://www.bonsai-ka.com/celastrus-orbiculatus-bonsai-ref-17340.html details that bonsai plants were exported from Japan in 2017. |
| **Most likely stages associated with the pathway** | **Seeds:** as highlighted above, seeds can be purchased from online suppliers and sent via mail order in packets.<br>**Whole plants (excluding bonsai):** Whole plants can be imported from outside of the EPPO region. However, it is unlikely that *C. orbiculatus* plants are imported from Asia into the EPPO region for horticulture nowadays (EWG opinion).<br>**Whole plants – bonsai**. Bonsai plants can be imported from outside of the EPPO region and are most likely to come from Asia.<br>**Cuttings:** Although there is no evidence that cuttings are or have been imported into the EPPO region, this type of plant material may be imported into the EPPO region. |
| **Important factors for association with the pathway** | Plants for planting will be packaged and maintained to ensure their survival during transportation along the pathway.<br>Seeds sent via mail order have the potential to be delivered to any country in the EPPO region. |
| **Survival during transport and storage** | It is likely that live plants will survive transport and storage as the plant (or seed) is the commodity itself. Seed can survive (at least) 12 months (Van Clef and Stiles, 2001). Provided they are cared for, live plants should be able to survive the period of transport and storage. |

| **Pathway** | **Plants for planting** |
|---|---|
| **Trade** | Beringen *et al*. (2017) states 'According to two Dutch trade centres (Flora Holland in Aalsmeer and Plantion in Ede), *C. orbiculatus* is being traded in small volumes. However, figures on the volume of trade and market value of the species are not separately available. *Celastrus* is categorized with other garden plants as "other plants". The species is not among the top 25 most sold species in the Netherlands, meaning that sales amount to less than 4 million euros per year amounting to less than 2 million yearly transactions (Flora Holland, 2014).' |
| **Will the volume of movement along the pathway support entry?** | It is unlikely that the current volume of movement will support frequent entry as although the species is traded, most of the live plants will be propagated and traded within the EPPO region. However, seed and bonsai plants can be imported into the EPPO region but, as already stated, the species is not a very popular species in horticulture. Small numbers of bonsai are imported from Japan (pers. Comm. J van Valkenburg, 2020). |
| **Will the frequency of movement along the pathway support entry?** | Given that the organism being assessed is the actual commodity any trade will support entry. However, it is unlikely that the amount traded will support entry. |
| **Transfer to a suitable habitat** | *C. orbiculatus* can transfer to a suitable habitat via the pathway plants for planting. Live plants and seed are likely to be grown outside in private gardens where the fruits can be eaten by mammals and birds and transferred to a suitable habitat.<br>If *C. orbiculatus* is planted and becomes 'weedy' in the garden, management practices may facilitate transfer from where it is planted Improper disposal of garden waste can facilitate the transfer of the species to a suitable habitat (Beringen *et al*., 2017).<br>Bonsai trees can be notoriously difficult to maintain and upon their death, it is likely that the plants are discarded. Bonsai trees may already have developed fruits, and viable seeds. |
| **Likelihood of entry and uncertainty** | **Plant for planting (excluding bonsai): Low** (some trade (plants and seeds), but frequency and volume lower than other plants, widely available in the PRA area and therefore unlikely to be imported) with a **high uncertainty** (little information on frequency and volume).<br>**Plants for planting Bonsai: Low** (confidence that import into the EPPO region does exist but low rating because of a low likelihood of transfer to a suitable habitat) with a **moderate uncertainty** (EWG discussed potential for low and high likelihood score and therefore the moderate score captures the difference). |

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

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

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

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

- **Cut branches of *C. orbiculatus*.** Cut branches are produced and traded within the EPPO region. This pathway includes cut branches of *C. orbiculatus* which contain fruit and seeds. Such branches are used for decoration (CABI, 2020). In the USA, cut branches of *C. orbiculatus* can be incorporated into decorative wreathes or other floral displays especially around the festive period (Thanksgiving and Christmas) (Mehrhoff *et al*., 2003). Cut branches may also be displayed on their own. In almost all cases, fruit and seed will be present as it is the colour of the fruit (orange, red) that makes the species attractive in such displays. In the USA, the use of *C. orbiculatus* as part of a floral display is not encouraged and awareness campaigns have been conducted to inform the public about the negative effects of using the species: https://www.youtube.com/watch?v=6n6gvWr_GOw. At present, there is no evidence that cut branches have been imported into the EPPO region.
- **Contaminant of round wood and sawn wood.** There is no evidence that *C. orbiculatus* is moved as a contaminant of round and sawn wood, however, the EWG considered the potential and noted that the commodity would be cleaned of any obvious contaminant before it is transported. The EWG considered this pathway as a very low likelihood of entry.
- **Travellers: footwear and leisure equipment**, *C. orbiculatus* fruit may be a contaminant of travellers (recreationists in nature) and their belongings (e.g. tread of shoes and leisure equipment (tents, bags, etc.). As *C. orbiculatus* is mainly associated with woodlands and disturbed areas, travellers may encounter *C. orbiculatus* seeds. Data is lacking to fully assess this pathway.
- **Used machinery and equipment.** *C. orbiculatus* fruit may have the potential to enter the EPPO region as a contaminant of used forest machinery and equipment. However, there is currently no evidence that the species has moved along this pathway. Referring to ISPM 41 can cover the risk of this pathway.
- **Natural spread.** Taking into consideration the current area of distribution (see section 6), it is unlikely that *C. orbiculatus* can naturally spread from outside the PRA area into the PRA area. Natural spread can occur in the Russian Far East (where the species is native) but the EWG considered this pathway to be a minimal risk.

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

*Celastrus orbiculatus* is established in limited areas of the EPPO region outside parks and gardens. Habitats where the species is established include natural and ruderal habitats. Suitable habitats are widespread within the EPPO region and thus further establishment is possible in regions where climatic conditions and other abiotic factors are conducive for its establishment.

*Celastrus orbiculatus* benefits from disturbance and it "uses a 'sit and wait' invasion strategy" (see section 2.5).

### 9.1 Natural habitats

*Celastrus orbiculatus* is established within the natural environment in a limited area of the EPPO region (Gudžinskas *et al.*, 2020; Adolphi, 2015; Heber & Zernig, 2013; Tokarska-Guzik *et al*., 2012). Where *C. orbiculatus* occurs, for example in Lithuania, dense stands of mature individuals occur in natural forest habitats.

In western Poland, Purcel (2010; 2011) records that *C. orbiculatus* is fully established in the natural environment, where it has spread from historically planted populations used to cover fortified structures.

In Germany, detailed observations exist for four stands in the Federal Land of Hessen (Alberternst & Nawrath, 2018; 2019). One stand originated from a nursery and has spread into an area protected under the EU Habitats Directive[4] and classified as Annex I habitat type code 91E0. Another stand occurs in a nature protection area of light pine forest on sandy soils resembling 91T0. Regeneration and spread of the species was observed in three of the four stands. Another stand was found on railway land, where the plant covers unused tracks (Adolphi *et al*., 2013).

Gudžinskas *et al*. (2020) detail that *C. orbiculatus* has established within natural habitats in Lithuania for at least 21 years. These forests have not been managed for at least 70 years (pers comm. Z. Gudžinskas, 2021). In Paneriai Forest (Vilnius), a dense stand of this species with mature individuals occupies an area of 2600 m$^2$. The total area of the stand, including recorded seedlings and saplings, comprises 3640 m$^2$ (Gudžinskas *et al*., 2020). At the Vandžiai site (Raseiniai distr., Central Lithuania) the species occupies 880 m$^2$ while the other studied stands of *C. orbiculatus* were significantly smaller (Gudžinskas *et al*., 2020). Gudžinskas *et al.* (2020) further defines habitats where the species is present in Lithuania including 2180 Wooded dunes of the Atlantic, Continental and Boreal region, 6120 Xeric sand calcareous grasslands, 9010 Western Taiga, 9050 Fennoscandian herb-rich forests with *Picea abies*, 91E0 Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*, 9020 Fennoscandian hemiboreal natural old broad-leaved deciduous forest. While the EWG is certain that the species occurs in these specific habitat types, it is not expected that it will be restricted to these habitats only. Beringen *et al*. (2017) detail that the most likely habitats for establishment in the EU are forest habitats on moist, fertile, neutral soils like 91E0: "Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (Alno-Padion, Alnion incanae, Salicion albae)" or 91F0 "Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along major rivers (Ulmenion minoris)".

### 9.2 Managed habitats

Managed habitats can facilitate the establishment of *C. orbiculatus* as the species benefits from disturbance.

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[4] https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

In the USA, it is commonly found in managed habitats like transportation networks and harvested forests (Hoosein and Robinson, 2018; Silveri *et al.*, 2001).

Invasion of forests by *C. orbiculatus* may be triggered by logging and other forest management. *C. orbiculatus* can persist in forest understories for a number of years, and following a disturbance in the canopy (e.g., tree or limb falls causing a canopy gap), rapid growth can occur (Greenberg *et al*. 2001; Leicht and Silander 2006). Disturbances, such as canopy gaps, also promote~~s~~ flowering and fruiting (Silveri *et al*. 2001).

In the EPPO region, forests undergo different types of management from land abandonment to short rotation cycles. However, most of the forests in the EPPO region are managed to a certain extent and thus the disturbances lead to gaps that can be easily occupied by *C. orbiculatus*.

### 9.3 Other factors affecting establishment

#### ***Reproductive ecology***
The variable reproductive strategies (dioecious, monoecious, polygamo-dioecious and vegetative reproduction) used by *C. orbiculatus* across the EPPO region will influence its ability to establish seed-producing populations. Functionally or purely dioecious populations will be highly dependent on having both genders in reasonable proximity as well as pollinators.

#### ***Mycorrhizal fungi association***
*Celastrus orbiculatus* has been shown to benefit from mycorrhizal fungi association in the USA. Lett *et al*. (2011) showed that *C. orbiculatus* potentially forms associations with native endomycorrhizal but not with native ectomycorrhizal fungi regardless of phosphorus level. There are no known studies of the effects of mycorrhizal associations with *C. orbiculatus* in the EPPO region.

#### ***Competition with native vegetation***
Competition with native vegetation is unlikely to limit the establishment of *C. orbiculatus* in the EPPO region. Purcel (2010) details that in Poland in natural forests, *C. orbiculatus* is a strong competitor of native vegetation and forms a dense ground cover which can prevent the formation of native vegetation. Other studies highlight that *C. orbiculatus* uses ground cover vegetation as a support to grow up into the canopy. Competition may occur with other native lianas with some indication in North America that *C. orbiculatus* is less competitive than native *Vitis* sp., *Parthenocissus quinquefolia*, *Toxicodendron radicans* and the non-native *Lonicera japonica* (Ladwig & Meiners, 2009). However, in managed forests in the EPPO region, other liana species, with the exception of *Hedera helix* and *Clematis vitalba*, are limited.

#### ***Host preference***
There is no information to indicate that *C. orbiculatus* has a preference to utilise certain tree species in forests where it invades. In North America, Ladwig & Meiners (2009) showed that *C. orbiculatus* has no preference for host trees and it colonizes trees less effectively than other native and non-native vines. The fact that *C. orbiculatus* is used for greening walls/urban structures and that it is found in a variety of woodland/forest types and on different tree species provides some evidence towards a lack of host preference (Purcel 2010, 2011; Gudžinskas *et al*., 2020). However, in North America, Leicht-Young *et al*. (2010) did show that *C. scandens* preferred *Pinus banksiana*.

#### ***Pollinators***
Within the EPPO region, general pollinators are present (e.g. *Hymenoptera* spp.). Wind pollination has also been documented (CABI, 2020 citing Wyman, 1950).

#### ***Natural enemies***

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

## Abiotic factors

### *Light*

*Celastrus orbiculatus* is tolerant of a wide range of light intensities which can facilitate establishment under closed canopies (Greenberg *et al*., 2001).

### *Soil*

Soil conditions do not seem to restrict the establishment of *C. orbiculatus* in the EPPO region as the species can tolerate a wide range of conditions including texture (light to medium soils) and soil pH (acidic to neutral). Purcel (2010) highlights that the species grows well in nutrient rich soils in Poland though it can also withstand infertile soils (CABI, 2021). There is some evidence that the seedlings benefit (growth) from moist circumneutral soils in North America (Silveri *et al.*, 2001).

### *Precipitation*

*Celastrus orbiculatus* benefits from moist soils associated with relatively high levels of precipitation, especially in warmer months. This may be explained in part to its lack of root pressure, poor specific conductivity, and dependence on secondary xylem growth to overcome cavitation (Tibbetts and Ewers, 2000). A closer association with wetter summers may decrease the probability of embolism if rapid xylem production is not possible or enough to overcome drought conditions.

### *Slope and elevation*

Within the Appalachian Mountain provinces in the USA, *C. orbiculatus* is associated with the lower elevations or valleys and shallow slope inclinations or relatively flat land types (Albright *et al.*, 2009).

### *Climate conditions*

Beringen *et al*. (2017) suggest that cold temperatures limit the distribution of *C. orbiculatus* in the EU. However, Gudžinskas *et al*. (2020) show that in Lithuania even prolonged very cold winter temperatures below –25 °C (e.g. in 2003, 2006, 2010, 2012) and occasionally below –30 °C (in 1997) do not damage *C. orbiculatus* shoots significantly to inhibit radial increments in the following growth period.

