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# Contents

# Summary

This report describes a risk assessment of the alien Staff-vine (*Celastrus orbiculatus*) in the European Union (EU). This plant species has recently been identified in a horizon scanning as a potential invasive alien species with a limited distribution in the EU. The species is native to Eastern Asia. It is a deciduous, twining, woody vine or shrub, growing up to 12 m high. It has been present in European botanical gardens since 1863. Nowadays, it is offered for sale as an ornamental plant in many European countries because of its colourful display of fruits and leaves in late summer and autumn.

The present risk assessment is based on a detailed risk inventory of *C. orbiculatus*, which includes a science based overview of the current knowledge on taxonomy, habitat preference, introduction and dispersal mechanisms, current distribution, ecological impact, socio-economic impact and consequences for public health of the species. A team of experts used this information to assess and classify the (potential) risks of spread, invasiveness and impact of *C. orbiculatus* in the EU using the Harmonia$^+$ and Invasive Species Environmental Impact Assessment (ISEIA) protocols. The report also includes a risk assessment of *C. orbiculatus* that is focussed on the Netherlands.

Since 1980, records of *C. orbiculatus* naturalizing in several EU member states have been made, mostly in or nearby urban areas. The species has been reported as invasive in a very wide range of habitats in parts of its introduced range (United States of America and New Zealand), such as sand dunes, open fields, reforested agricultural fields, both wet and dry forests and old-growth forests. The risks of establishment and spread within the EU are expected to be high, considering the climate match, the wide range of habitat conditions in which the species can occur, and the availability of suitable habitat in the EU. Suitable habitats in the EU are most likely to be forests on moist, fertile, and neutral soils, such as alluvial and riparian mixed forests (Natura 2000 codes 91E0 and 91F0).

The high fecundity, berry production and germination success rate, the seedlings that survive low light levels, the growth rate of 3 m/year and the dispersal of seeds by birds and small mammals are characteristics that might facilitate the establishment of *C. orbiculatus*. In addition to the dispersal of diaspores by berry eating birds, unintentional distribution through the improper disposal of garden waste from gardens to the wild can contribute to the spread of the species. As soon as the species is established and the requirement of multiple clones to guarantee fruit set in this dioecious species is met, the number of locations where the species is recorded will increase. After the initiation of sexual reproduction, *C. orbiculatus* may spread rapidly, and unintentional distribution by berry eating birds will occur. The propagule pressure will thus increase over time if management policies remain unchanged.

Reports on the species' negative impact in the USA and New Zealand, and the climate match with, and availability of suitable habitat in the EU suggest that *C. orbiculatus* may adversely affect the biodiversity and functioning of mature forest ecosystems in the EU. The alien species may occasionally colonise high conservation value habitats. The presence of disturbance in forests and sufficient light may allow *C. orbiculatus* to become the dominant canopy species and significantly alter habitat conditions for native species. The species limits transport of assimilates in trees caused by twining around their stems and branches. It also increases the risk of wind-throw. Furthermore, forest undergrowth can become overgrown with *C. orbiculatus*. Additionally, nutrient availability resulting from nitrogen mineralization and litter decomposition may increase as a result of *C. orbiculatus* establishment. The impact of *C. orbiculatus* on ecosystem functioning as a result of, for example, the physical modification of habitat, is expected to be high. These changes are expected to be hardly reversible.

*C. orbiculatus* may also negatively impact timber production because the alien species suppresses regeneration and can totally overgrow young trees in forest plantations. Yet, no information on the potential costs of damage to biodiversity, ecosystem services and the economy was found in the available literature.

The expert team allocated *C. orbiculatus* the total risk score "**medium**". The total risk score refers to the ecological risks in the EU using the Harmonia$^+$ and ISEIA protocols. The total risk score implies that *C. orbiculatus* should be added to the **watch list** of the BFIS-list system, both for the current situation (class B1). Future climate change (defined as a 2 °C increase over current temperatures), and unchanged EU and national policies for *C. orbiculatus*, are expected to have no effect on its ecological risk. Furthermore, a temperature increase will likely not change the risk of spread within the EU, but will probably result in a northerly geographical shift in suitable habitat and increase in altitude in available mountain habitats. Available risk classifications for *C. orbiculatus* in the USA and New Zealand are higher in comparison with the Harmonia$^+$ and ISEIA assessments for the EU.

# 1. Introduction

## 1.1 Background and problem statement

Recently, several horizon scanning reports have been published to identify potential invasive alien species (IAS) that may be introduced or have a very limited distribution in the Netherlands or the European Union (EU) (Matthews et al. 2014, 2017, Roy et al. 2015). Staff-vine (*Celastrus orbiculatus*) was one of the species that scored a high ecological risk for the Netherlands and larger areas of the EU, and is currently present on a limited scale in the EU. Therefore, the Office for Risk Assessment and Research of the Netherlands Food and Consumer Product Safety Authority (NVWA) requested to perform a scientific risk assessment for this species.

*C. orbiculatus* is native to Eastern Asia. It is a deciduous, twining, woody vine or shrub, growing up to 12 m high. The species has been reported as invasive in several areas of its introduced range and in a very wide range of habitats (Chapter 3). The species has been present in European botanical gardens from 1863 onwards and nowadays is offered for sale as a garden plant in many European countries because of its colourful display of fruits and leaves in late summer and autumn.

The present report presents the risk assessment of *C. orbiculatus* for the European Union. Additionally, appendix 2 presents a risk assessment of the species that has been undertaken for the Netherlands. The assessments are based on a detailed risk inventory. The analyses of available data and risk classifications of the species have been performed by a team of experts using the Harmonia$^+$ and Invasive Species Environmental Impact Assessment (ISEIA) protocols.

## 1.2 Research goal

The goals of this study is to conduct a risk assessment of the alien *C. orbiculatus* for the EU that complies with the criteria for listing IAS of EU concern described in Regulation 1143/2014. This risk assessment concerns the probability of introduction, establishment, spread, colonisation of high conservation value habitats, (potential) ecological and socio-economic effects, and impact on public health.

## 1.3 Outline and coherence of the research

The coherence between various research activities and outcomes of the study are visualised in Figure 1.1. The present chapter describes the problem statement, goals and research questions in order to assess and classify the risks of *C. orbiculatus* in the European Union. Chapter 2 describes the results of the risk inventory, which includes a science based overview of the current knowledge on taxonomy, habitat preference, introduction and dispersal mechanisms, current distribution, ecological impact, socio-economic impact and consequences for public health of the species. A team of experts used the information provided in the risk inventory to assess and classify the (potential) risks of spread, invasiveness and impact of *C. orbiculatus* in the EU using the ISEIA and Harmonia$^+$ protocols. Chapter 3 includes the results of these risk assessments and classifications. Moreover, in this chapter, the results of other available risk classifications are summarized and compared with the results of the present risk assessments. The uncertainties in the risk assessments, relevant knowledge gaps and differential outcomes (risk classifications) of available risk assessments are discussed in chapter 4. Chapter 5 draws conclusions. Chapter 6 summarizes the evidence for compliance with the criteria for listing the species as an IAS of EU concern. Appendix 1 describes the methods used for the inventory (including literature review and data collection), assessment and classification of the risks of the introduction and spread of this species. Appendix 2 summarizes the results of the risk classification of *C. orbiculatus* for the Netherlands using the ISEIA protocol. Appendix 3 includes an overview of the current distribution of *C. orbiculatus* in the EU. Finally, details on outcomes of the peer review procedure for this report are summarized in appendix 4.

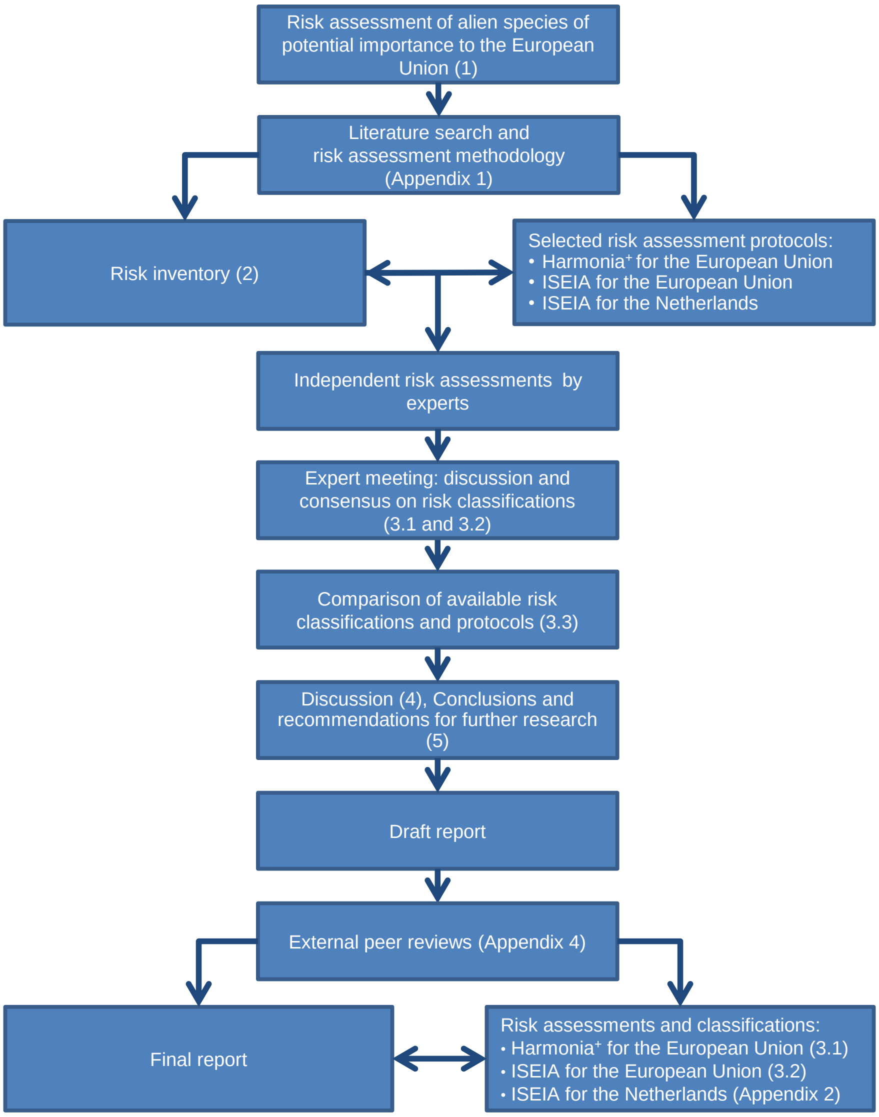



**Figure 1.1:** Flow chart visualising the coherence of various research activities (chapter numbers are presented between brackets; ISEIA: Invasive Species Environmental Impact Assessment protocol).