*Celastrus orbiculatus* is present in the following Köppen-Geiger[5] climatic regions:
**Asia:** Cfa, Dfa, Dfb, Cwa, Dwa
**North America:** Cfa, Dfa, Dfb
**Oceania:** Cfb

All of these Köppen-Geiger zones are present in the EPPO region although Dwa is significantly limited in area (0.5 % of Russian Far East). Appendix 5 provides details of the percentage of Köppen-Geiger zones which are present in EPPO member countries (from MacLeod & Korycinska, 2019).

The ensemble model conducted during the EWG (see Appendix 2) shows the suitability for *C. orbiculatus* at the global scale and resolution of the model was more strongly limited by climate than habitat variables. The strongest limiting factors were excessively low summer precipitation (Bio18) and low or high winter temperature (Bio6). Summer temperature (Bio10) and Human Influence Index also had relatively strong

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[5] Cfa – Uniform precipitation throughout the year, humid subtropical: Cfb - Uniform precipitation throughout the year, temperate oceanic: Dfa Uniform precipitation hot summer, , Dfb - Uniform precipitation , warm summer, Cwa - Dry winter, sub-tropical: Dwa - Dry winter, hot summer:

effects. Weaker preferences for low elevations, moderate moisture balance (CMI) and tree cover were also modelled.

In the EPPO region, the model predicts a large climatically suitable area across most of central, eastern and northern Europe, excluding the far north, and a smaller suitable region in Georgia and southern Russia (Figure 2). Western Britain and Ireland are also predicted to have areas with marginal suitability. The model suggests the main limiting factor in unsuitable parts of northern Europe is low summer precipitation (Bio18), though low summer temperatures (Bio10) are suggested as important in the far north and high annual moisture balance (CMI) in the far west. Regions which are in part (see Appendix 2, Fig. 9), highly suitable for establishment in the current climate are the Continental, Pannonian, Alpine and Boreal biogeographical Regions (Bundesamt fur Naturschutz (BfN), 2003).

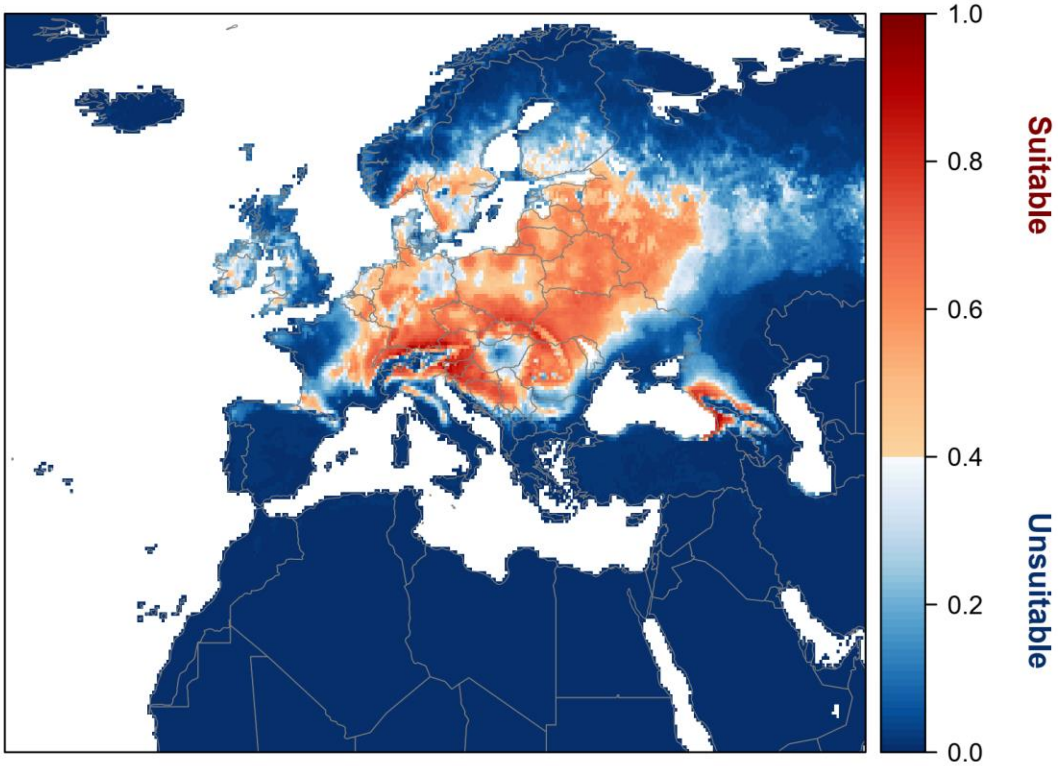

Fig. 2. Projected current suitability for *Celastrus orbiculatus* establishment in Europe and the Mediterranean region (see Appendix 2 for details).

## Conclusion

There are clearly limiting climatic factors to the establishment of *C. orbiculatus* in parts of the EPPO (e.g. Mediterranean, northern regions). Although the species can tolerate a wide range of climatic and other abiotic factors, the current limited establishment of the species in the natural environment in the EPPO regions with suitable climates cannot be easily explained. Where reasonably large areas of establishment have been recorded (e.g. Lithuania), it has been shown that these populations contain monoecious plants.

The EWG consider that the likelihood of establishment outdoors is very high as the species is already established in the EPPO region in several different habitats. There are peer reviewed scientific papers detailing this establishment. The EWG consider the uncertainty is low.

| | | | | | |
|---|---|---|---|---|---|
| *Rating of the likelihood of establishment outdoors* | 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

There is no evidence that *C. orbiculatus* is established under protected conditions in the current area of distribution.

Protected conditions, such as in nurseries, polytunnels, tropical greenhouses may offer appropriate conditions for the development of *C. orbiculatus*. The management of temperatures under protection (e.g. polytunnels, glasshouses) maintains average temperatures between 20 and 35°C which would be more favourable for the development of the species. However, they are highly managed production systems that would limit the likelihood of establishment due to short intervals between consecutive management practices.

The EWG consider that the likelihood of establishment in protected conditions is very low due to the management of the system in the protected conditions.

| | | | | | |
|---|---|---|---|---|---|
| *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

### Natural spread

***Spread (sexual and vegetative) without animal vectors***

Dispersal of the seed by gravity alone (barochory) is common with most seed falling in the close vicinity of the parent plant. Seeds are dispersed when the 3-valved capsules split open and expose the arils (Greenberg *et al*., 2001).

Seeds can potentially be dispersed via water as the fruits float (Merhoff *et al*., 2003), though seed that float may be less viable than seed that does not float (Dreyer *et al*., 1987). However, the species does not grow well in waterlogged soils (section 2.9 *Environmental requirements*).

Natural spread by growth of the shoots can be up to 3 m /year. Stems may reach up to 18 m long , Gudžinskas *et al*., 2020).(section 2.5 *Growth rates*). In Connecticut (USA), the cover of *C. orbiculatus* (in an area of 0.1 acre (0.04 ha)) increased from 5% to 100% within 5 years Patterson (1973), i.e. the species can spread and cover 400m² within 5 years.

***Birds and mammals***

In the USA *C. orbiculatus* has spread from sites where it has been planted for ornamental purposes and has subsequently established extensively in natural and managed habitats. An important factor for this spread is the natural spread of the species by mammals and birds (Merow *et al*., 2011; LaFleur *et al*., 2009; Greenberg *et al*., 2001).

Throughout the literature, the European starling (*Sturnus vulgaris*) which is present in North America and native to parts of the EPPO region, is detailed to spread seed of *C. orbiculatus* (Merow *et al*., 2011; La Fleur *et al*., 2009). Additionally, in North America other frugivorous birds are reported to eat the fruit of *C. orbiculatus* including northern flickers (*Colaptes auratus*), yellow-rumped warblers (*Setophaga coronate*), American robins (*Turdus migratorius*) and other thrushes (Turdidae), mockingbirds and catbirds (Mimidae), and mynas (Sturnidae). Greenberg *et al.* (2001) highlight that 75% of seed was apparently removed by vertebrates and presumably dispersed in an oak forest in North Carolina. The fruit are not a preferred fruit of migratory birds, which select, when they are available, several native vine with higher polyphenol and anthocyanin concentrations over *C. orbiculatus* (Bolser *et al*., 2013). Seeds ingested by birds have a higher germination rate compared to seeds with intact fruits (section 2.7. *Seed germination and emergence of seedlings*).

In the EPPO region, there is no additional information on bird species which use *C. orbiculatus* berries as a food source, but it is likely a number of frugivorous species do.

In Germany, bird dispersal has been recorded at 400 m from the parent plants (Alberternst & Nawrath, 2018).

Deer have been reported to feed on *C. orbiculatus* in the USA (Averill *et al*., 2016; Mundahl and Borsari, 2016), though it is not clear to what extent, if any, they spread propagules.

**Human assisted spread**

The main historical pathway for this species has been the ornamental industry and the use of the species as a garden plant. Online vendors sell seeds of *C. orbiculatus*. Nurseries also multiplicate and produce rooted *C. orbiculatus* plants for planting within the EPPO region. Therefore, further spread within the EPPO region is likely via horticultural production and trade of plants for planting.

Human assisted spread may be facilitated by people collecting and moving branches (e.g. for decorative purposes) directly from the natural environment (for example Michigan Department of Natural Resources, 2012). Positive aesthetic values (floral decor for the holidays) may be associated with the species (Beringen *et al*., 2017). However, the cultural importance of these uses may between countries.

Local movement of forest management equipment, and to a lesser extent timber contaminated with *C. orbiculatus* may act to spread the species. Management practices may act to spread *C. orbiculatus* locally. Small pieces of root left during clearing operations can resprout quickly and may form new plants (Dreyer *et al*., 1987; Ellsworth *et al*., 2004).

Management using prescribed burning has been shown to increase the density of *C. orbiculatus* in North America. Burning and combined cutting and burning resulted in a resprout density four times greater than stem density prior to treatment for stems <2.5 mm diameter than cutting alone. (Pavlovic *et al*., 2016).

Beringen *et al*. (2017) note that improper disposal of bonsai trees (discarded into the natural environment), or cut branches used for decorations can contribute to the spread of the species. This would also be the case if *C. orbiculatus* is managed in small gardens, parks, arboretums, or botanical gardens.

**Conclusion**

In the EPPO region, there is some evidence that the species is increasing its rate of spread. Gudžinskas *et al*. (2020) details that the historic rate of spread in Europe has been slow between 1953 and 2005 with only three new sites every ten years. However, since 2005, a tenfold increase of the rate of spread has been noted where an average of almost three sites per year have been recorded. Gudžinskas *et al*. (2020) classifies pre-2005 as the lag phase of the species expansion and considered post-2005 as the exponential growth phase.

Although specific information on spread is limited for the EPPO region, there are clear mechanisms for long distance dispersal of fruit (movement by mammals and birds and human assisted spread from the horticultural trade). Therefore, the EWG consider that the magnitude of spread to be high. However, spread in the EPPO region is occasional and there are limited studies that underline the mechanisms of spread which leads to low predictability to rates of spread and therefore the EWG consider an associated moderate uncertainty score.

| | | | | | |
|---|---|---|---|---|---|
| *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 PRA area)**

Fryer (2011) provides a detailed overview of the negative impacts of *C. orbiculatus* in North America. More specific references are detailed in the sections below. The author highlights that in general the species is considered a severe pest plant in the North-eastern USA where it is listed as a high threat in deciduous, coniferous, and mixed conifer-deciduous forests, old fields, grasslands, riparian areas, and freshwater wetlands.

**12.1 Impacts on biodiversity and habitats**

This species forms dense thickets in open natural and disturbed areas as well as in forest understories and canopies. Such growth reduces light availability and may smother native plant species, suppressing or excluding them (McNab and Meeker, 1987). In the eastern USA, *C. orbiculatus* invades the same habitats as the native *C. scandens*. There has been a decline in *C. scandens* occurrence while *C. orbiculatus* has shown an increase, especially in areas with older *C. orbiculatus* populations (Steward *et al.*, 2003). Hybridization with *C. scandens*, though hybrids appear to be in relatively low numbers, is asymmetrical with pollen coming primarily from *C. orbiculatus*, wasting the *C. scandens*' limited reproductive effort and potentially accelerating its decline (Zaya *et al*., 2015).

In North America, *C. orbiculatus* grows in close proximity to the threatened pitcher thistle (*Cirsium pitcheri* (Leicht-Young & Pavlovic, 2012) and the threatened bird, the piping plover in coastal areas (Dreyer, 1994), potentially threatening their habitats (Leicht-Young & Pavlovic, 2012). If migratory birds are limited to consuming *C. orbiculatus* over other native vine fruits, they may suffer from an inadequate diet, possibly hindering their migration (Bolser *et al*., 2013).

Locally, *C. orbiculatus* can act as an ecosystem engineer by transforming the structure of habitats, such as forests in which it may affect all strata (understory, mid-story, and canopy) (Fike & Niering, 2009). *Celastrus orbiculatus* growth in tree canopies may weaken the host trees making them more vulnerable to abiotic influences, including damage from wind, ice and snow (Siccama *et al*., 1976*). Celastrus orbiculatus* may facilitate the growth of other destructive vines in forests, including grapes (Fike & Niering, 2009). *Celastrus orbiculatus* responds positively to fire via root suckering, adding potential fuel to forest systems (Pavlovic *et al.*, 2016). *C. orbiculatus* can have negative impacts on tree regeneration which may impact the course of succession in a forest system (Ellsworth *et al*., 2004).

In New Zealand, this species is in the early stage of invasion putting vulnerable habitat communities at risk including open scrub, shrublands, early successional forest, and the margins of mature forests, particularly those on alluvial or colluvial sites (Williams & Timmins, 2003).

### 12.2 Impacts on ecosystem services

*Celastrus orbiculatus* has negative impacts in managed forests. Reductions in tree regeneration and timber production are the most-documented negative impacts on ecosystem services due to *C. orbiculatus*. The twining habit of *C. orbiculatus* on trees restricts tree growth, overtops canopies and increases the probability of wind and ice damage (Horton & Francis, 2014). Increased weight in the tree crowns can lead to major limb breakage or trunk failure (Delisle & Parshall, 2018). Marks & Canham (2015) demonstrate that tree-mortality in Connecticut (USA) caused by vines is primarily due to *C. orbiculatus* and that this vine causes 9.8% of all tree mortality. Additionally, Delisle & Parshall (2018) showed that *Populus grandidentata* and *Quercus rubra* that had been infested with *C. orbiculatus* for many years had reduced growth.

The impact of *Celastrus orbiculatus* on soils is less clear. Leicht-Young *et al.* (2009) showed that sites invaded by *C. orbiculatus* were associated with soils having significantly higher soil pH, potassium, calcium and magnesium levels. In a subsequent study, adding *C. orbiculatus* litter to previously uninvaded soil increased nutrients significantly after three years. However, positive soil feedback could not be documented. Growing *C. orbiculatus* in soil (*C. orbiculatus*-primed soil) showed an increase in potassium but lower nitrogen mineralization with no other nutrient changes. Native vines appeared to impact soil nutrient use more than *C. orbiculatus* (Leicht-Young *et al*., 2015). These results suggest that *C. orbiculatus* may indeed act like a nutrient pump as suggested by Beringen *et al*. (2017), but impacts may be tempered by the presence of other vines.

Negative impacts on cultural ecosystem services are not reported in the literature.

### 12.3 Socio-economic impacts

In addition to the impact on wood production (mentioned under 12.2), they may be cost to control the species. There is little information on costs of controlling *C. orbiculatus*. Williams & Timmins (2003) highlight: 'costs of controlling *C. orbiculatus* in the period 1999 to 2003 in New Zealand amounted to 40 800 NZ$', (approximately 27 000 Euros). However, the authors do not provide information on the size of the infestation.

Ellsworth *et al.* (2004) suggest that failure to control *C. orbiculatus* can result in severe forest degradation and considerably higher future costs associated with forest restoration. If detected early, especially prior to any timber harvest, removal costs can be minimal. Unfortunately, in forested areas of the USA this shade-tolerant species is often small and without flowers and fruit, making it difficult to distinguish from the native congener.

There are general management costs for controlling this species along with other invasive plants in natural areas as well as managed forests. There also may be management costs associated with control of *C. orbiculatus* along transportation networks in the USA, however, the EWG has not been able to find any additional information to support this.

Horse DVM (2020) detail that all parts of *C. orbiculatus* are considered toxic to horses though the toxin is an unknown gastrointestinal irritant. However, further information on this aspect is lacking in the literature. There is evidence that *C. scandens* is toxic to dogs, cats and horses due to chemical compounds such as cardenolides and alkaloids which cause vomiting (not horses), diarrhoea, seizures (rare) and weakness. White-tail deer consume *C. orbiculatus* foliage (Lynch, 2009 and McNab & Meeker, 1987). The fruit may be toxic to humans.

The EWG rated the magnitude of impact in the current area of distribution as moderate with a moderate uncertainty. The moderate rating reflects that impacts have been demonstrated but that there are limited studies. This conclusion has been derived by comparing this species with other invasive alien plants that invade similar habitats in North America. A moderate uncertainty reflects the lack of information on negative impacts e.g. competition and hybridization.

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

The EWG consider that potential impacts in the PRA area will be largely the same as in the current area of distribution outside of the PRA area (a moderate rating of magnitude). The EWG consider that a higher impact than in the current area of distribution is not justified based on direct evidence and the current situation. At present there are no known studies that have assessed the impact of *C. orbiculatus* in the EPPO region. However, as the species has been shown to invade natural woodland in the EPPO region (Gudžinskas *et al*., 2020; Purcel, 2010), in a similar manner as in North America, similar impacts are expected. The EWG consider the uncertainty will be higher in the PRA area compared to the current area of distribution. Therefore, the EWG consider the potential impact in the PRA area will be moderate with a high uncertainty. From a precautionary point of view the increased uncertainty indicates the risk may be higher than that of the current area of distribution.

The high uncertainty is justified by:

- Whether there will be a higher impact on biodiversity in the EPPO region. There are no equivalent native species that can compete with *C. orbiculatus*, especially in boreal regions.
- the species potentially being able to fill an empty niche, which can facilitate invasion.
- the effect of intensity of forest management on impact.
- Lack of scientific studies in the EPPO region.

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

Within the EPPO region, *C. orbiculatus* often invades urban and ruderal environments where its impact on biodiversity is likely to be low. However, Gudžinskas *et al*. (2020) highlight that *C. orbiculatus* is documented to invade natural and semi-natural environments in Austria, Germany, Poland and Lithuania.

Similar impacts on biodiversity may be seen in the rest of the EPPO region, especially as the species can cover the canopy (80 – 100 %) as recorded in Hessen, Germany (Alberternst & Nawrath, 2018). Even under more open forest canopies as observed in Lithuania, light penetration was reduced to the lower vegetation layers when *C. orbiculatus* was present.

Purcel (2010) details that in Poland in natural forests, *C. orbiculatus* is a strong competitor of native vegetation and forms a dense ground cover which can prevent the formation of native vegetation. *C. orbiculatus* can entangle two or more tree crowns, increasing the risk of trees being toppled by wind. Trees and shrubs, on which it twines, are often deformed, moreover, they are also more susceptible to damage from snow, ice, and wind.

Hybridization is unlikely to be a negative impact in the EPPO region as there are no native congeners, and *C. scandens* has a limited occurrence in the EPPO region. It is possible that both *C. scandens* and *C. orbiculatus* are imported and hybridization may occur where both species are established. Additionally, material imported from North America may include the hybrid. The hybrid is more vigorous than *C. scandens* though hybrid seed are smaller than both species (Pooler *et al*., 2002; Zaya *et al*., 2015).

The EWG consider that the main impacts will be seen in forest and woodland habitats in the EPPO region. There is also the potential for negative impacts in adjacent grassland, heathland, and coastal areas within the EPPO region. These habitat types feature highly on the list of endangered habitats (European Union, 2016).

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

There is no known information on the impact on ecosystem services of *C. orbiculatus* in the EPPO region.

In the EPPO region, forests undergo different types of management from land abandonment to short rotation cycles. However, most of the forest in the EPPO region is managed to a certain extent. Managed habitats can facilitate the establishment of *Celastrus orbiculatus* as the species benefits from disturbance. Similar impacts as those shown in the USA are likely (impacts on provisioning ecosystem services, i.e. wood production).

In the EPPO region, the species invades forest systems and has been shown to grow on different tree species (Purcel, 2010; 2011).

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

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

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

There is the potential of socio-economic damage if the species invades sites of historic value or sites of cultural significance e.g. fortified sites in Poland (Purcel, 2010; 2011).

## 14. Identification of the endangered area

The EWG consider that the endangered area is predominantly woodland and forest habitats in central, eastern and northern Europe (excluding the far north), and a smaller suitable region in Georgia and southern Russia. In addition, coastal habitats, grassland and heathland in the vicinity of woodland or forests colonised by *C. orbiculatus* are also endangered and the impact on biodiversity may be larger due to the endangered status of areas within these habitats. The EWG considered the species distribution modelling conducted as part of this PRA (see Figure 2) to be a realistic projection of the potential establishment of *C. orbiculatus* in the EPPO region. The whole of the area of potential establishment is at risk on moderate impact.

## 15. Overall assessment of risk

Although the likelihood of entry of *C. orbiculatus* into the EPPO region via imported plants for planting is low with a moderate uncertainty, *C. orbiculatus* is already produced and widely available in trade within the EPPO region and occurs in parks and gardens throughout the EPPO region.

*Celastrus orbiculatus* is established in limited areas of the EPPO region. Potential habitats that *C. orbiculatus* can invade are widespread and include disturbed habitats (e.g. harvested forests), transportation networks (e.g. verge of railway tracks, roadsides and habitats under powerlines) and natural habitats (e.g. forests and woodlands and adjacent grassland and heathland). Further establishment is likely because the species can tolerate a wide range of climatic and other abiotic factors'. Where conditions are suitable, the likelihood of further establishment outdoors is very high with low uncertainty. Likelihood of establishment in protected conditions is very low with a low uncertainty, as management practices within protected conditions would prevent establishment. The potential for spread within the EPPO region is high with a moderate uncertainty. *C. orbiculatus* can spread both naturally (e.g. seed via mammals and birds) and with human assistance.

The magnitude of impact in the current area of distribution is moderate with a moderate uncertainty. In North America, *C. orbiculatus* threatens natural habitats, and the species can act locally as an ecosystem engineer by transforming the structure of habitats and supressing native species with its dense thickets. *C. orbiculatus* can reduce tree growth and regeneration which can have a negative impact on timber production in forests. The EWG consider that potential impact in the PRA area will be largely the same as in the current area of distribution but with an increased uncertainty. Direct impact studies and/or comparative studies are lacking, however, taking a precautionary approach, the increased uncertainty indicates the risk may be higher than that of the current area of distribution.

Due to the wide availability of the species in the EPPO region already, the overall risk of the species is not strongly influenced by further entry.

| | **Likelihood** | **Uncertainty** |
|---|---|---|
| **Entry** | Low | Moderate |
| Plants for planting (excluding bonsai) | Low | High |
| Bonsai | Low | Moderate |
| **Establishment outdoors in the PRA area** | Very high | Low |
| **Establishment in protected conditions in the PRA area** | Very low | Low |
| **Spread** | High | Moderate |
| **Impact in the current area of distribution** | Moderate | Moderate |
| **Potential impact in the PRA area** | Moderate | High |

## Stage 3. Pest risk management

The results of this PRA show that *C. orbiculatus* poses a moderate risk to the endangered area (see section 14) with a moderate uncertainty. Based on the risk, the EWG consider that *C. orbiculatus* should be recommended for regulation within the EPPO region.

### 16. Phytosanitary measures

The EWG considered that phytosanitary measures should be recommended for plants for planting (mentioned in 16.1).

### 16.1 Measures on individual pathways to prevent entry into the EPPO region

| **Possible pathways *(in order of importance)*** | **Measures identified** |
|---|---|
| **Plants for planting (including seed and bonsai)** | Prohibition of import into the EPPO region |

### 16.2 Recommendations within EPPO countries

Early detection is important to identify new occurrences of the species. *Celastrus orbiculatus* should be monitored. Where it occurs in the area of potential establishment in the PRA area (see 16.3), control measures should be implemented with the aim of eradication or containment. In addition, public awareness campaigns to prevent spread from existing populations in countries at high risk are necessary. *Celastrus orbiculatus* should be banned from sale in countries within the EPPO region and action to remove it from the natural environment encouraged.

### 16.3 Eradication and containment

#### Eradication

Eradication measures provided in this section should be promoted where feasible with a planned strategy to include surveillance, containment (see following paragraph), treatment and follow-up measures including habitat restoration where applicable 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 may be feasible in some EPPO countries where this species is at an early stage of invasion using methods detailed below. It is recommended that member countries eradicate this species where feasible to prevent further spread and impact.

#### Containment

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

A number of **management techniques** proved to be effective at controlling and containing *C. orbiculatus* including manual, mechanical and chemical control methods, both in USA and New Zealand (Willams &

Timmins, 2003, Ward and Henzell, 2003). NRCS (n.d.) highlight that a combination of management methods may be used for increased effectiveness.

### *Mechanical Control*

Small liana plants can be hand-pulled but the entire plant should be removed including the entire root system. For climbing vines, first cut the vines near the ground at a comfortable height to kill upper portions and relieve the tree canopy. Try to minimize damage to the bark of the host tree. Rooted portions will remain alive and should be pulled, repeatedly cut to the ground or treated with herbicide. Cutting without herbicide treatment will require vigilance and repeated cutting because plants will resprout from the base.

### *Chemical control*

Herbicides with systemic active principles like triclopyr and glyphosate are effective as they are absorbed into plant tissues and carried to the roots, killing the entire plant within about a week. Basal bark application can be highly effective (Lynch, 2009). Chemical control is effective if the stems are first cut by hand or mowed and herbicide is applied immediately to cut stem tissue.

### *Biological control*

There are no known biological control agents against *C. orbiculatus*.

### *Integrated control*

Integrated control or integrated pest management, i.e., a program based on a combination of preventive, cultural, mechanical, and chemical practices should be always considered, particularly in the case of large infestations.

## 17. Uncertainty

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

- Cut branches as a pathway at import,
- The mechanisms of spread which leads to low predictability to rates of spread,
- Uncertainty as to whether seed production or vegetative growth is the main lifecycle strategy,
- Why establishment is not occurring more often in climatically suitable areas of the EPPO region,
- Reproductive biology and ecology in populations within the EPPO region,
- Impact on biodiversity and ecosystem services in the EPPO region,
- Host tree preferences and competition with native liana species in the EPPO region.