# 2. Risk inventory

## 2.1 Species description

### 2.1.1 Nomenclature and taxonomic status

The nomenclature and taxonomic status of *C. orbiculatus* are summarized in Table 2.1. The risk of misidentification is low during bloom or fruiting. The species can be distinguished from other species of the same genus by its inflorescences, fruit capsules or pollen (see §2.1.2).

**Table 2.1:** Nomenclature and taxonomic status of Staff-vine (*Celastrus orbiculatus*).

**Scientific name:** *Celastrus orbiculatus* Thunb.

**Synonyms**[1]**:**
*Celastrus articulatus* Thunb.
*Celastrus insularis* Koidz.
*Celastrus jeholensis* Nakai ex Nakai & Kitag.
*Celastrus lancifolia* Nakai
*Celastrus stephanotiifolius* (Makino) Makino
*Celastrus strigillosus* Nakai
*Celastrus tatarinowii* Rupr.
*Celastrus versicolor* Nakai

**Taxonomic tree**

| According to CABI (2014): | According to GBIF (2016): |
|---|---|
| Domain: Eukaryota | Domain: Eukaryota |
| Kingdom: Plantae | Kingdom: Plantae |
| Phylum: Spermatophyta | Phylum: Magnoliophyta |
| Subphylum: Angiospermae | Class: Magnoliopsida |
| Class: Dicotyledonae | Order: Celastrales |
| Order: Celastrales | Family: Celastraceae |
| Family: Celastraceae | Genus: *Celastrus* |
| Genus: *Celastrus* | Species: *Celastrus orbiculatus* |
| Species: *Celastrus orbiculatus* | |

**Preferred Dutch name:** Boomwurger

**Preferred English name:** Staff-vine (Stace 2010)

**Other Dutch names:** Not available

**Other English names:** Oriental Bittersweet (USA), Asiatic bittersweet (CABI), Asian bittersweet, Asian Staff-vine, Oriental Staff-vine, Climbing spindle berry (NZ), Japanese bittersweet, Round-leaved bittersweet.

**Native range:** China (north of the Yangtze River), Korea, Japan (Hou 1955; Ohwi 1965), Russian Far East and Sakhalin Island (Pietsch et al. 2012).

[1] Only including species names, for a complete list of varieties see Hou (1955).

**Figure 2.1:** Trees infested by Staff-vine (*Celastrus orbiculatus*) (© Photo: L.J. Mehrhoff, University of Connecticut, Bugwood.org, CC BY 3.0 US).

### 2.1.2 Species characteristics

*C. orbiculatus* is a deciduous, twining, woody vine or shrub, growing up to 12 m high. The branchlets are glabrous, grey-brown or brown, with sparse and inconspicuous lenticels (the definition of botanical terms is available in the glossary). The axillary buds are small, depressed, ovoid to subglobose, 1-3 mm long, sometimes the outermost scales becoming deltoid, sharp-spinose. Stipules filiform, tufted, about 1-2 mm long. Petioles slender, 1-3 cm long. Leaves extremely variable in size, blade generally broadly ovate to suborbicular, or rectangular-elliptic, or oval-oblong, on average 5-12 cm long (min-max: 2-13 cm) and 3-8 cm wide (min-max: 1.5-9 cm), glabrous above or sparsely pubescent on veins beneath, base broadly cuneate to obtuse-orbicular, apex broadly rounded, shortly cuspidate to acute, or shortly acuminate, margins crenate-serrate, secondary veins 3-5 (rarely 6) pairs.

Cymes axillary, sometimes also terminal in the male plant, 3-7 (rarely 1) flowered. Peduncles subequal, glabrous, 3-8 mm long. Pedicels 2-3 mm long, accrescent, the articulation usually at the base or lower third of the stalk. The flowers are yellowish-green, usually unisexual, but occasionally bisexual in late growth. Sepals and petals are both 5. Male flowers: sepals obtuse-triangular, subacute to obtuse, glandular-ciliolate, about 1.5 mm long; petals obovate-elliptic to rectangular, 3-4 mm long and 2-2.5 mm wide, subentire to slightly ciliolate or erose; disk shallowly cupuliform, lobes shallow, stamens arising from the margin of the disc, 2-3 mm long, filaments filiform, glabrous; sterile pistil columnar, about 2 mm long. Female flowers: petals sometimes shorter than that of male flower; disk slightly thick, carnose; staminodes about 1.3 mm long; pistil flask-shaped, about 4 mm long; ovary ovoid-globose, narrowed into a columnar style, styles ca. 1.5 mm long; stigma deeply three-lobed, lobe apex sometimes shallowly two-lobed. Fruits subglobose, 8-13 mm wide, (bright) yellow, three-valved, with 3-6 seeds. Valves broadly elliptic to suborbicular, about 6-8 mm long and 5-7 mm wide. Seeds ovoid to elliptic, slightly flat, 4-5 mm long and 2.5-3.5 mm wide, reddish/pinkish brown; aril orange-red (Hou 1955, Zhixiang & Funston 2008).

**Figure 2.2:** Staff-vine (*Celastrus orbiculatus*), foliage (© Photo: L.J. Mehrhoff, University of Connecticut, Bugwood.org, CC BY 3.0 US).

*Differences with visually similar species*

*C. orbiculatus* resembles the native North American species *Celastrus scandens* L. (American bittersweet) (Pavlovic et al. 2007). Both species are widely cultivated commercially for their colourful fruits (Hou 1955, Cullen et al. 2011a). Correct identification of these two species is often difficult because of their similar vegetative characteristics. The species can be distinguished by their inflorescences, fruit capsules or pollen when they are in bloom or fruiting. *C. orbiculatus* always has axillary cymes, and in male plants terminal cymes can be produced as well; *C. scandens* has terminal panicles only. The fruit capsules of *C. orbiculatus* are yellow; capsules of *C. scandens* are orange. The pollen of *C. orbiculatus* is white; the pollen of *C. scandens* is yellow. Fruit volume is higher in *C. scandens* (>250 $mm^3$) than in *C. orbiculatus* (<115 $mm^3$). *C. scandens* fruits are seedless or have only one seed; *C. orbiculatus* fruits have mostly 5 or more seeds. In early spring the folding of the leaves at leaf out is a useful identifying characteristic. The margins of young leaves of *C. scandens* are rolled inward (involute); the unfolding leaves of *C. orbiculatus* are folded lengthwise (conduplicate) (Leicht-Young et al. 2007a).

**Figure 2.3:** Flowers of Staff-vine (*Celastrus orbiculatus*) (© Photo: L.J. Mehrhoff, University of Connecticut, Bugwood.org, CC BY 3.0 US).

Within its native range in Eastern Asia, *C. orbiculatus* resembles several other *Celastrus* species featuring axillary inflorescences such as *Celastrus gemmatus* Loes., *C. rosthornianus* Loes. and *C. punctatus* Thunb. (Hou 1955). *C. gemmatus* has large conic axillary buds, and firmly membranaceous and densely reticulated leaves which separates it from *C. orbiculatus* that has small, depressed and ovoid axillary buds (Hou 1955). *C. rosthornianus* can be distinguished from other *Celastrus* species by its ovoid or ellipsoid yellowish-brown seeds and the clustered, usually sessile, flowers in the inflorescences (Hou 1955). *C. punctatus* resembles *C. orbiculatus* and was once considered a variety of that species (*C. orbiculatus* var. *punctatus* (Thunb.) Rehd.). *C. punctatus,* however, is a semi-evergreen species, and replaces *C. orbiculatus* in southeast China, Taiwan and Kyushu (Japan) (Hou 1955, Del Tredici 2014).

*Reproduction*

Flowers of *Celastrus* species frequently become unisexual through the abortion of male or female organs. Plants are often functionally dioecious (Brizicky 1964, Burnham & Santanna 2015). Occasionally monoecious plants, with both male and female flowers, are reported (Hou, 1955), and occasionally plants develop both unisexual and perfect flowers on the same plant (polygamo-dioecious) (Dreyer et al. 1987). The cultivar *C. orbiculatus* ‘Hermaphroditus' is self-pollinating. The cultivar *C. orbiculatus* 'Diana' is a female clone and only sets fruit if a male clone is present locally. *C. orbiculatus* 'Hercules' is a male clone and is used as a pollinator for female plants (e.g., Marczyński 2016).

*C. orbiculatus* produces abundant fruit. In a deciduous forest in Massachusetts density of seed rain varies from 14-826 seeds/$m^2$, with a mean of 168 seeds/$m^2$

(Ellsworth et al. 2004a). Germination percentages in the USA vary between 71% and 95% (Dreyer et al. 1987, Van Clef & Stiles 2001, Ellsworth et al. 2004a). *C. orbiculatus* also spreads vegetatively using underground root suckers that form new stems and by aboveground stolons (Dreyer et al. 1987, Hutchison 2007).

**Figure 2.4:** Fruits of Staff-vine (*Celastrus orbiculatus*) (© Photo: L.J. Mehrhoff, University of Connecticut, Bugwood.org, CC BY 3.0 US).

It is unclear whether establishment occurred by means of seed dispersal by birds or by the dumping of garden waste containing root fragments at sites in the Netherlands and Belgium. Some plants may be mere relics of former cultivation (Personal communication with R. Bult, W. Braam and F. Verloove). In Austria, a specimen recorded climbing in a *Pyracantha* shrub probably originated from seeds dispersed by birds (Sauberer & Till 2015).

*Life cycle*

*C. orbiculatus* is a deciduous vine with leaves that emerge in spring. Flowering occurs in May and June in north eastern USA (Huebner et al. 2006), and from April to June in its native Asian range (Hou 1955). Hymenopterous insects, especially bees, are its main pollinators and wind pollination may also occur. The fruits mostly contain five seeds and are dispersed by birds and small mammals (Brizicky 1964). The fruits and seeds mature around late September and often remain on the vines throughout winter. More than 80% of fruits remain on the plants until December, while more than 50% remain until mid-January. By early March circa 80% of the fruits are eaten by birds or mammals, and ca. 20% has fallen on the ground (Greenberg et al. 2001). Germination of seeds within intact fruits is inhibited and delayed compared to bird-ingested seeds, but even fruits that are not consumed or dispersed by vertebrates may contribute to the spread of the species (Greenberg et al. 2001, LaFleur et al. 2009). A study in the USA revealed that ingestion by introduced European starlings

(*Sturnus vulgaris*) improves the germination of *C. orbiculatus* seeds. Starlings retain seeds for 43 ± 20 minutes, long enough for seed dispersal over substantial distances (LaFleur et al. 2009).

**Figure 2.5:** Seedlings of Staff-vine (*Celastrus orbiculatus*) (© Photo: L.J. Mehrhoff, University of Connecticut, Bugwood.org, CC BY 3.0 US).

*C. orbiculatus* does not form a persistent seed bank. The germination success rate is high (71%-95%) and almost all seeds germinate during the first spring or summer, leaving very few seeds left to enter the seed bank (Van Clef & Stiles 2001, Ellsworth et al. 2004a). Instead of a seed bank, *C. orbiculatus* forms a seedling bank. Light intensity does not affect the proportion of seeds germinating, the time until germination, or seedling survival. Seeds are capable of successful establishment under closed canopy conditions. In dense forest understories, a relatively high proportion of *C. orbiculatus* seedlings can survive at light levels that are as low as 2% of full sun (Ellsworth et al. 2004b). Once established the seedlings practice a "sit and wait" strategy. This strategy allows *C. orbiculatus* to invade intact forests and await a canopy disturbance for an opportunity to proliferate under more favourable light conditions (Greenberg et al. 2001). The annual growth rate of *C. orbiculatus* may exceed 3 m (Patterson 1974), allowing plants in open-light habitats to climb a canopy-sized tree in three to four growing seasons. In open-light habitats, *C. orbiculatus* stems produce fruit by their fourth year (Silveri et al. 2001).

In conclusion, the high germination success rate, seedling survivorship at low light levels, a growth rate of 3 m/year, and the dispersal of seeds by birds and small mammals are characteristics that may facilitate the establishment of *C. orbiculatus*.

## 2.2 Probability of introduction

The species *C. orbiculatus* has been cultivated for many years in several member states of the EU. In 1859, the botanist Dr. P. Von Siebold sent seeds of *C. orbiculatus* (erroneously designated by him as *C. punctatus*) from Japan to colleagues in Europe for cultivation. *C. orbiculatus* is offered for sale in the 1863 catalogue of Von Siebold's nursery in Leiden. This listing in a catalogue of a Dutch nursery is probably the first recorded commercial offering of *C. orbiculatus* outside of Asia (Del Tredici 2014). The species is mentioned in the 1902 list of living plants cultivated in the collection of the Arboretum of Kew Gardens in the UK (Royal Botanic Gardens Kew 1902). The Kew Gardens specimens, however, originate from seeds sent from the USA to Kew in 1891 (Del Tredici 2014). Abromeit (1911) notes that *C. orbiculatus* was in 1910 already cultivated in the botanical garden in Königsberg (currently known as Kaliningrad in Russia), so by that time *C. orbiculatus* was already present in eastern Europe.

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).

In Europe, there is no evidence of intentional introductions to the wild. Nevertheless, the species has been recorded in eight countries in the EU: Austria, Belgium, the Czech Republic, Germany, the Netherlands, Poland, Sweden, and the United Kingdom (§2.3.2). New introductions are likely to occur because *C. orbiculatus* is offered for sale as a garden plant in nurseries and web shops in at least 19 European countries (Appendix 3). There are several clones available, and gardeners are advised to plant male and female cultivars side by side to achieve a better fruiting. Additionally, seeds are offered by web shops and traded worldwide (Amazon 2016). Furthermore, *C. orbiculatus* is traded internationally as a bonsai tree (Rakuten Global Market 2016).

## 2.3 Probability of establishment

### 2.3.1 Current global distribution (excluding the European Union)

The native range of *C. orbiculatus'* includes China north of the Yangtze, North and South Korea, central and northern Japan, the Russian Far East (Hou 1955) and the southern tip of the Sakhalin Island (Pietsch et al. 2012) (Figure 2.6).

The non-native range of *C. orbiculatus* comprises the USA, Canada (http://plants.usda.gov/) and New Zealand (Williams & Timmins 2003). In the USA, it has been reported in at least 25 mainly north-eastern states. In Canada it is reported from Ontario, Quebec, New Brunswick and Nova Scotia. In the USA and Canada, it is naturalized on a large scale and listed as an invasive species (http://plants.usda.gov/, http://epe.lac-bac.gc.ca/). In New Zealand it has a very localised, but widely dispersed, distribution on the North Island (Williams & Timmins 2003).

In Norway, *C. orbiculatus* has been recorded in urban areas in Kristiansand (GBIF, Artsdatabanken), Oslo and the Akershus province (Gederaas et al. 2012). The 2001 record in Kristiansand is characterised as a garden relic growing against a garage wall. *C. orbiculatus* is recorded in one region within European Russia, but is not considered invasive there (Morozova 2014).

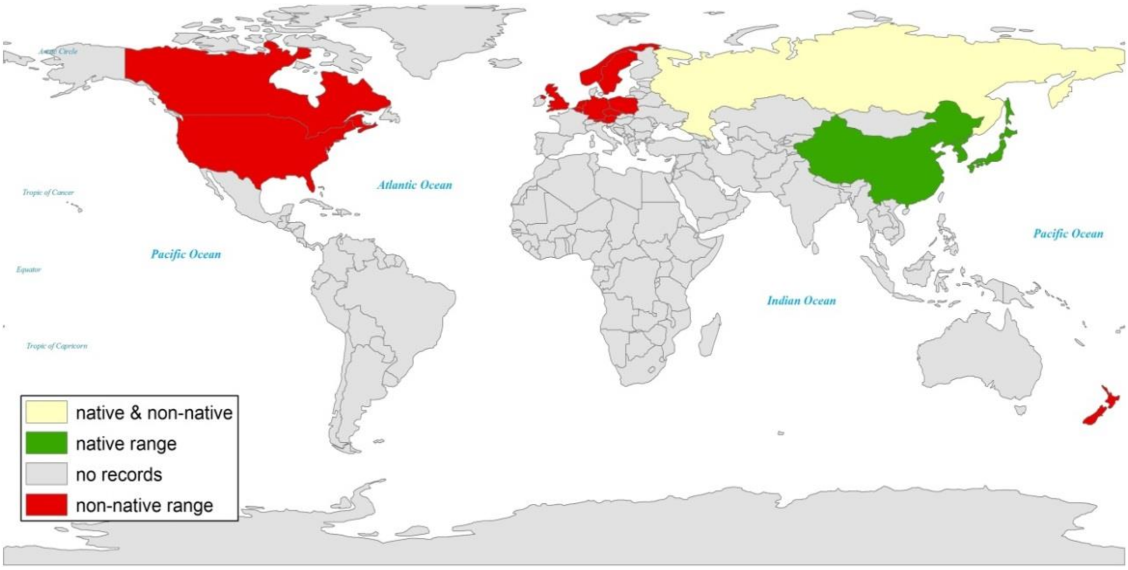



**Figure 2.6:** Global distribution of Staff-vine (*Celastrus orbiculatus*). Entire countries or states coloured based on published records.