Uncertainties related to the species distribution model are detailed in Appendix 2.

## 18. Remarks

The EWG suggest the following actions for consideration:

- Perform surveys to determine the extent of occurrences in the EPPO region,
- Include *C. orbiculatus* as a species to be surveyed in citizen science programmes (Good identification guides must be provided to avoid misidentifying specimens (see 2.2.1)),
- Suggest alternatives to key stakeholders for decoration and planting (e.g. *Euonymus europaeus* and *Euonymus verrucosus, Ilex aquifolium),*
- Inform RPPOs and/or specific countries where *C. orbiculatus* has the potential to have negative impacts outside of the EPPO region,
- Conduct additional research on impacts in different habitats,
- Conduct additional research on patterns of monoecy vs dioecy within the EPPO region,
- Conduct research on biological control options.

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## Appendix 1. Relevant illustrative pictures

Fig. 1 *Celastrus orbiculatus* flowers. Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

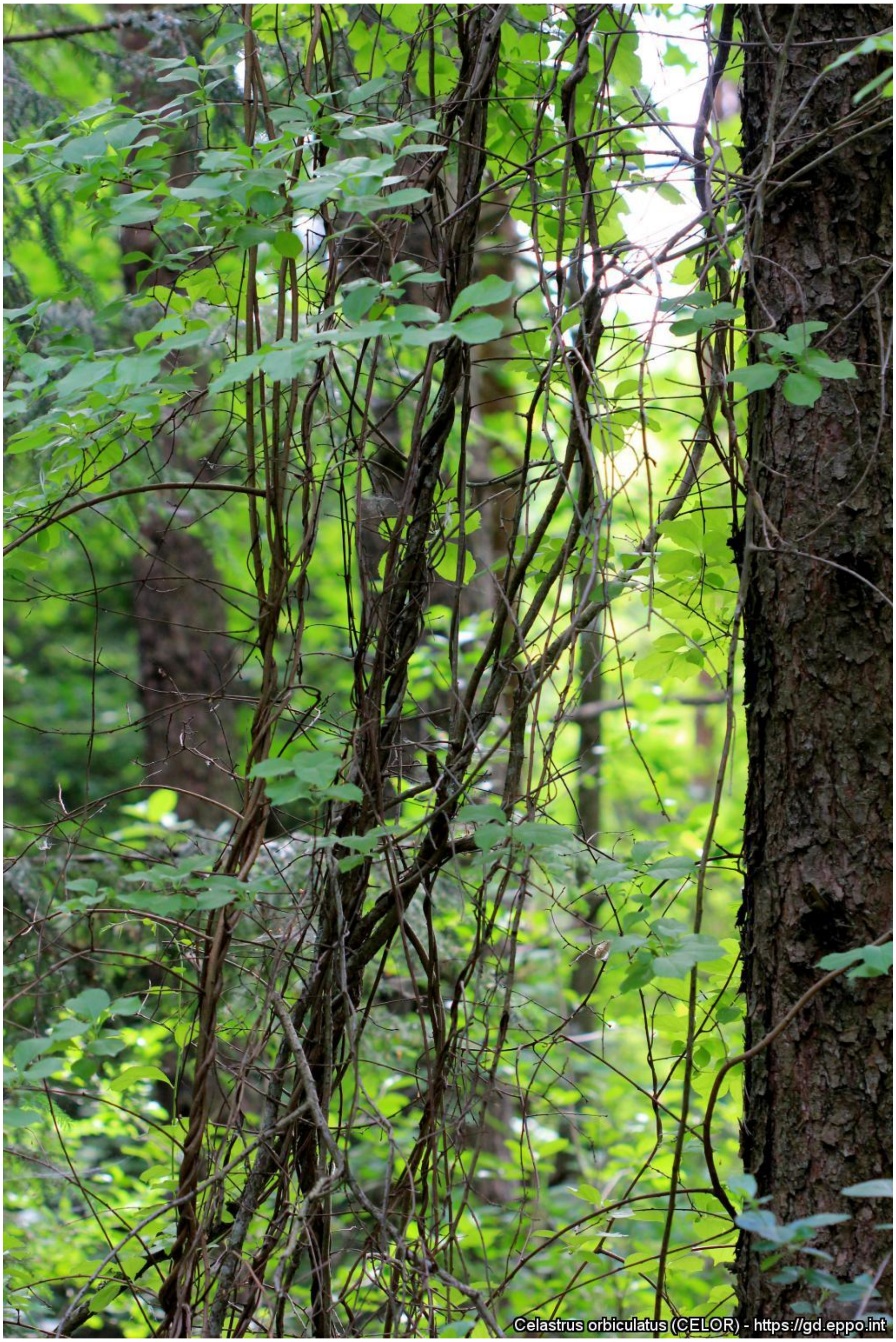


Fig. 2. Twining stems of *Celastrus orbiculatus* Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

Fig. 3. *Celastrus orbiculatus* fruits. Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

Fig. 4. *Celastrus orbiculatus* invading forest in Lithuania. Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

Fig. 5. *Celastrus orbiculatus* invading woodland in Lithuania. Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

Fig. 6. *Celastrus orbiculatus* invading forest in Lithuania. Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

Fig. 7.
*Celastrus orbiculatus* invading grassland in Lithuania. Image: EPPO Global Database Courtesy: Zigmantas Gudzinskas

## Appendix 2 Projection of climate suitability for *C. orbiculatus* establishment in the EPPO region

### Aim

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

### Data for modelling

Species occurrence data were obtained from the Global Biodiversity Information Facility (GBIF, 2021), Integrated Digitized Biocollections (iDigBio), USGS Biodiversity Information Serving Our Nation (BISON), Early Detection and Distribution Mapping System (EDDMapS), USDA Forest Service Forest Inventory and Analysis (FIA) plot data and additional records provided by the EWG. The records were scrutinised to remove any considered of dubious quality (e.g. known casual or cultivated occurrence, imprecise or bad coordinates, no date or older than 1970). Records were classified as native if occurring in China, South Korea, North Korea, Japan, Taiwan or the Russian far east, though we note there is some uncertainty about the native status in southern China (Beringen et al., 2017).

The records were gridded at a 0.25 x 0.25 degree resolution for modelling (Figure 1a). This resulted in 1869 grid cells containing valid records of *C. orbiculatus* (Figure 1a), which is a sufficient number for distribution modelling.

Based on the life history requirements of *C. orbiculatus* and likely limiting factors for establishment in Europe, the following predictor variables for climatic suitability and preferred habitat availability were assembled on the same grid:

- Mean minimum daily temperature of the coldest month (Bio6 °C) from WorldClim v2 (Fick & Hijmans, 2017). Seed germination of *C. orbiculatus* is benefitted by cold stratification at 5 °C (Greenberg, Smith, & Levey, 2001).
- Mean temperature of the warmest quarter (Bio10 °C) from WorldClim v2 (Fick & Hijmans, 2017). Though there is no specific evidence, it seems likely that growth and reproduction of *C. orbiculatus* would be limited by low growing season temperatures.
- Precipitation of the warmest quarter (Bio18 ln+1 transformed mm) from WorldClim v2 (Fick & Hijmans, 2017) as a measure of growing season moisture availability. *C. orbiculatus* survival and growth are impacted in both very dry and very wet soils (Leicht-Young, Silander, & Latimer, 2007).
- Climatic moisture index (CMI, ln+1 transformed) calculated as annual precipitation (Bio12 from Worldclim v2; Fick & Hijmans, 2017) divided by Potential Evapotranspiration (PET) and reflecting moisture availability for plants. PET (mm $yr^{-1}$) was estimated using monthly WorldClim v2 temperatures (Fick & Hijmans, 2017) following Zomer et al (2008). CMI represents the overall annual water balance, so is an alternative moisture variable to Bio18.
- Tree cover derived from a 500m global product based on MODIS data from 2008 (Kobayashi, Tsend-Ayush, & Tateishi, 2010).
- Human Influence Index (HII) (WCS & CIESIN, 2005) as a general measure of anthropogenic activity. HII is based on variables reflecting human population density, land use (built-up areas, nighttime lights, land use/land cover) and access (coastlines, roads, railroads, navigable rivers).
- Mean elevation (m asl) derived from NOAA Terrainbase (Row, Hastings, & Dunbar, 1995).

To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for the 2070s under the Representative Concentration Pathway (RCP) 4.5 and 8.5 were also obtained. For both scenarios, the above variables were obtained as averages of outputs of eight Global

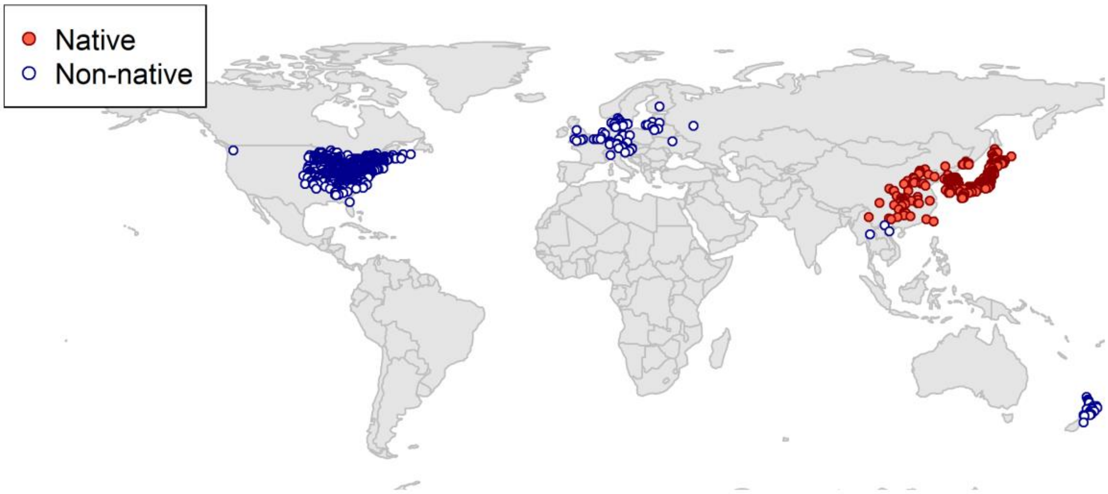
Climate Models (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, IPSL-CM5A-LR, MIROC-ESM, MRI-CGCM3, NorESM1-M), downscaled and calibrated against the WorldClim v1 baseline.

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

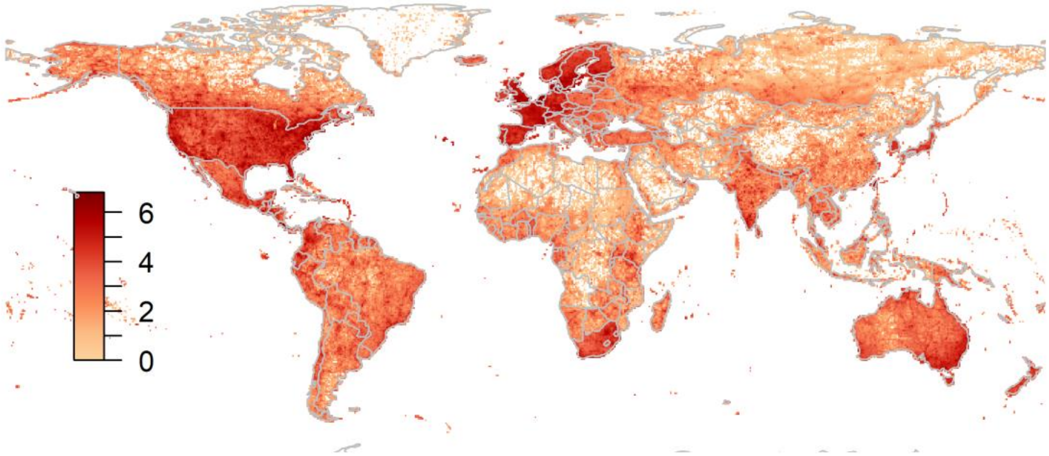
Finally, the recording density of vascular plants (phylum Tracheophyta) on GBIF was obtained as a proxy for spatial recording effort bias (Figure 1b).