### 2.3.2 Current distribution in the European Union

There are records of *C. orbiculatus* naturalizing in Europe since 1980. Records in **Germany** date from 1980 (http://Floraweb.de). Here**,** *C. orbiculatus* has a very scattered distribution. It has been observed in Bavaria, Baden-Württemberg, Hessen, Mecklenburg-Vorpommern and Rheinland-Pfalz. In Neuwied (Rheinland-Pfalz) a large stand has been recorded growing on an abandoned railway-track (Adolphi 2013, Adolphi 2015). In **Austria** *C. orbiculatus* is naturalized at several locations in Graz. Here it climbs in several trees, but also covers riparian areas along the river Mur over a length of 50 m (Leonhartsberger 2013, GBIF). Other records are situated in Baden and on the western shores of Lake Ossiach (GBIF, GBIF-Austria). In 2014, a specimen was discovered south of Vienna in the village of Traiskirchen (Sauberer & Till 2015). The Austrian records date from 2013, and are all located in the eastern part of the country. Červinka & Sádlo reported a single record of *C. orbiculatus* from the town of Čelákovice in the **Czech Republic** in 2000 (Pyšek et al. 2012). In the **United Kingdom** *C. orbiculatus* is recorded in four 10x10 km-squares. The first recording in Surrey dates back to the year 1985. There are also locations in

Hampshire and Somerset (https://data.nbn.org.uk/). According to Stace (2010), *C. orbiculatus* is spreading into woodland in the UK. The Global Biodiversity Information Facility (GBIF) contains several records from the period 1964-2015 from **Sweden**. Some records relate to herbarium vouchers (pressed plant samples) in Uppsala or to individual specimens in gardens, but presumably also to some other records that represent sites with naturalized plants (e.g., an abandoned industrial site in Lund, a railway station at Karlshamn). *C. orbiculatus* is mentioned by Tokarska-Guzik et al. (2012) as an alien plant in **Poland**. However, the locations and number of sites in Poland could not be retrieved within the scope of this project. In **Belgium** there are four known sites all located in Flanders (http://waarnemingen.be). One location occurs within a former arboretum in Lommel, so the huge specimen growing there is probably a relic of former cultivation. There are no known records for Wallonia and Luxembourg (Pers. comm. F. Verloove). The records for Flemish Belgium date from 2009 and later on. The first record of naturalized *C. orbiculatus* in **the Netherlands** dates from 2014. One specimen was recorded near Gasselte in the province of Drenthe. In 2015 a site was discovered in the province of Utrecht near Abcoude (http://waarneming.nl).

Most recorded locations are situated in or nearby urban areas in Europe. Only Stace (2010) reporting for the UK describes plants “spreading into woodland”. The lack of reports of regeneration in the period 1860-1980 is probably caused by the fact that male or female dioecious *C. orbiculatus* plants were grown separately. Nowadays there is a greater diversity of clones available and gardeners are advised to plant male and female cultivars side by side to achieve a better fruiting. An overview of the current distribution of *C. orbiculatus* in the EU is given in Appendix 3.

### 2.3.3 Habitat description and physiological tolerance

*Habitats*

Within its native range, *C. orbiculatus* grows in mixed forests, at forest margins and in thickets on grassy slopes at altitudes between 400-2200 m (Hou 1955, Zhixiang & Funston 2008). In the USA, *C. orbiculatus* grows in a very wide range of habitats ranging from sand dunes and open fields to wet and dry forests, old-growth forests and wind-throw disturbance patches in forests (Leicht-Young et al. 2007a, 2007b, 2009, 2015). Coniferous forests are less favourable habitats. Large, continuous patches of coniferous forests may act as a barrier against spread of *C. orbiculatus* (Merow et al. 2011).

In the USA, *C. orbiculatus* is also found in areas with a former agricultural use like recently abandoned fields and reforested agricultural fields. It also grows within residential areas and along paved roads. *C. orbiculatus* thrives best in recently disturbed habitats and in edge habitats. It has benefited from increased forest fragmentation and residential development (Mosher et al. 2009, Lundgren et al. 2004).

Colonization of the canopy by young *C. orbiculatus* is facilitated when other vine species are numerous. Climbing existing vine stems offers a quick pathway to the canopy (Ladwig & Meiners 2009). Power lines and fences alongside roadsides encourage the establishment of *C. orbiculatus* while attracting resting birds who deposit seeds (Lundgren et al. 2004).

In Europe, most sites are situated in or near urban areas. Therefore, it is not clear in which EU habitats *C. orbiculatus* will establish. The most likely areas for establishment 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)”.

*Relations to other species*
*C. orbiculatus* plants grown in greenhouses in soil inoculated with native American fungi formed associations with endomycorrhizal (arbuscular mycorrhizal or AM) fungi but not with ectomycorrhizal (EM fungi). Under low phosphorus conditions these mycorrhizae appeared to be beneficial to the plant. This suggests that *C. orbiculatus* is mycorrhizal and phosphorus acquisition is enhanced by this (Lett et al. 2011).

In Massachusetts (USA) the native leaf-mining chrysomelid beetle *Sumitrosis rosea* feeds on *C. orbiculatus.* This species probably also feeds on the native *C. scandens* (Eiseman 2014).

Within the native range in Korea, the fungus *Marssonina celastri* (Ascomycota, Dermateaceae) is associated with leaf spots on *C. orbiculatus* (Shin & Lee 1999).

*Light*
Seedlings exhibit a wide tolerance to light conditions and are able to survive for long periods in lowlight (Ellsworth et al. 2004b, Leicht-Young et al. 2007b, Leicht & Silander 2006). *C. orbiculatus* can grow very rapidly when a forest-gap occurs, subsequently dominating native vegetation in the opening (Greenberg et al. 2001).

*Soil*
*C. orbiculatus* tolerates a wide range of edaphic conditions (Leicht-Young et al. 2007b). In a field experiment, seedlings grew largest in moist, circum-neutral soil under high irradiance (Silveri et al. 2001), but seedlings do not tolerate excessively moist conditions (Leicht-Young et al. 2013). *C. orbiculatus* preferred more mesic soil moisture conditions than *C. scandens* (Leicht-Young et al. 2007b). High potassium (K) and percentage organic matter have a significantly positive effect on germination and seedling survival (Leicht-Young et al. 2013).

In a study with paired plots, in which one plot contained an infestation of *C. orbiculatus* and the other did not, it appeared that plots with *C. orbiculatus* had significantly higher soil pH, potassium, calcium and magnesium levels than similar plots without *C. orbiculatus* (Leicht-Young et al. 2015).

Fire treatments and litter removal treatment do not promote germination and seedling survival. The type of habitat where seeds were introduced had a greater influence on the peak percentage of germination and survival than did the fire treatments or the removal of litter (Leicht-Young et al. 2013).

Nitrogen mineralization and litter decomposition rates were higher in plots with *C. orbiculatus*. It is likely that these differences were caused by *C. orbiculatus*. Compared to *Quercus rubra* leaf litter, the litter of *C. orbiculatus* contained more than three times the percentage of calcium (3.8% versus 1.3%), as well as a higher pH and a lower C:N ratio (Leicht-Young et al. 2009). Addition of *C. orbiculatus* leaf litter to uninvaded field soils showed an increase in soil nutrients, in pH, and nitrogen mineralization rate (Leicht-Young et al. 2015).

**Table 2.2:** Physiological conditions tolerated by *Celastrus orbiculatus* in Michigan, USA (Pavlovic & Leicht-Young 2011).

| **Parameter** | **Occurrence (Mean ± SD)** |
|---|---|
| pH | 5.9±1.2 |
| CEC (meq/100gr) | 6.0±0.7 |
| Moisture (%) | 15.0±3.1 |
| Organic matter (%) | 4.6±0.9 |
| Sand (%) | 71.0±5.7 |
| Silt (%) | 20.7±4.0 |
| Clay (%) | 8.5±1.8 |
| Magnesium (ppm) | 120.8±15.6 |
| Potassium (ppm) | 58.8±6.7 |
| Total phosphorus (ppm) | 18.6±4.0 |
| Nitrogen as nitrates (ppm) | 3.6±1.7 |
| Ammonia-N (ppm) | 13.4±1.6 |