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

(a) Species distribution used in modelling



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



**Species distribution model**

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

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

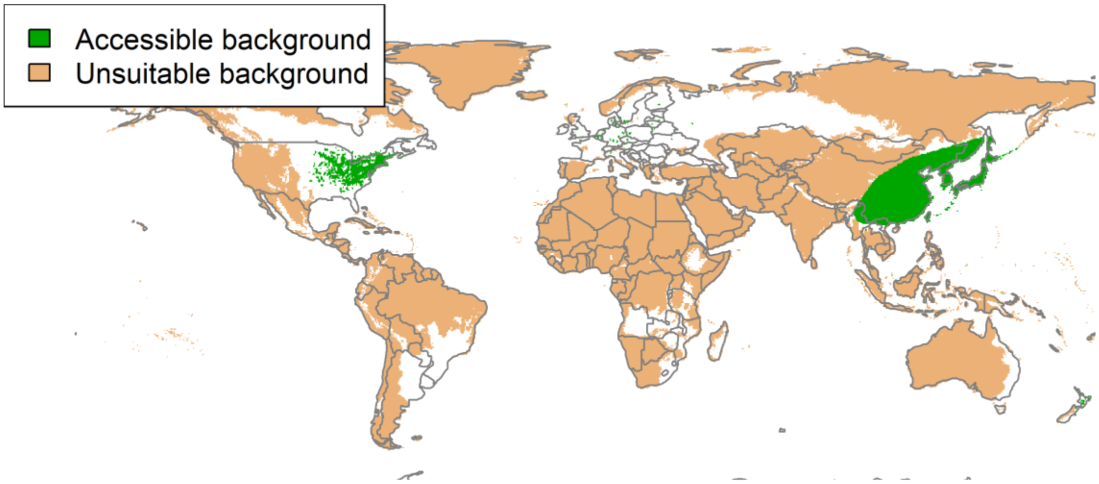
- An accessible background includes places close to *C. orbiculatus* populations, in which the species is likely to have had sufficient time to disperse and sample the range of environments. Based on a high potential for long-distance seed dispersal by birds, the accessible background was defined as a 400 km buffer around the native range (minimum convex polygon bounding native occurrences) and a 30 km buffer around non-native occurrences (capturing a 4-cell neighbourhood of the non-native occurrences). Sampling was more restrictive from the invaded range to account for stronger dispersal constraint over a shorter residence time. In previous testing of the model approach alternative buffer radii did not substantively affect the model projections (Chapman et al., 2019).
- An unsuitable background includes places expected to be physiologically unsuitable for the species, so that absence will be irrespective of dispersal constraints. Little specific ecophysiological information was available so, other than where stated, extreme values of the predictors at the species occurrences were used to define unsuitability as:
    - Mean temperature of the warmest quarter (Bio10) < 11 °C, presumed too cold for growth or seed maturation; OR
    - Mean temperature of the warmest quarter (Bio10) > 28 °C, presumed too hot for growth or seed maturation; OR
    - Minimum temperature of the coldest month (Bio6) < -31 °C, presumed too cold for survival based on observations of severe damage at temperatures this low in Lithuania (Zigmantas Gudžinskas, pers. comm.); OR
    - Minimum temperature of the coldest month (Bio6) > 14 °C, presumed too warm for seed stratification; OR
    - Precipitation of the warmest quarter (Bio18) < 140 mm, presumed too dry; OR
    - Precipitation of the warmest quarter (Bio18) > 1300 mm, presumed too wet; OR
    - Climatic moisture index < 0.35, presumed too dry; OR
    - Climatic moisture index > 3, presumed too wet.

No valid occurrences fell in the unsuitable background.

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

- From the accessible background 1869 samples were drawn, which is the same number as the occurrences. Sampling was performed with realistic recording bias using the target group approach (S. J. Phillips, 2009) in which sampling was weighted by GBIF Tracheophyte recording density (Figure 1b). Taking the same number of background samples as occurrences ensured the background sample had the same level of bias as the data.
- From the unsuitable background 5000 simple random samples were taken. Sampling was not adjusted for recording biases as we are confident of absence from these regions.

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



Using these data, a presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.4.6 (Thuiller, Georges, Engler, & Breiner, 2016; Thuiller, Lafourcade, Engler, & Araújo, 2009). Each dataset (presences and the five individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, six 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
- Classification tree analysis (CTA)
- Random forest (RF)
- Maxent (Steven J Phillips, Dudík, Dudik, & Phillips, 2008)

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

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

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

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

## Results

The ensemble model suggested that suitability for *C. orbiculatus* at the global scale and resolution of the model was more strongly limited by climate than habitat variables (Table 1). The strongest limiting factors were excessively low summer precipitation (Bio18) and low or high winter temperature (Bio6) (Figure 3). Summer temperature (Bio10) and Human Influence Index also had relatively strong effects. Weaker preferences for low elevations, moderate moisture balance (CMI) and tree cover were also modelled (Table 1, Figure 3).

Global projection of the ensemble model in current climatic conditions indicates that nearly all valid native and invaded records fell within regions predicted to have high suitability (Figure 4). Indeed, 98% of records were in grid cells predicted as suitable, i.e. above the minRocDist threshold of 0.4. The model suggests potential for ongoing expansion of the species into southern USA (from Mississippi to North Carolina) in which records of the species are currently sparse. In addition, the model identifies climatically suitable areas in temperate South America southern Africa, and Australia that are currently uninvaded.

In the EPPO region, the model predicts a large climatically suitable area across most of central, eastern and northern Europe, excluding the far north, and a smaller suitable region in Georgia and southern Russia (Figure 5). Western Britain and Ireland is also predicted to have areas with marginal suitability. The model suggests the main limiting factor in unsuitable parts of northern Europe is low summer precipitation (Bio18), though low summer temperatures (Bio10) are suggested as important in the far north and high annual moisture balance (CMI) in the far west.

Predictions of the model for the 2070s, under the moderate RCP4.5 climate change scenario suggests a northwards and eastwards expansion of the suitable area, driven by warming temperatures (Figure 7). It also predicts a contraction of the suitable area in southern and central parts of the current suitable area, driven by reduced summer precipitation. Similar patterns are projected for the more extreme RCP8.5 climate change scenario but with eve stronger limitation by lack of summer precipitation (Figure 8) but with no land use change, suggest large increases in suitability in northern Europe driven by warmer summers (Figures 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 Continental, Pannonian, Alpine and Boreal. With future climate projections, the Continental and Pannonian regions become less suitable, while the Boreal region increases strongly in suitability.

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

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

| **Algorithm** | **AUC** | **In the ensemble** | **Variable importance** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Minimum temperature of coldest month (Bio6)** | **Mean temperature of warmest quarter (Bio10)** | **Precipitation of the warmest quarter (Bio18)** | **Climatic moisture index (CMI)** | **Tree cover** | **Human Influence Index** | **Elevation** |
| GAM | 0.9064 | yes | 34% | 15% | 34% | 3% | 0% | 9% | 4% |
| GLM | 0.9060 | yes | 38% | 18% | 35% | 4% | 0% | 0% | 4% |
| GBM | 0.9032 | yes | 27% | 8% | 36% | 0% | 1% | 27% | 0% |
| Maxent | 0.9000 | yes | 34% | 8% | 35% | 4% | 6% | 10% | 3% |
| CTA | 0.8694 | no | 24% | 5% | 29% | 2% | 0% | 38% | 0% |
| RF | 0.8300 | no | 29% | 8% | 28% | 6% | 8% | 17% | 3% |
| Ensemble | 0.9058 | | 33% | 12% | 35% | 3% | 2% | 12% | 3% |

**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: Bio18 = ln Precipitation of the warmest quarter (mm) + 1; Bio6 = minimum temperature of coldest month (°C); Bio10 = mean temperature of warmest quarter (°C); HII = Human influence index; elevation = mean elevation (m asl); CMI = ln climatic moisture index +1; trees = proportion cover of trees.

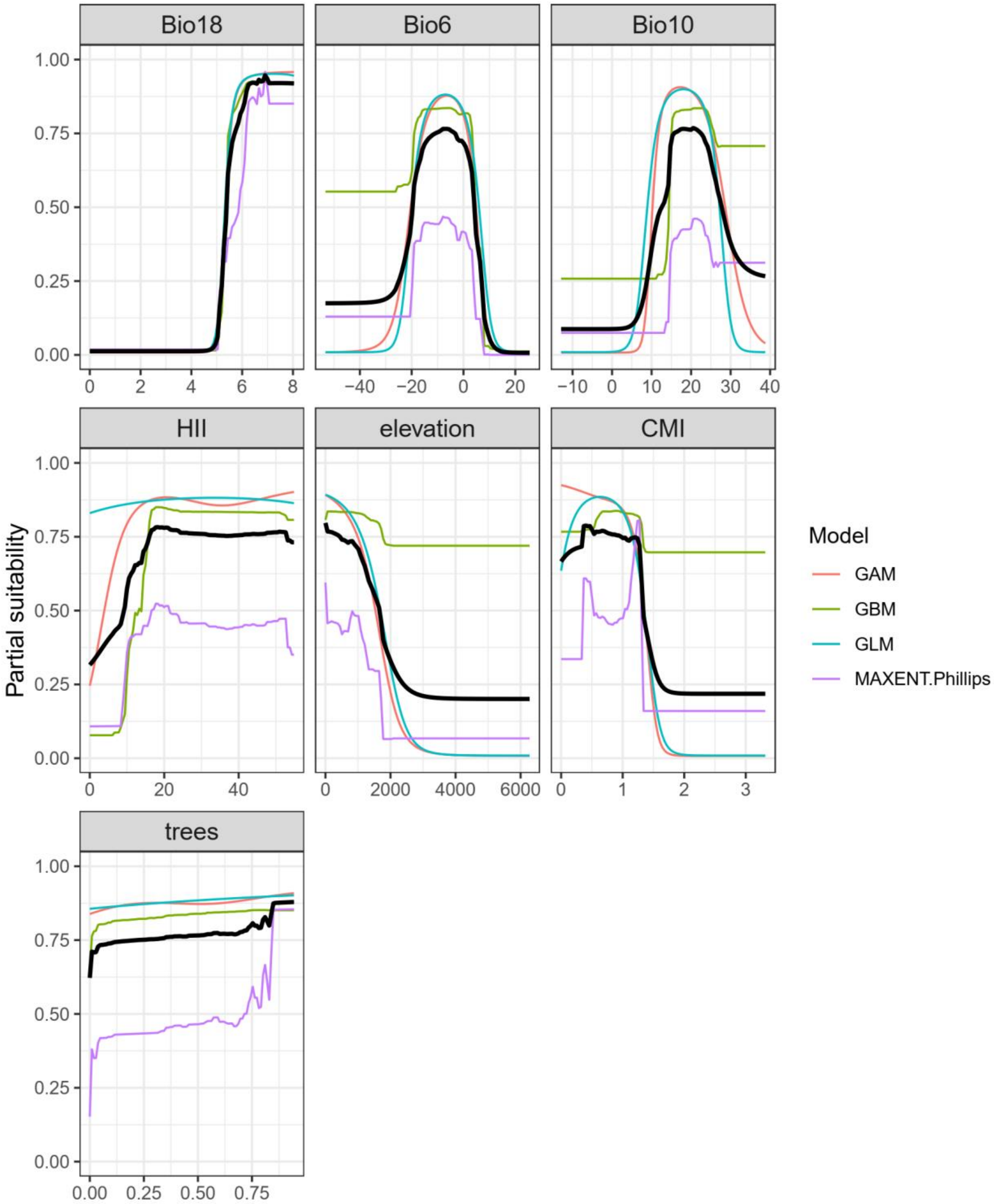
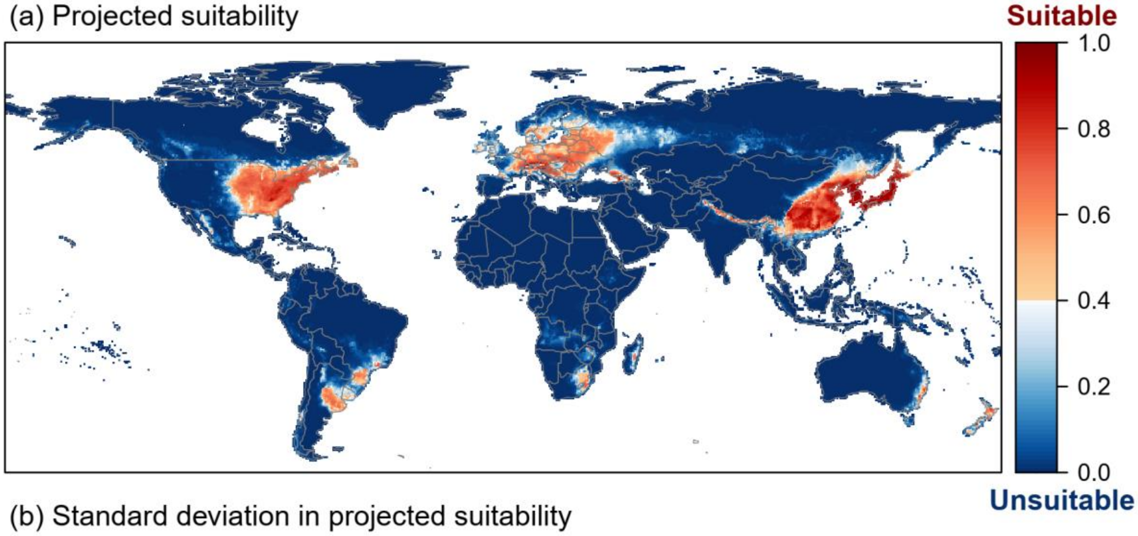


**Figure 4.** (a) Projected global suitability for *Celastrus orbiculatus* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Red shading indicates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

(a) Projected suitability



(b) Standard deviation in projected suitability

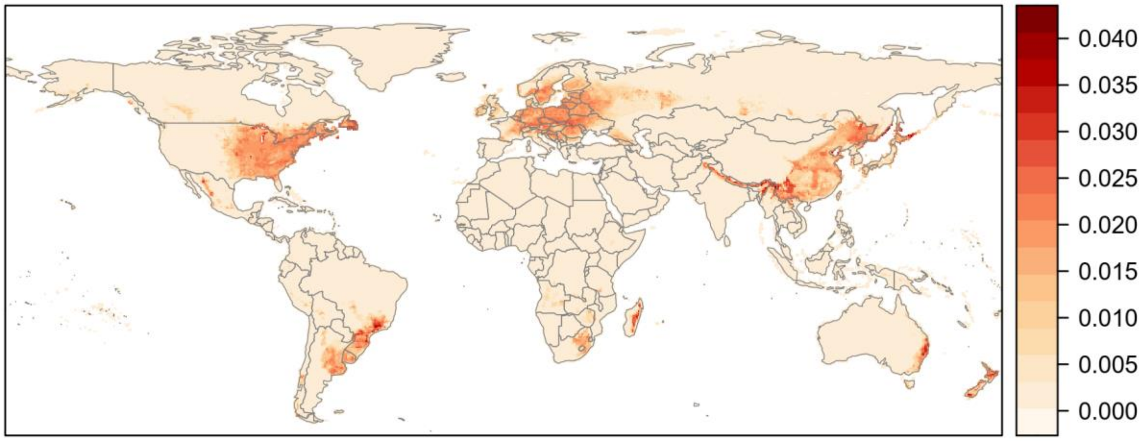


**Figure 5.** Projected current suitability for *Celastrus orbiculatus* establishment in Europe and the Mediterranean region.

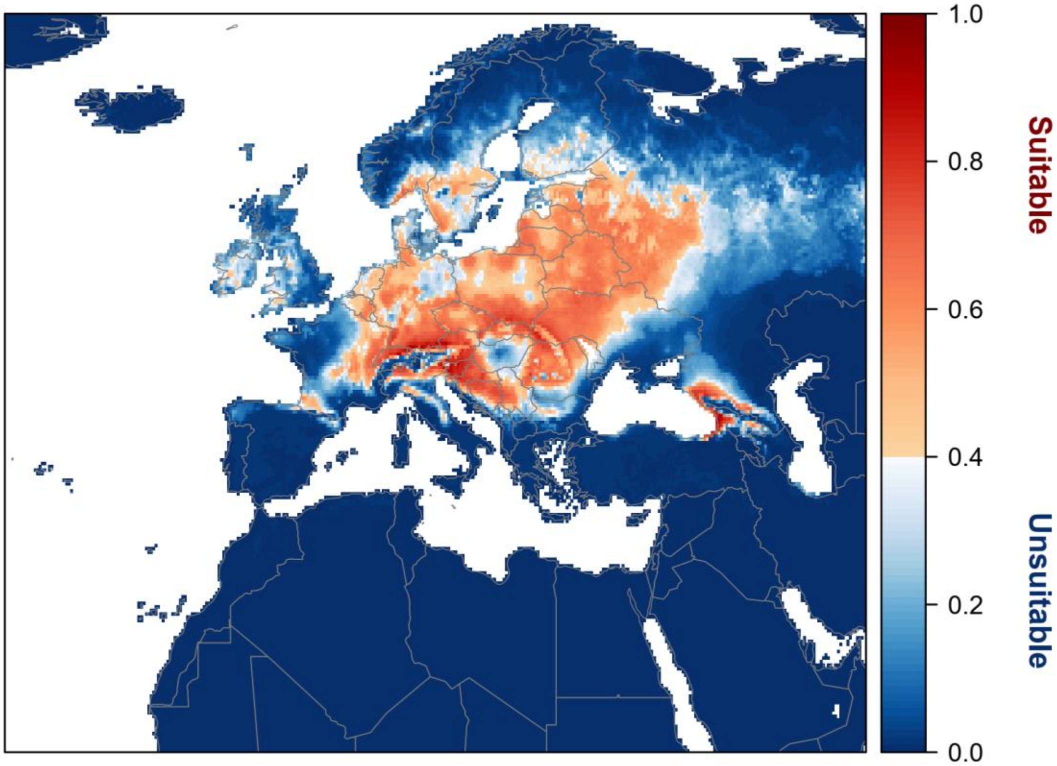


**Figure 6.** Limiting factor map for *Celastrus orbiculatus* in Europe and the Mediterranean region in the current climate. Colours show the variable most strongly limiting suitability.

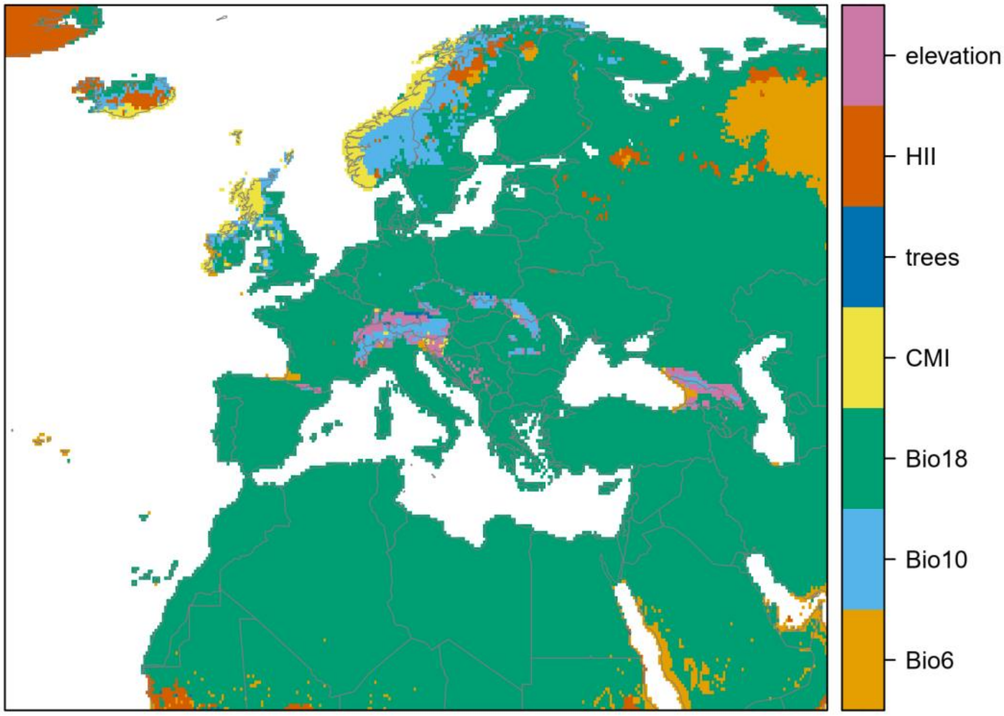


**Figure 7.** Projected suitability for *Celastrus orbiculatus* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP4.5.

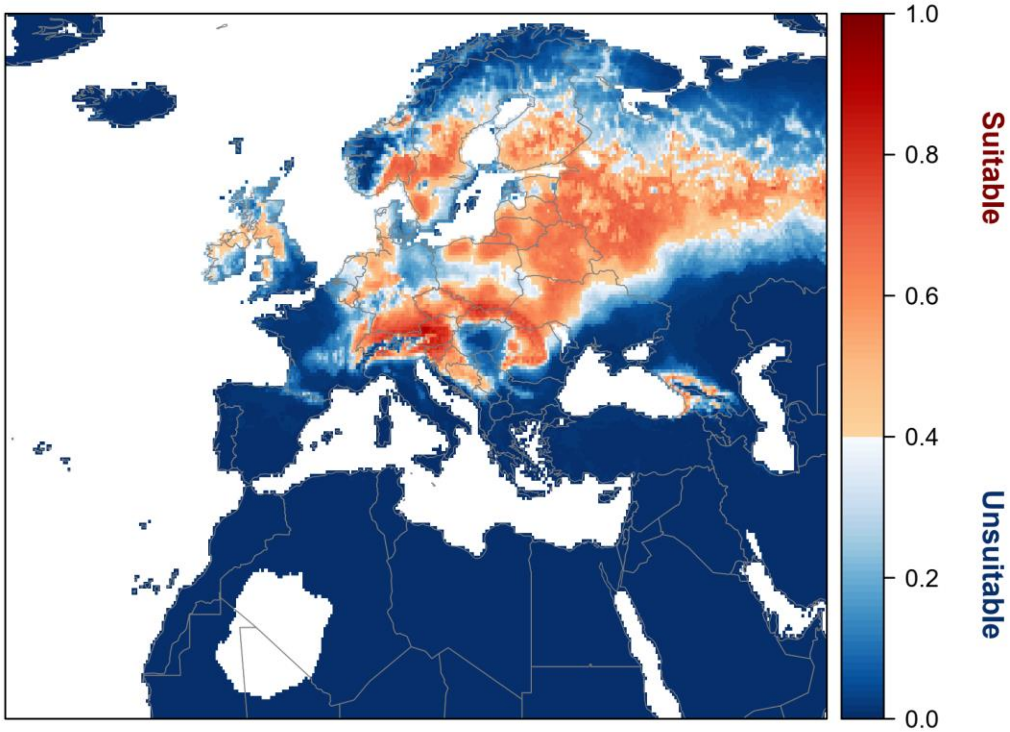


**Figure 8.** Projected suitability for *Celastrus orbiculatus* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP8.5.

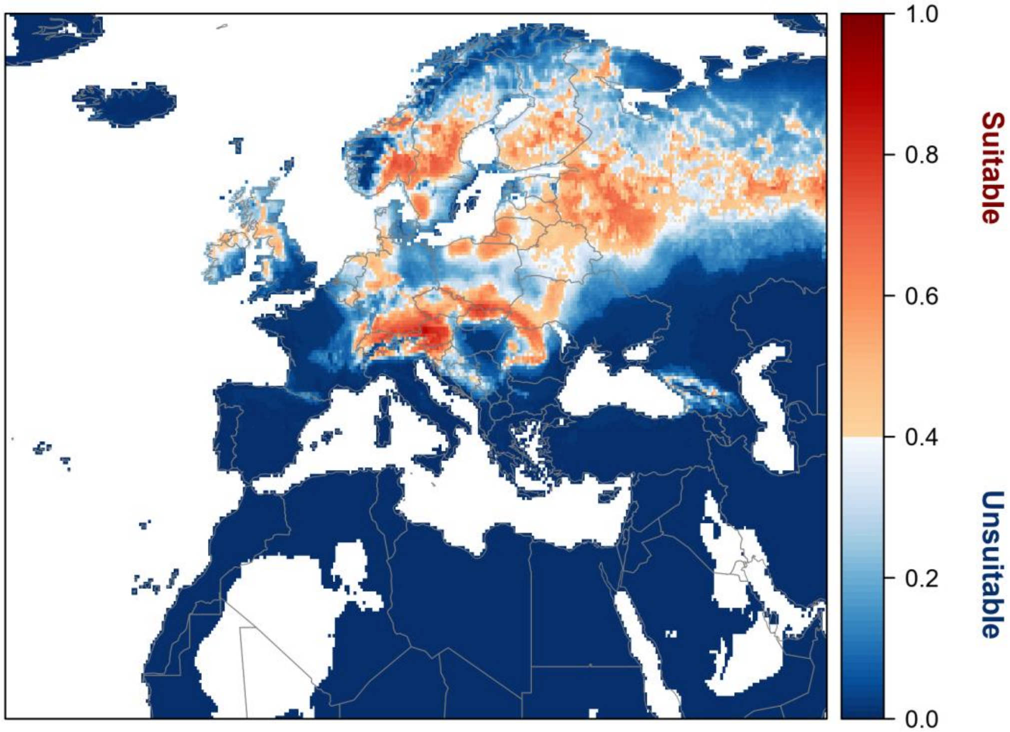


**Figure 9.** Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). Bar plots show the proportion of grid cells in each region classified as suitable in the current climate and projected climate for the 2070s under emissions scenarios RCP4.5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