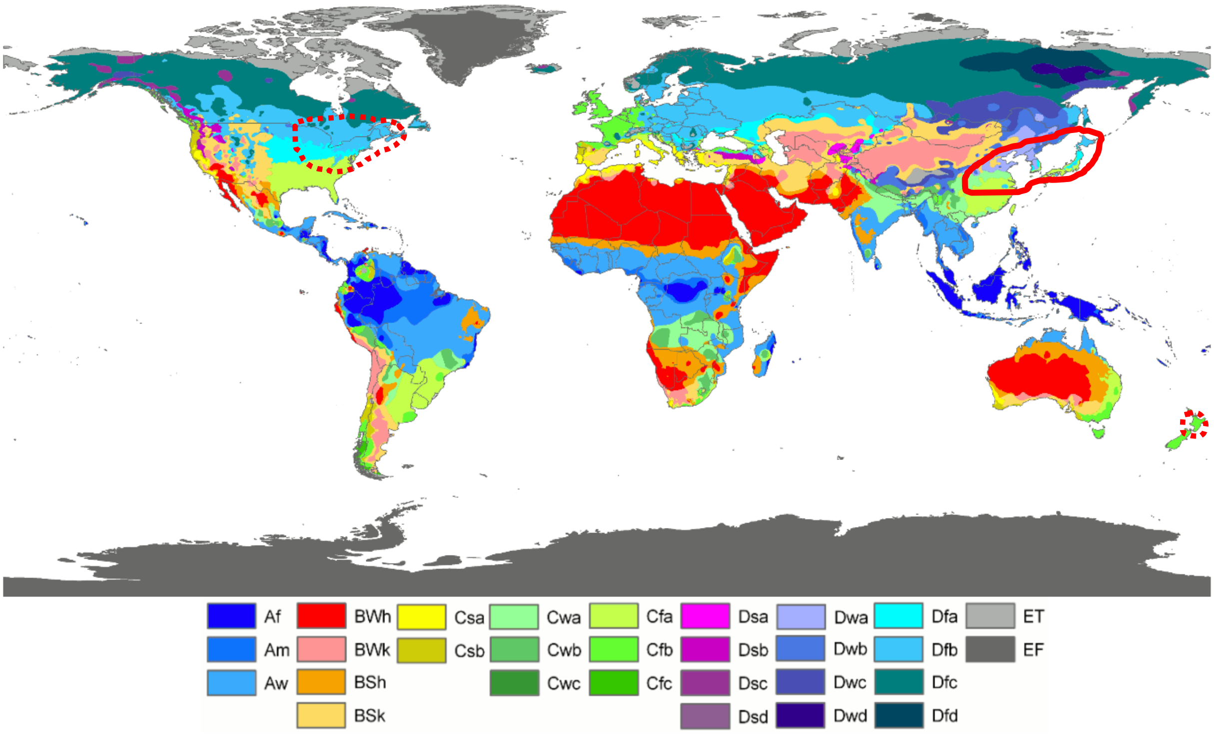
*Temperature / Climate change*

While cold currently appears to limit the distribution of *C. orbiculatus*, climate change may render high-elevation sites increasingly vulnerable to *C. orbiculatus* and other plant invaders, as extreme cold temperatures become less frequent (Albright et al. 2009). An overview of available data on the physiological conditions tolerated by *C. orbiculatus* in nature in Michigan (USA) is given in Table 2.2.

### 2.3.4 Climate match and bio-geographical comparison

The climate characteristics of native and introduced ranges of *C. orbiculatus* match the following Köppen-Geiger regions (Figure 2.7):

- **Cfa** - *Mild with no dry season, hot summer, subtropical*: China, South Japan, South-Eastern USA.
- **Cfb** - *Warm temperate, fully humid with a warm winter*: New Zealand.
- **Dfa** - *Humid continental hot summer, wet all year*: central Japan, South Korea, Eastern USA.
- **Dfb** - *Humid with severe winter, no dry season, warm summer*: north Japan, North-Eastern USA, South-Eastern Canada.
- **Cwa** - *Mild with dry winter, hot and wet summer*: Northern China.
- **Dwa** - *Humid with severe, dry winter, hot summer*: North Korea.




| Main climate | | Precipitation | | Temperature | | |
|---|---|---|---|---|---|---|
| A: equatorial | D: snow | W: desert | s: dry summer | h: hot dry | b: warm summer | f: polar frost |
| B: dry | E: polar | S: prairie | w: dry winter | k: cold dry | c: cool summer | t: polar tundra |
| C: warm | | f: fully humid | m: monsoon system | a: hot summer | d: extremely continental | |

**Figure 2.7:** Climate zones according to the Köppen-Geiger climate classification (Adapted from Peel et al. 2007a). Native range *C. orbiculatus* is circled in red. Dotted lines indicate vast contiguous introduced ranges.

The **Dfb** and **Cfb** climate regions also occur in Europe. Region **Cfb** covers Western Europe: the Netherlands, Belgium, Denmark, France, Ireland, northern Spain and Portugal, the United Kingdom, and the western part of Germany. Eastern Europe and the south of Scandinavia (Sweden) lie largely in region **Dfb**. The whole Atlantic, Continental and southern Boreal biogeographic regions of Europe are likely to be suitable for establishment of *C. orbiculatus* (Figure 2.8).

The whole Mediterranean biogeographic region in southern Europe covering the Köppen-Geiger regions **Bsk**, **Csa** and **Csb** with dry summers does not match the climate requirements of *C. orbiculatus*. Also sub-montane and montane regions within climate regions **Dfc** and **ET,** like the Massif Central, Harz, Carpathians, Tatra, and Pyrenees do not match the climate requirements of *C. orbiculatus*.

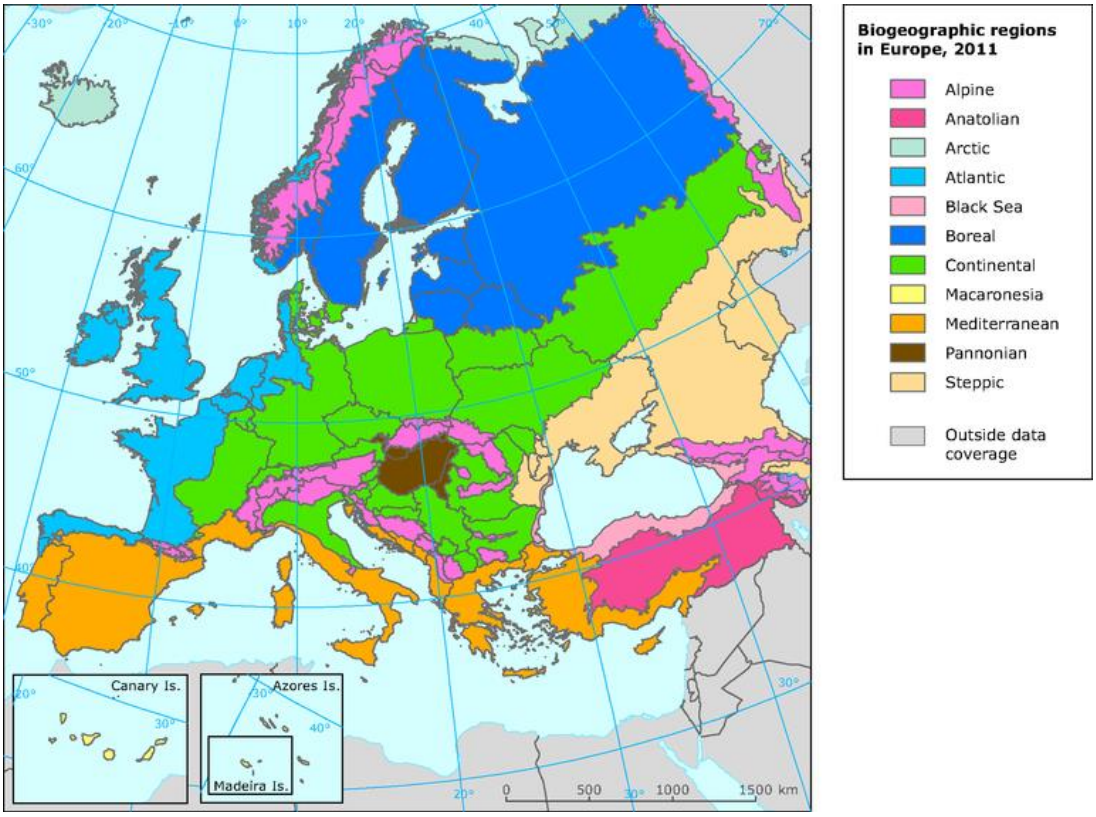



**Figure 2.8:** Biogeographic regions in Europe (European Environment Agency 2012).

The hardiness code applicable to *C. orbiculatus* in the European Garden Flora is H1 (Cullen et al. 2011b), indicating that this species is hardy to -20 °C and below (Figure 2.9). In the present day scenario, cold/hardiness is not a limiting factor for *C. orbiculatus* in Europe.

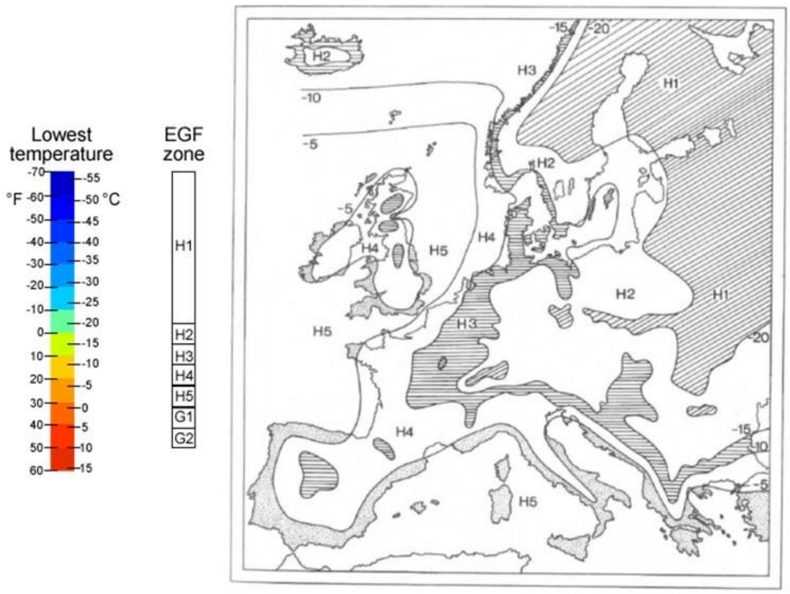



**Figure 2.9:** Minimum temperatures tolerated by plant species classified under the European Garden Flora (EGF) zones (left) and mean minimum January isotherms for Europe (hardiness codes; right) (Cullen et al. 2011b).

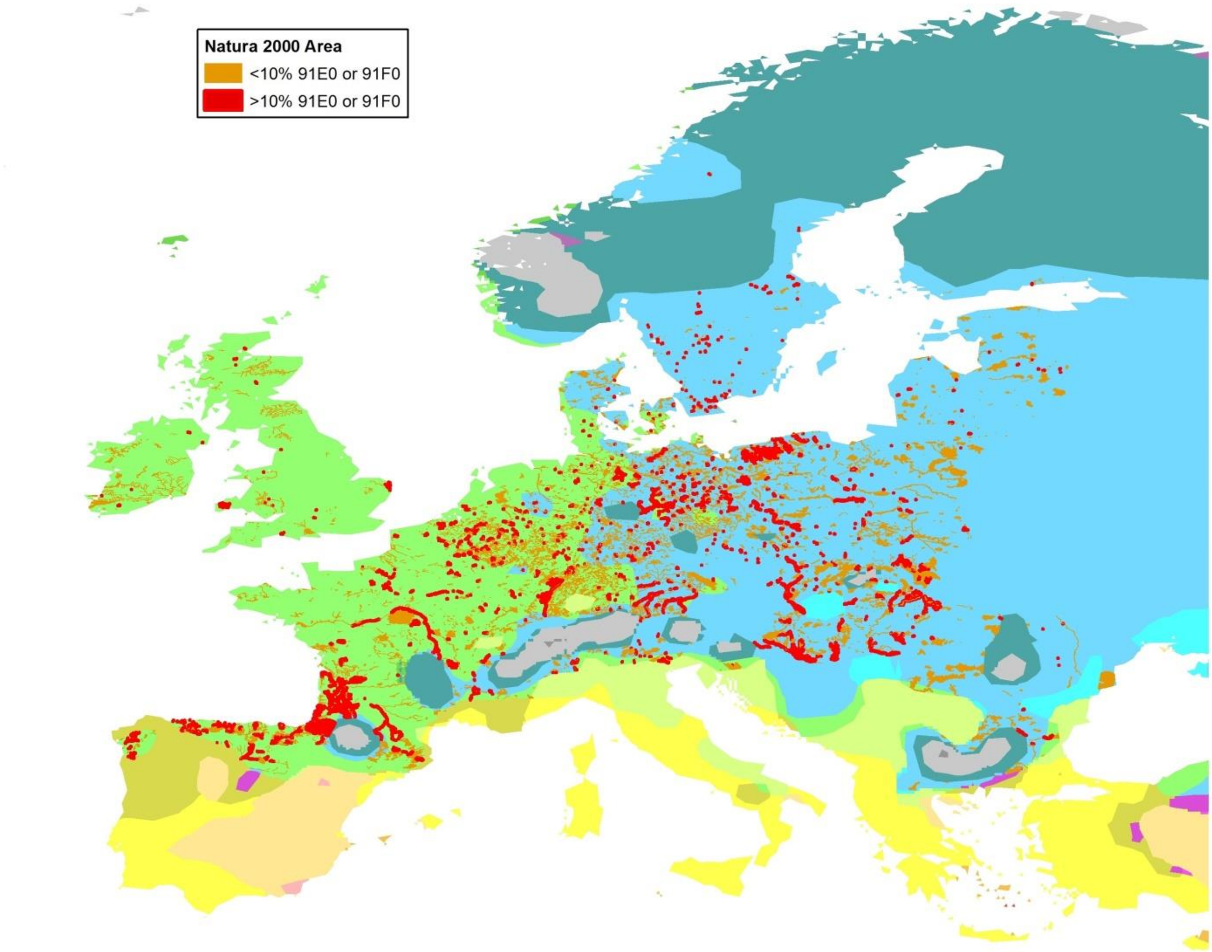



**Figure 2.10:** Presence of alluvial forests with habitat types 91E0 and / or 91F0 in Natura 2000 areas within the Köppen-Geiger climate zones Dfb (blue) and Cfb (green) (Köppen-Geiger map: Peel et al. 2007b; Natura 2000 database and shapefile: European Environment Agency 2015).

**Table 2.3:** Estimated potential area of Natura 2000 habitats ($km^2$) in which *Celastrus orbiculatus* could establish in the EU by matching Natura 2000 habitats 91E0 and 91F0 with Köppen-Geiger climate zones Dfb and Cfb (European Environment Agency 2015, Peel et al. 2007b)[a].

| Country | Cfb | Dfb | Country | Cfb | Dfb |
|---|---|---|---|---|---|
| Belgium | 2654 | | Italy | 580 | 3398 |
| Bulgaria | 320 | 4184 | Lithuania | | 2261 |
| Czech Republic | 580 | 4323 | Luxembourg | 462 | 10 |
| Germany | 11491 | 12365 | Latvia | | 4575 |
| Denmark | 814 | 2962 | Netherlands | 1495 | 17 |
| Estonia | | 3998 | Poland | | 33345 |
| Spain | 9349 | 935 | Portugal | 2 | |
| Finland | | 158 | Romania | 679 | 11976 |
| France | 15788 | 1178 | Sweden | | 1092 |
| Greece | | 354 | Slovenia | 797 | 514 |
| Hungary | | 10581 | Slovakia | | 10009 |
| Ireland | 2242 | | United Kingdom | 1255 | |

[a] No information was available for Austria.

Figure 2.10 shows locations of suitable habitats for *C. orbiculatus* in the climate regions Dfb and Cfb in the European Union. These climate regions match with the native and introduced ranges of the species in the USA, Canada, Japan and New Zealand (Figure 2.7). The Natura 2000 habitat types in which *C. orbiculatus* is most likely to establish are alluvial forests 91E0 and 91F0 (§2.3.3). The risk of establishment of *C. orbiculatus* is highest in these locations and they could therefore be considered to be the endangered area in the European Union. The potential high risk areas are quantified in Table 2.3.

*Endangered areas*

Based on current climatic conditions and habitat requirements, *C. orbiculatus* could establish in almost all EU member states. The most endangered areas are deciduous forests on moist (but not too wet) soils, including the Natura 2000 habitats 91E0 and 91F0, in Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Romania, Slovakia, Slovenia, Sweden, Spain, and United Kingdom (Table 2.3). The Mediterranean region and central and northern Scandinavia are less endangered according to climate. When temperature increases due to climate change, the potential area of establishment will expand northward (Finland, Sweden) and from a lower to a higher altitude in mountainous areas.

### 2.3.5 Influence of management practices

Invasion of forests by *C. orbiculatus* may be triggered by logging disturbance. In a logged forest in Massachusetts (USA), *C. orbiculatus* invaded two years after harvest. Even fourteen years after harvest, logging roads continued to provide superior habitat for establishment and growth. *C. orbiculatus* is also able to invade forested habitats in the absence of significant disturbance, but is not able to reproduce sexually. Gaps in the canopy are required for flowering and fruiting (Silveri et al. 2001).

Germination and seedling survival were highest in forest stands planted with trees with quickly decaying litter, low C:N ratios and thin litter layers. Forest stands that are particularly susceptible to invasion, such as those dominated by tulip poplar (*Liriodendron tulipifira*), may warrant special treatment at the time of timber harvest and/or shortly thereafter by eradicating *C. orbiculatus* seedlings that are already present or may become established due to harvesting activities (Horton & Francis 2014). In oak dominated stands, measures should be taken to minimize disturbance of the leaf litter layer that may counteract the establishment of *C. orbiculatus* seedlings (Kuhman et al. 2013).

## 2.4 Pathways and vectors for dispersal

### 2.4.1 Dispersal potential by natural means

Spreading of *C. orbiculatus* in the north-eastern USA has been facilitated by starlings. Flocks of starlings forage on the fruits of the plant during late autumn and winter when other resources are scarce. The mean gut transit time of seeds in starlings has been measured within a range of 43 ± 20 minutes. Starlings occasionally retain seeds for nearly two hours and can fly at speeds of up to 48 km/hr (La Fleur et al. 2009, Merow et al. 2011). These figures indicate that starlings can easily effectuate long-distance dispersal over several kilometres.

### 2.4.2 Dispersal potential by human assistance

*C. orbiculatus* has been present in European botanical gardens since 1863 onwards. Nowadays *C. orbiculatus*, and its North American counterpart *C. scandens*, are planted ornamentally in gardens because of their colourful display of fruits and leaves in late summer and autumn. In the USA, *C. orbiculatus* has been planted along interstate highways in the Northeast to control erosion (Dreyer et al. 1987, Steward et al. 2003). Formerly, *C. orbiculatus* was used in Christmas wreaths in the USA, however, this is discouraged nowadays in some states (NCAdvertiser 2013). Improper disposal of bonsai trees or decorations, either outdoors or in compost, can contribute to the spread of *C. orbiculatus* (Table 2.4).

**Table 2.4:** Active (A) and potential future (F) pathways and vectors which contribute to the spread of *C. orbiculatus* in the European Union.

| Category | Subcategory[a] | A | F | Examples and relevant information |
|---|---|---|---|---|
| Escape from confinement | 2.3 Botanical garden | X | X | See Appendix 3 for countries in which the plant and its seeds are for sale |
| | 2.8 Horticulture | X | X | |
| | 2.9 Ornamental | X | X | |

[a] As described by the UNEP (2014).

## 2.5 Impacts

### 2.5.1 Environmental effects: biodiversity and ecosystems

Gederaas et al. (2012) regard *C. orbiculatus* as a high risk invasive species, mainly because of detrimental interactions with indigenous endangered or rare species and endangered or rare habitats.