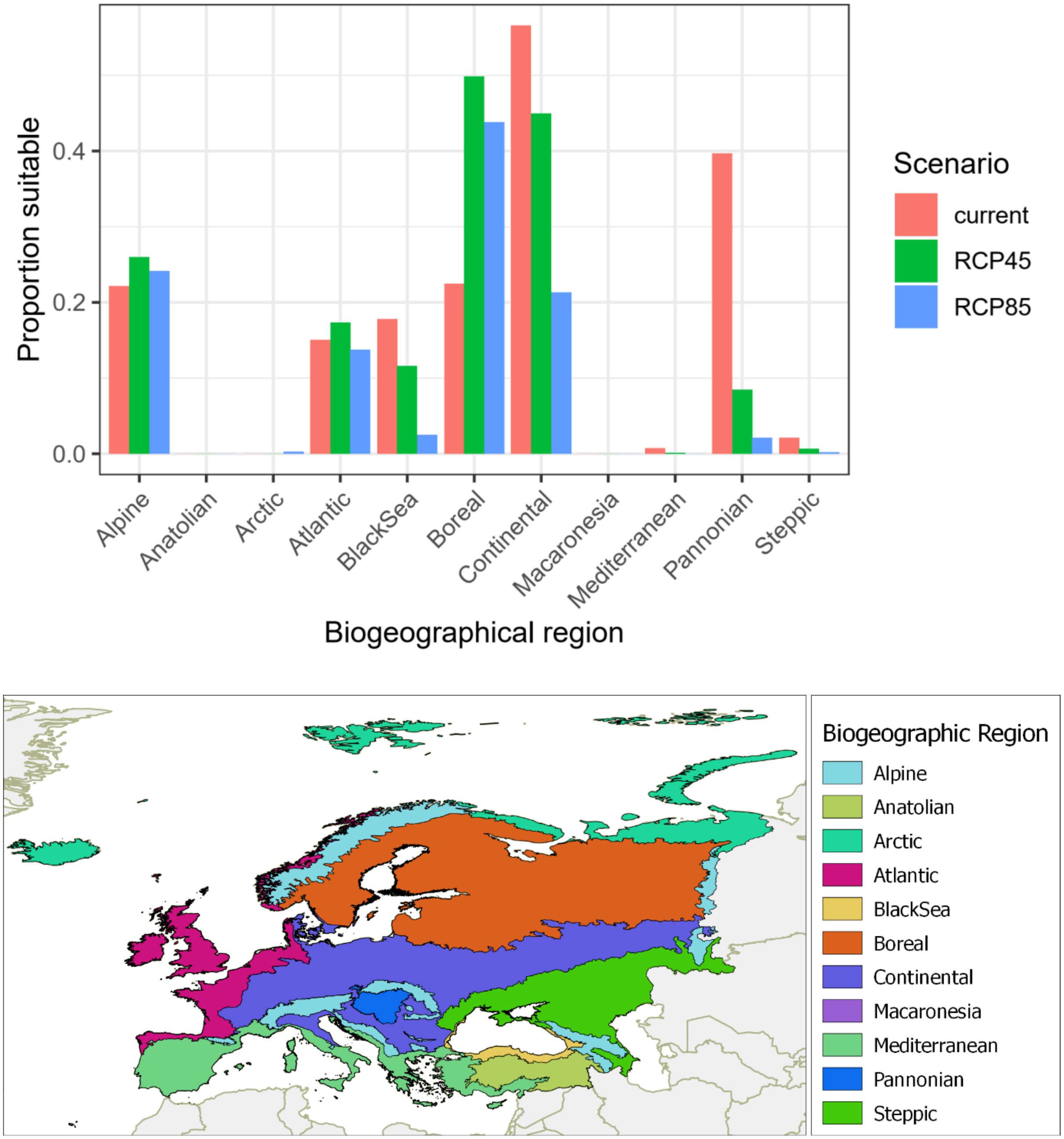


**Table 2.** Projected % suitability among EPPO member countries, sorted from high to low in the current climate. Values are the % of grid cells in each country classified as suitable in the current climate and projected climate for the 2070s under RCP4.5 and RCP8.5.

| EPPO country (ISO3) | Current | RCP4.5 | RCP8.5 |
|---|---|---|---|
| LTU | 100 | 100 | 72 |
| BLR | 100 | 97 | 44 |
| CZE | 100 | 87 | 75 |
| SVN | 97 | 97 | 90 |
| LVA | 97 | 95 | 74 |
| POL | 88 | 63 | 38 |
| AUT | 82 | 85 | 81 |
| SVK | 81 | 74 | 62 |
| BIH | 79 | 67 | 8 |
| EST | 78 | 66 | 35 |
| BEL | 78 | 32 | 21 |
| HRV | 75 | 56 | 11 |
| DEU | 75 | 50 | 41 |
| ROU | 65 | 44 | 27 |
| NLD | 62 | 21 | 20 |
| SRB | 59 | 11 | 1 |
| CHE | 56 | 64 | 68 |
| MDA | 55 | 18 | 2 |
| UKR | 50 | 35 | 16 |
| GEO | 37 | 23 | 3 |
| HUN | 33 | 7 | 1 |
| FRA | 24 | 5 | 3 |
| LUX | 20 | 0 | 0 |
| DNK | 19 | 16 | 9 |
| SWE | 16 | 39 | 38 |
| ITA | 16 | 11 | 9 |
| IRL | 10 | 24 | 17 |
| MNE | 9 | 4 | 0 |
| BGR | 5 | 0 | 0 |
| FIN | 5 | 45 | 42 |
| NOR | 4 | 11 | 16 |
| RUS | 3 | 8 | 6 |
| GBR | 2 | 24 | 18 |
| TUR | 1 | 0 | 0 |
| ESP | 0 | 0 | 0 |
| ALB | 0 | 0 | 0 |
| AZE | 0 | 0 | 0 |
| CYP | 0 | 0 | 0 |
| DZA | 0 | 0 | 0 |
| GGY | 0 | 0 | 0 |
| GRC | 0 | 0 | 0 |
| ISR | 0 | 0 | 0 |
| JEY | 0 | 0 | 0 |
| JOR | 0 | 0 | 0 |
| KAZ | 0 | 0 | 0 |
| KGZ | 0 | 0 | 0 |
| MAR | 0 | 0 | 0 |
| MKD | 0 | 0 | 0 |
| PRT | 0 | 0 | 0 |
| TUN | 0 | 0 | 0 |
| UZB | 0 | 0 | 0 |
| MLT* |  |  |  |

* No prediction possible due to lack of predictor GIS layer coverage.

### 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. Southern China might have been better regarded as non-native.
- The models were constructed using convenient climate and habitat layers, which may not be the most appropriate for *C. orbiculatus*. Specific predictors layers capturing requirements for different stages of the life cycle (e.g. for germination in spring or seed ripening in late summer) may have improved the predictions.
- Habitat preferences seem to differ between native and non-native ranges (with a stronger affinity for urban areas in the invaded ranges). The models used could not account for this difference and this may have impeded prediction of habitat effects on the potential distribution.
- The selection of the background sample was weighted by the density of vascular plant records on the Global Biodiversity Information Facility (GBIF) to reduce spatial recording bias. While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species recording, especially because additional data sources to GBIF were used.

### Acknowledgements

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## Appendix 3 Distribution of *C. orbiculatus* data used for the modelling