As a stem twiner *C. orbiculatus* needs the support of small diameter stems to wrap around in order to reach the canopy of mature forest trees (Figure 2.10, Pavlovic & Leicht-Young 2011).

Deformation and shading of mature tree crowns, an increase in the risk of ice and wind damage, and damage to seedlings and middle aged trees is commonly seen (GPIP 2013). The foliage of *C. orbiculatus* enlarges the surface area of the tree canopy that catches wind and increases the risk of tree falls in summer. The tight twining of *C. orbiculatus* around stems and branches of young trees results in the inhibition, if not the complete obstruction, of downward transport of assimilates through the sieve tubes in the phloem. Normal radial growth of the stem continues for only a brief period, usually one or two years after the vine has become attached. Usually, trees are not killed because new transport tissues are formed parallel to the spiral constriction. However, when the flow of assimilates to the roots stops, the parts below the constriction die of starvation. As long as the roots remain alive upward transport of water and inorganic solutes in the woody xylem takes place even though the downward movement of organic assimilates in the inner bark (phloem) has been limited. Girdled stems become more vulnerable to decay or the effects of woodborers, and the abnormal wood structure make trees worthless as timber. In winter, the surplus weight of snow and ice add weight to the canopy. Weakened girdled trunks and branches covered with snow or ice are more vulnerable to wind-throw. Hardwoods are more commonly damaged than conifers because the relatively dense canopy of conifers offers unfavourable light conditions for *C. orbiculatus* (Lutz 1943).

**Figure 2.10:** Staff-vine (*Celastrus orbiculatus*), twining stem. (© Photo: L.J. Mehrhoff, University of Connecticut, Bugwood.org, CC BY 3.0 US).

*C. orbiculatus* intercepts much light (40-80%) in the forest canopy and negatively affects host growth. Growth-ring widths of host trees have been found to be smaller than those of vine-free trees (Ichihashi & Tateno 2011).

Probable causes for the increasing rarity of the native *C. scandens* in parts of the USA are the competition and hybridization effects of introduced *C. orbiculatus*. Overall seed germination is 27% for *C. scandens* and 71% for *C. orbiculatus*. In addition to high pollen and seed viability, bird, mammal and human dispersal mechanisms are considered to be important to the rapid expansion of *C. orbiculatus* populations in the USA (Dreyer et al. 1987). Fruit production is also higher for *C.*

*orbiculatus. C. orbiculatus* produces numerous axillary inflorescences, whereas *C. scandens* produces only a single terminal inflorescence on a branch (Steward et al. 2003).

In the USA, the native *C. scandens* and the closely related alien *C. orbiculatus* hybridize. Interspecific hybrids easily occur, and artificially produced hybrid plants by hand-crossing tend to grow faster and have shorter seed dormancy than native *C. scandens*. The competitive advantage of hybrids, as well as competition resulting from *C. orbiculatus* establishment itself, could be one factor contributing to the decline of *C. scandens* in the USA (Pooler et al. 2002). However, in the wild across the eastern USA Zaya et al. (2015) identified only 4.2% of *Celastrus* individuals as hybrids. All identified hybrids had *C. scandens* as the female seed parent. These hybrids were found scattered throughout the sympatric range, and showed signs of reduced fecundity, with reduced seed set and small, probably sterile pollen, indicating that there is no ‘‘hybrid swarm’’ nor that invasiveness increases after interspecific hybridization (Zaya et al. 2015). *C. scandens* is offered for sale in the Netherlands and elsewhere in Europe, and hybrids could occur if both species are grown closely together.

In the USA, *C. orbiculatus* poses a substantial threat to mature forests. It persists in the ground layer until a canopy gap or other disturbance provides the light and supports necessary for it to ascend to the canopy and damage trees. Vines like *C. orbiculatus* have the ability to suppress regeneration of canopy trees in these forest gaps (Pavlovic & Leicht-Young 2011). When a forest-gap occurs, *C. orbiculatus* can grow very rapidly, subsequently dominating native vegetation in the opening (Greenberg et al. 2001).

After *Lythrum salicaria* and *Berberis thunbergii*, *C. orbiculatus* was one of the most frequently occurring invasive species present at rare species sites in the New England region of the USA (Farnsworth 2004).

Fike & Niering (1999) describe how *C. orbiculatus* blocks forest succession completely on a post-agricultural site in southern New England. Here, *C. orbiculatus* facilitated the spread of the native vine *Vitis labrusca* by serving as a ‘ladder’ that allowed this species to climb into the tree canopy, eventually forming a *Celastrus*-dominated vine community (Fike & Niering 1999).

*C. orbiculatus* has the ability to move out from forests into open dune habitats via vegetative growth along Lake Michigan. By invading this habitat it could pose a threat to the endangered *Cirsium pitcheri* (Leicht-Young & Pavlovic 2012).

*C. orbiculatus* probably accelerates nitrogen mineralization and litter decomposition. Addition of *C. orbiculatus* leaf litter to uninvaded field soils showed an increase in soil nutrients, in pH, and nitrogen mineralization rate (Leicht-Young et al. 2015).

Leaf extracts of *C. orbiculatus* showed allelopathic potential in bioassays by inhibiting seed germination of Radish (*Raphanus sativus*). This allelopathic potential was not shade induced (Ladwig et al. 2012). *C. orbiculatus* extracts have a much greater effect on seed germination than those of the invasive vine *Lonicera japonica* (Pisula & Meiners 2010).

### 2.5.2 Effects on cultivated plants

In the USA, *C. orbiculatus* has a negative impact on silviculture. Girdled stems become more vulnerable to decay or woodborers, and the abnormal wood structure make trees worthless as timber (Lutz 1943). Young trees can become totally overgrown in forest plantations.

### 2.5.3 Effects on domesticated animals

No information regarding the effects of *C. orbiculatus* on domesticated animals was found in the available literature.

### 2.5.4 Effects on public health

No information regarding the effects of *C. orbiculatus* on public health was found in the available literature.

### 2.5.5 Socio-economic effects

In New Zealand, the costs of controlling *C. orbiculatus* in the period 1999 to 2003 amounted to 40800 NZ$ (Williams & Timmins 2003), or approximately 27000 Euros using exchange rates that were valid at the time of writing. No further information regarding socio-economic loss caused by this species within its existing geographic range, including the cost of any current management was found in the available literature. Furthermore, no information regarding effects on recreational activities or future management costs in the EU were found in the available literature.

*Management actions*

Several management actions have been undertaken to eliminate or control *C. orbiculatus* (Ellsworth et al. 2004a, Leicht-Young et al. 2013, Mervosh & Gumbart 2015, Williams & Timmins 2003). Below chemical, physical and mechanical measures are described.

*Chemical measures*

Low-growing vines can be sprayed with herbicides. Applied to foliage, triclopyr has generally been more effective than glyphosate in controlling *C. orbiculatus* in the USA. For climbing vines, an effective approach is the application of herbicide directly to the cut stumps, or the application of herbicide that penetrates the bark at the base of the vine. In general, application of herbicides to cut stems is more effective than applications to the basal bark. Spring and summer herbicide applications are more effective than applications in the autumn. Bark treatments with triclopyr in autumn are ineffective. Cut-stump treatments with triclopyr and glyphosate were both effective in reducing vine survival, number and length of sprouts. A very small amount of glyphosate or triclopyr is needed to prevent regrowth of *C. orbiculatus* after cutting (Mervosh & Gumbart 2015).

*Mechanical measures*
Experience from the USA has shown that monthly mowing and the digging out of roots will eventually eliminate *C. orbiculatus*. These management practices are suitable only for small populations in environmentally sensitive areas where herbicides cannot be used. If mowing is carried out only two or three times a year, the plants will resprout by suckering. Any root fragment not removed may also resprout (Williams & Timmins 2003).

The low survival of *C. orbiculatus* in the seed bank suggests that eradication of seedlings and adult plants prior to seed rain may be an effective control strategy. However, the intact forest floor litter of an undisturbed forest will not prevent seedling establishment (Ellsworth et al. 2004a).

*Physical measures*
Fires conducted in the spring (prior to green up) with temperatures higher than 140$^{o}$C may aid control due to fire intolerance of *C. orbiculatus* seeds (low percentage of seed germination after treatment). If fire management is properly applied, the year's crop of seeds would be essentially eliminated (Leicht-Young et al. 2013). Fire as a management tool, however, is not applied within the EU.

#### 2.5.6 Effects on ecosystem services
The potential effects of *C. orbiculatus* on ecosystem services are summarized in Table 2.5. Due to a lack of information, these scores are mainly based on best professional judgement by the authors.

*Provisioning services*
No evidence of *C. orbiculatus* being used as food for humans or livestock was found in available literature. *C. orbiculatus* has a negative impact on silviculture. Girdled stems become more vulnerable to decay and woodborers, and the abnormal wood structure that occurs as a result of girdling make trees worthless as timber (Lutz 1943). Furthermore, infested trees become more vulnerable to wind-throw in the winter if weakened girdled trunks and branches are covered with snow or ice. In forest gaps *C. orbiculatus* suppresses the regeneration of young trees.

Root, stem, leaf and seeds of *C. orbiculatus* have been used in the treatment of poisoning and infectious diseases. The plant helps the liver to process toxins and has been used as an antidote for snakebites and opium poisoning. It is believed that the plant contains numerous compounds that possess anti-tumor and antioxidant abilities (Scott 2010). *C. orbiculatus* contains Sesquiterpene esters that have been said to partially or completely reverse the resistance of multidrug-resistant cancer-cells (Kim et al. 1998).