Fig. 1. Distribution points for Asia

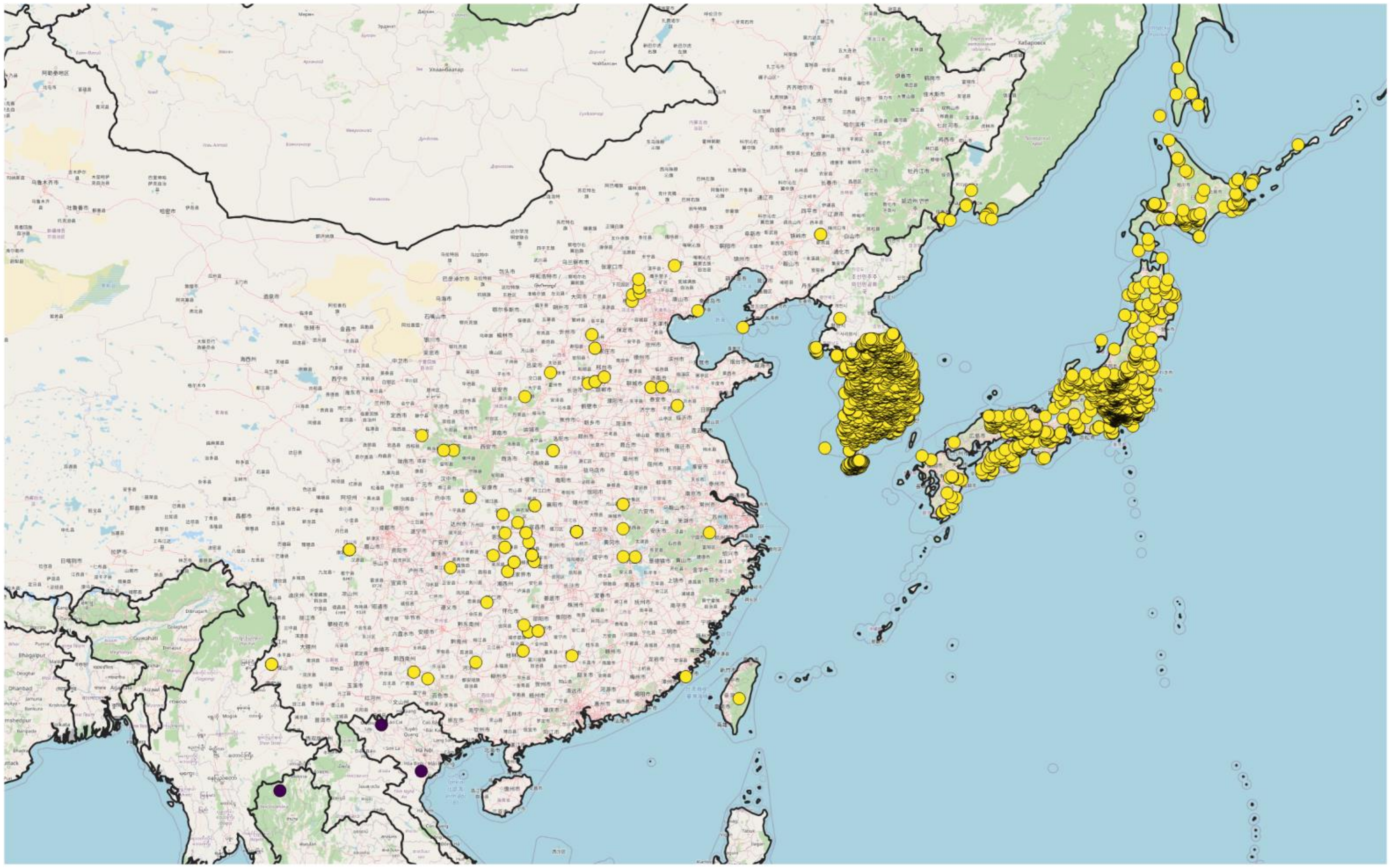


Fig. 2 Distribution points for North America

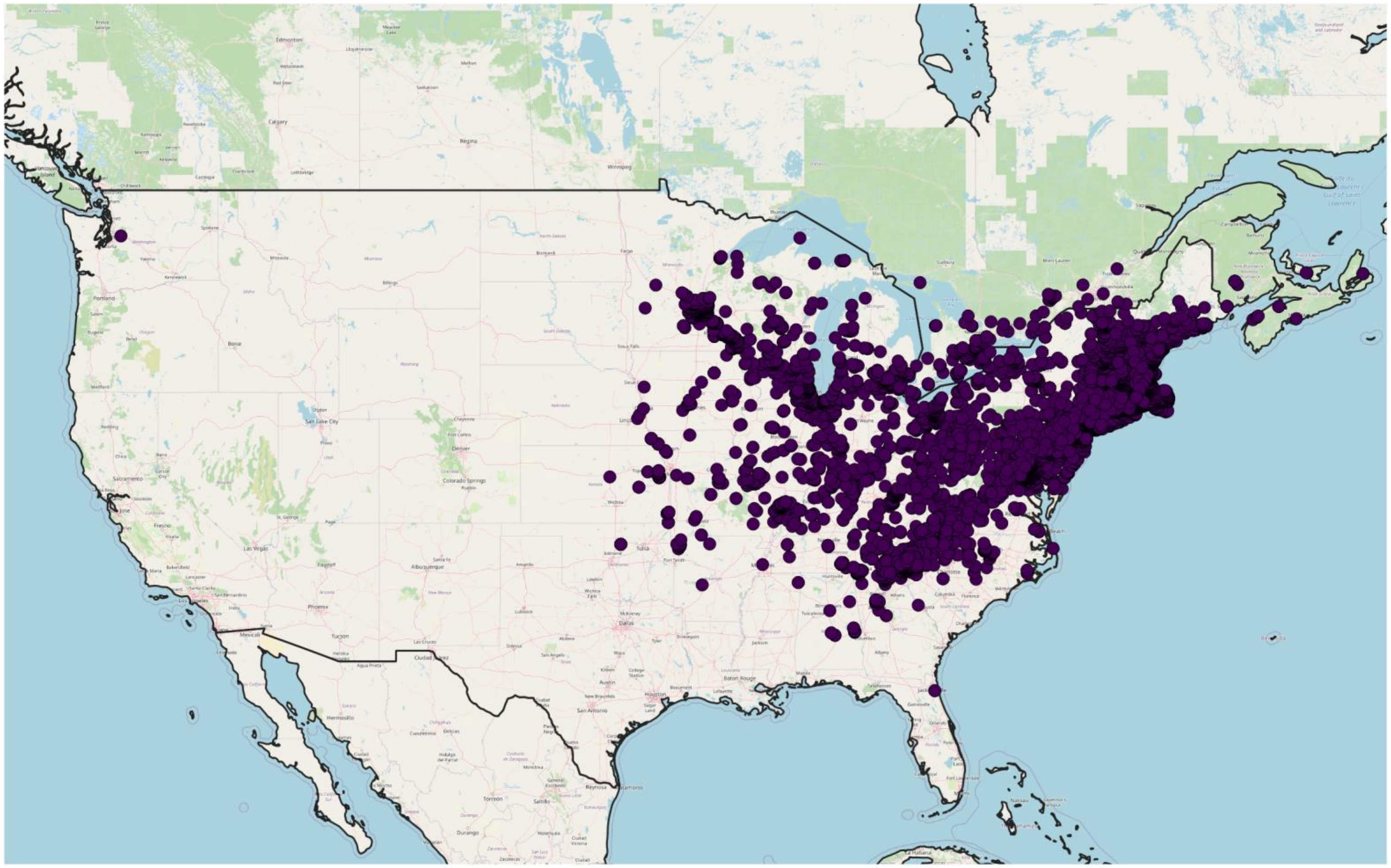


Fig. 3. Distribution points for Europe

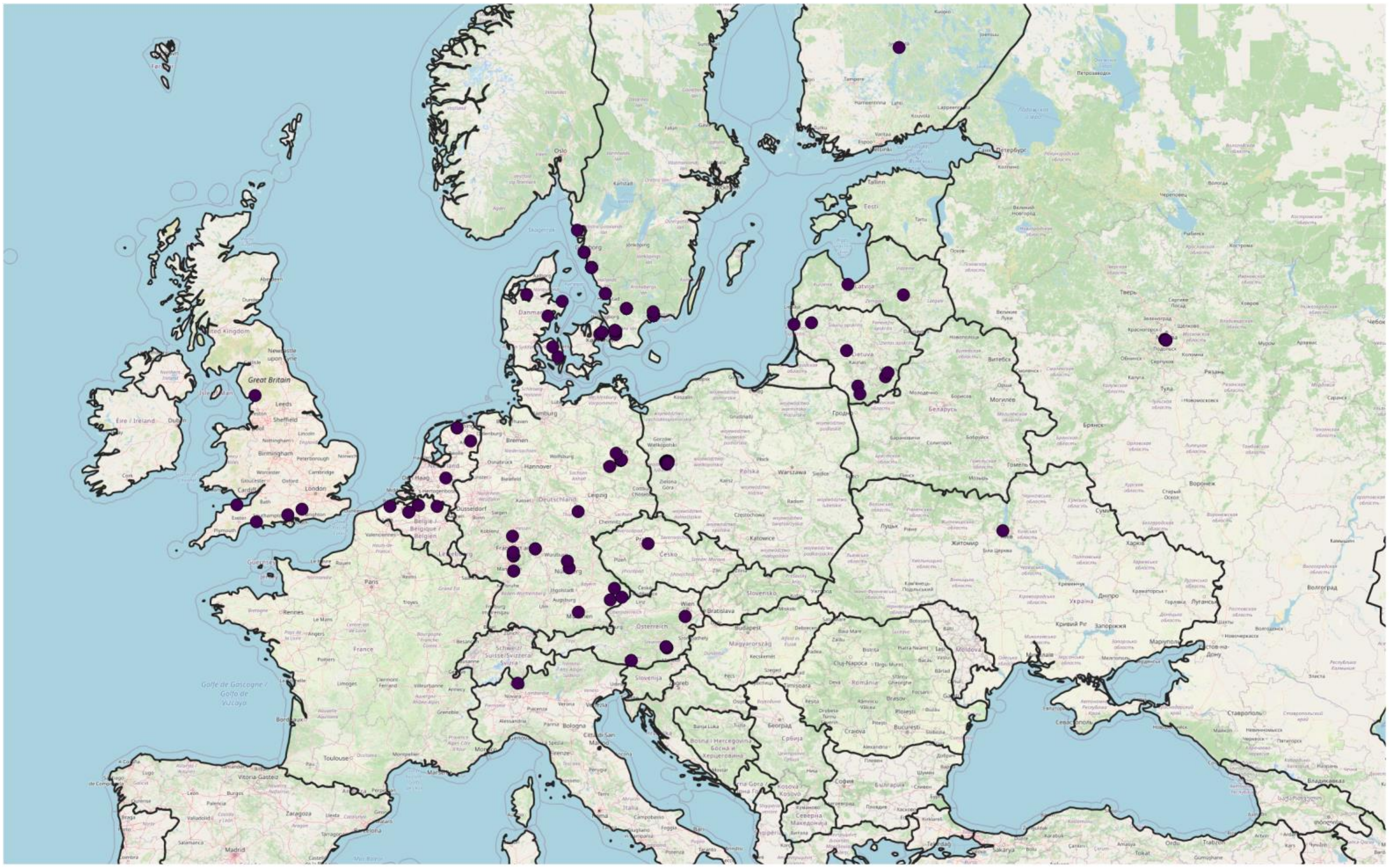
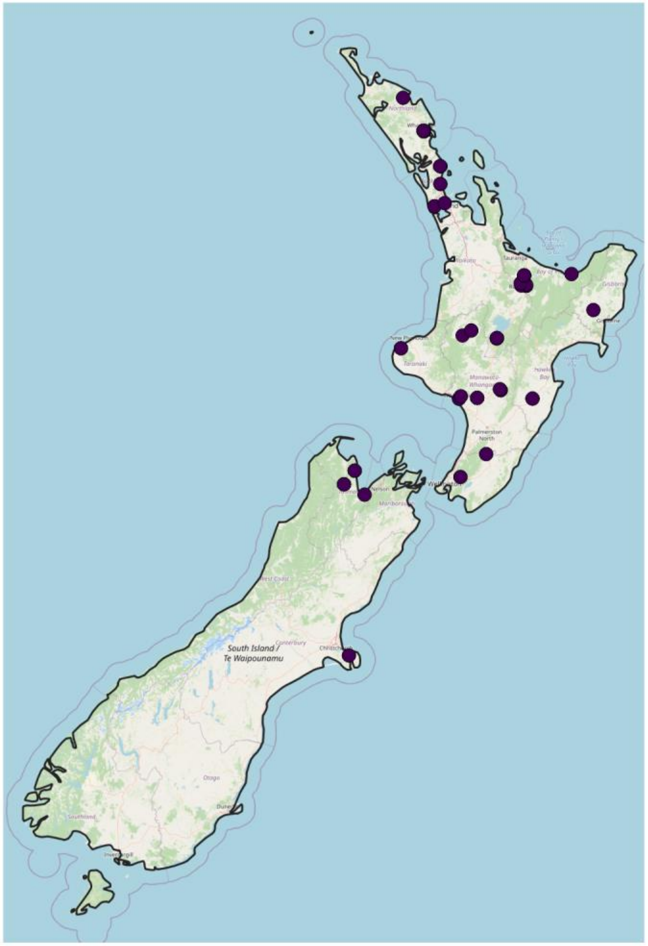
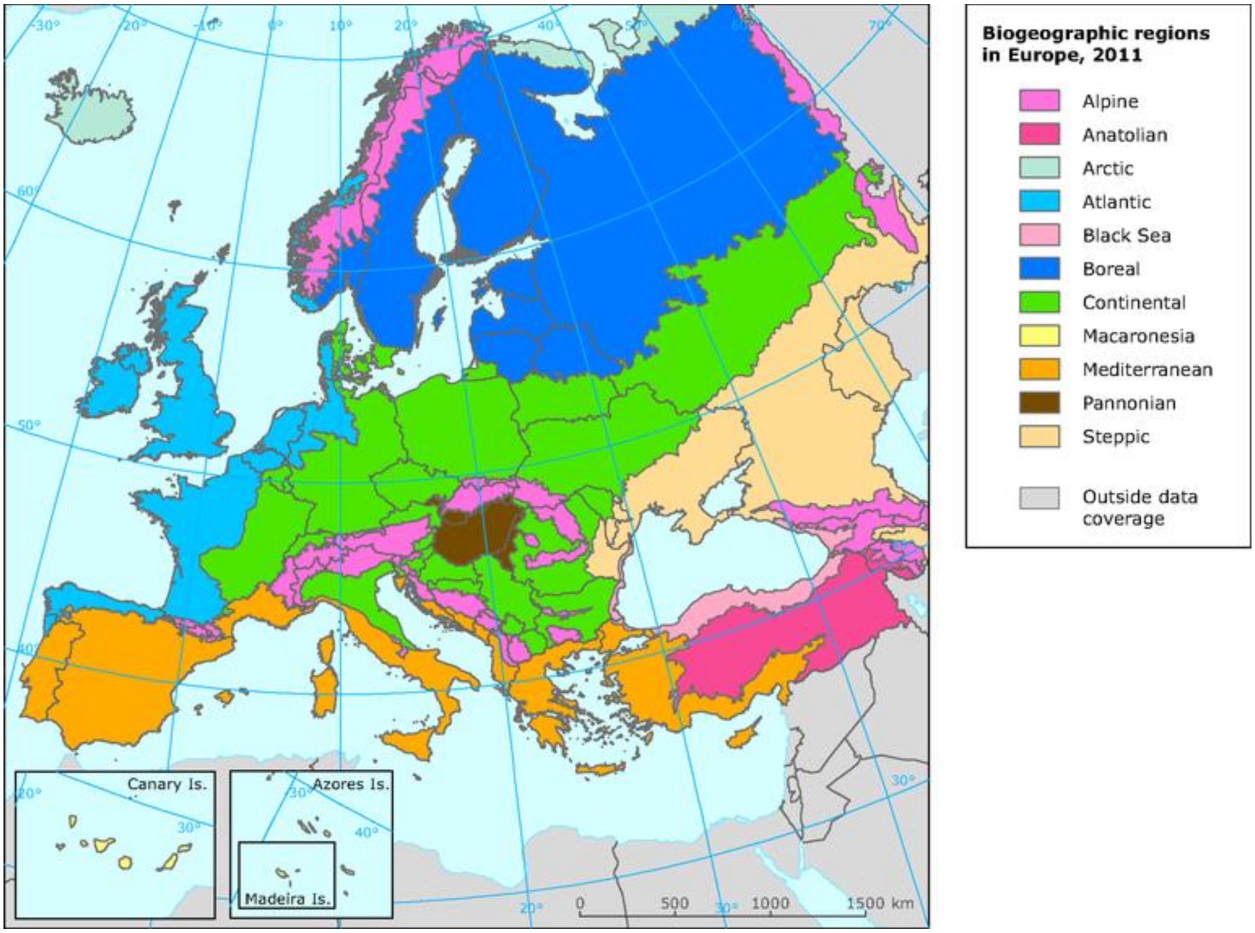


Fig. 4. Distribution points for New Zealand



## Appendix 4: Biogeographical regions in Europe



## Appendix 5. Percentage of relevant Köppen-Geiger zones present in EPPO member countries

| Country | Cfa | Cfb | Dfa | Dfb | Dwa |
|---|---|---|---|---|---|
| Austria | | 62.6% | | 9.5% | |
| Belgium | | **100.0%** | | | |
| Bulgaria | 61.8% | 25.7% | | 7.2% | |
| Croatia | 32.9% | 50.1% | | 0.6% | |
| Cyprus | | | | | |
| Czech Republic | | 92.0% | | 7.5% | |
| Denmark | | **100.0%** | | | |
| Estonia | | 6.3% | | 93.7% | |
| Finland | | | | 17.1% | |
| France (Corse) | | | | | |
| France (Mainland) | 7.3% | 84.6% | | | |
| Germany | | 99.6% | | 0.2% | |
| Greece (Crete) | | | | | |
| Greece (Mainland) | 3.3% | 2.2% | | 0.2% | |
| Hungary | 11.5% | 87.9% | | 0.6% | |
| Ireland | | **100.0%** | | | |
| Italy (Mainland) | 28.3% | 21.1% | | 0.6% | |
| Italy (Sardegna) | | | | | |
| Italy (Sicilia) | | | | | |
| Latvia | | 36.2% | | 63.6% | |
| Lithuania | | 20.8% | | 79.2% | |
| Luxembourg | | **100.0%** | | | |
| Netherlands | | **100.0%** | | | |
| Poland | | 93.1% | | 6.6% | |
| Portugal (Mainland) | | | | | |
| Romania | 36.5% | 34.1% | | 23.1% | |
| Slovakia | | 56.0% | | 38.1% | |
| Slovenia | 1.2% | 89.3% | | 4.5% | |
| Spain (Isles Baleares) | | | | | |
| Spain (Mainland) | 3.9% | 13.9% | | 0.0% | |
| Sweden | | 23.0% | | 5.5% | |
| United Kingdom (England) | | 99.9% | | | |
| United Kingdom (Northern Ireland) | | **100.0%** | | | |
| United Kingdom (Scotland) | | 80.8% | | | |
| United Kingdom (Wales) | | **100.0%** | | | |
| Albania | 2.3% | 18.0% | | 2.5% | |
| Algeria | 0.1% | | | | |
| Azerbaijan | 15.3% | 0.6% | 1.4% | 14.3% | |
| Belarus | | 3.9% | | 96.1% | |
| Bosnia and Herzegovina | 13.8% | 75.8% | | 5.6% | |
| Georgia | 30.9% | 4.4% | 5.3% | 39.9% | |
| Israel | | | | | |
| Jordan | | | | | |
| Kazakhstan | 0.1% | | 9.0% | 26.1% | |
| Kyrgyzstan | 0.1% | | 2.3% | 9.8% | |

| | | | | | |
|---|---|---|---|---|---|
| Moldova | 83.9% | 16.1% | | | |
| Morocco | | | | | |
| Norway | | 10.2% | | 4.5% | |
| Serbia | 52.6% | 41.5% | | 5.5% | |
| Switzerland | | 57.8% | | | |
| Tunisia | | | | | |
| Turkey | 3.1% | 5.5% | 0.1% | 5.9% | |
| Ukraine | 15.2% | 10.8% | 15.1% | 58.2% | |
| Uzbekistan | | | | | |
| Montenegro | | 49.3% | | 28.3% | |
| Macedonia | 39.3% | 42.7% | | 6.4% | |
| Russia (Central Russia) | | 0.7% | 0.0% | 90.1% | |
| Russia (Eastern Siberia) | | | | 0.7% | |
| Russia (Far East) | | | | 15.1% | 0.5% |
| Russia (Northern Russia) | | | | 1.8% | |
| Russia (Southern Russia) | 15.8% | 0.8% | 35.4% | 33.6% | |
| Russia (Western Siberia) | | | | 34.4% | |
| Spain (Canarias) | | | | | |
| United Kingdom (Channel Islands) | | **100.0%** | | | |