**Table 2.5:** Potential effects of *C. orbiculatus* on ecosystem services (+ = positive effect, - = negative effect, 0 = no effect, NR = not relevant) (Maes et al. 2013).

| **Service** | **Subcategory** | **Effect** |
|---|---|---|
| **Provisioning Services** | | |
| Food | Crops | 0 |
| | Livestock / cattle | 0 |
| | Capture fisheries | NR |
| | Aquaculture | NR |
| | Wild plant and animal food products | 0 |
| Fiber | Timber | - |
| | Cotton, hemp, silk | NR |
| | Wood fuel | NR |
| Genetic resources | | 0 |
| Biochemicals, natural medicines, and pharmaceuticals | | + |
| Fresh water | | NR |
| **Regulating Services** | | |
| Air quality regulation | | 0 |
| Climate regulation | Global | 0 |
| | Regional and local | 0 |
| Water regulation | | 0 |
| Erosion regulation | | NR |
| Water purification and waste treatment | | NR |
| Disease regulation | | NR |
| Pest regulation | | NR |
| Pollination | | NR |
| Natural hazard regulation | | NR |
| **Cultural Services** | | |
| Cultural diversity | | 0 |
| Spiritual and religious values | | 0 |
| Knowledge systems | | 0 |
| Educated values | | 0 |
| Inspiration | | 0 |
| Aesthetic values | | + |
| Social relations | | 0 |
| Sense of place | | 0 |
| Cultural heritage values | | 0 |
| Recreation and ecotourism | | 0 |
| **Supporting services** | | |
| Soil formation | | 0 |
| Photosynthesis | | 0 |
| Primary production | | 0 |
| Nutrient cycling | | - |
| Water cycling | | 0 |

*Regulating services*

*C. orbiculatus* has been used in the USA for erosion control in the past (Dreyer et al. 1987, Steward et al. 2003). However, this potential service is no longer made use of in the USA or the EU.

*Cultural services*
*C. orbiculatus* is grown as an ornamental vine in gardens and therefore has aesthetic value.

*Supporting services*
According to expert judgement, the species has a negative effect on ecosystem nutrient cycling due to the plant's ability to function like a nutrient pump. Minerals become available to other species as the *C. orbiculatus* litter layer degrades easily and enriches the soil. The effect of the plant on overall photosynthesis levels is potentially neutral as the increase in photosynthesis due to growth of *C. orbiculatus* is potentially negated by the decrease in photosynthesis that results from the strangulation of host plants.

### 2.5.7 Influence of climate change on impacts

Cold currently appears to limit the distribution of *C. orbiculatus*. In the southern Appalachian Mountains, occurrence at elevations higher than >1500 m was very limited. Climate change may render high-elevation sites increasingly vulnerable to *C. orbiculatus* invasion when extreme cold temperatures become less frequent (Albright et al. 2009). Parts of the submontane and montane regions in the EU, such as the Massif Central, Harz and Pyrenees, might develop more suitable habitat for *C. orbiculatus* if the temperature increases. The maximum altitude of suitable habitat can increase by a few hundred meters if the temperature increases by 2 °C (Grace et al. 2002).

### 2.5.8 Positive effects

*C. orbiculatus* has aesthetic value. It shows a colourful display of fruits and leaves in late summer and autumn. Within its native range (Japan) it is grown as a bonsai-tree. In the USA *C. orbiculatus* has been planted along highways to control erosion.

# 3. Risk assessment

## 3.1 Risk assessment and classification with Harmonia$^+$

### 3.1.1 Classification for current situation

Table 3.1 presents an overview of the risk assessment of *C. orbiculatus* in the EU, using the Harmonia$^+$ protocol. The expert team discussed the underlying rationale for the risk scores and came to a consensus. The evidence supporting this risk classification is explained in more detail in the following paragraphs.

*Species introduction*

*C. orbiculatus* was introduced into the EU for cultivation in the 19$^{th}$ century. To date, the species has been recorded in eight countries in the EU (§2.2). The probability of new introductions of individuals of *C. orbiculatus* into the wild of EU member states from outside the EU via natural pathways within the time span of a decade is scored as low. Introductions via natural pathways are expected to occur less than once every 30 years, because it is highly unlikely that the species will enter the EU via earth-moving activities. It is more likely that introductions will occur due to the presence of *C. orbiculatus* in the eight known EU member states (see §3.1.1 'Spread'). The probability for the species to be introduced into the EU's wild from outside the EU by unintentional human actions is also scored as low (≤ 1 event expected per decade). There is no evidence of introductions of *C. orbiculatus* by intentional human actions into the wild. Therefore, experts judged the probability based on the manner of historical introductions and present-day occurrence in EU member states. The probability for the species to be introduced into the EU's wild from outside the EU by intentional human actions is scored medium (between 1 and 9 events per decade).

*Establishment*

Both climate in most EU member states and habitat are scored as optimal for the establishment of *C. orbiculatus*. The climatic requirements of the species are expected to be fully met in most EU member states as its native range (China, Korea, Japan, Russian Far East) and the EU are classified in the same climate zones (§2.3.4). In the USA, low winter temperature is considered as a main limiting factor, but in large parts of the EU winter temperature is not expected to limit *C. orbiculatus*' growth as it is hardy to -20$^{o}$C and below (except i mountainous areas at elevations > 1500 m and in northern parts of Europe). Habitat requirements are also expected to be fully met in the EU, because in its native and non-native range *C. orbiculatus* grows in a very wide range of soil types and habitats (wet and dry forests, sand dunes and open fields). This criterion is scored with medium confidence considering that there is no relevant information available within the EU, that the species thrives best in recently disturbed habitats, and that to date the species has not shown considerable spread at the current recorded locations in Europe.

**Table 3.1:** Consensus risk scores for Staff-vine (*Celastrus orbiculatus*) with the confidence levels for both the current and future situation in the European Union with the Harmonia+ protocol.

| | | |
|---|---|---|
| ***Context*** | | |
| A01. Assessor(s) | **Consensus scores of six experts** | |
| A02. Species name | **Staff-vine (*Celastrus orbiculatus*)** | |
| A03. Area under assessment | **European Union** | |
| A04. Status of species in area | **Alien and established within the area's wild** | |
| A05. Potential impact domain | **Environmental domain** | |
| **Risk category** | **Risk** | **Confidence** |
| ***Introduction*** | | |
| A06. Probability of introduction by natural means | Low | High |
| A07. Probability of introduction by unintentional human actions | Low | High |
| A08. Probability of introduction by intentional human actions | Medium | High |
| ***Establishment*** | | |
| A09. Climate for establishment | Optimal | High |
| A10. Habitat for establishment | Optimal | Medium |
| ***Spread*** | | |
| A11. Dispersal capacity within the area by natural means | High | Medium |
| A12. Dispersal capacity within the area by human actions | Medium | Medium |
| ***Impacts: environmental targets*** | | |
| A13. Effects on native species through predation, parasitism or herbivory | Inapplicable | High |
| A14. Effects on native species through competition | Medium | Medium |
| A15. Effects on native species through interbreeding | No | High |
| A16. Effects on native species by hosting harmful parasites or pathogens | Very low | Low |
| A17. Effects on integrity of ecosystems by affecting abiotic properties | High | Medium |
| A18. Effects on integrity of ecosystems by affecting biotic properties | Medium | Medium |
| ***Impacts: plant targets*** | | |
| A19. Effects on plant targets through herbivory or predation | Inapplicable | High |
| A20. Effects on plant targets through competition | Medium | Medium |
| A21. Effects on plant targets through interbreeding | Inapplicable | High |
| A22. Effects on integrity of cultivation systems | Medium | Medium |
| A23. Effects on plant targets by hosting harmful parasites or pathogens | Very low | Low |
| ***Impacts: animal targets*** | | |
| A24. Effects on animal health or production through parasitism or predation | Inapplicable | High |
| A25. Effects on animal health or production by properties hazardous upon contact | Very low | Medium |
| A26. Effects on animal health or production by parasites or pathogens | Inapplicable | High |
| ***Impacts: human health*** | | |
| A27. Effects on human health through parasitism | Inapplicable | High |
| A28. Effects on human health by properties hazardous upon contact | Inapplicable | High |
| A29. Effects on human health by parasites or pathogens | Inapplicable | High |
| ***Impacts: other targets*** | | |
| A30. Effects by causing damage to infrastructure | Low | High |
| ***Ecosystem services*** | | |
| A31. Effects on provisioning services | Moderately negative | Medium |
| A32. Effects on regulation and maintenance services | Neutral | Medium |
| A33. Effects on cultural services | Neutral | Medium |
| ***Effects of climate change*** | | |
| A34. Introduction | No change | Medium |
| A35. Establishment | No change | Medium |
| A36. Spread | No change | Medium |
| A37. Impacts: environmental targets | No change | Medium |
| A38. Impacts: plant targets | No change | Medium |
| A39. Impacts: animal targets | No change | Medium |
| A40. Impacts: human health | No change | Medium |
| A41. Impacts: other targets | No change | Medium |

*Spread*
The capacity of *C. orbiculatus* to disperse within the EU by natural means is scored as high, because spread of seeds (berries) by means of starlings over several tens of kilometres is reported in the USA (§2.4.1). The risk that the species will be spread within the EU by intentional human actions is scored medium (between 1 and 9 events per decade), in view of the present-day occurrence in EU member states. Both criteria were scored with medium confidence because detailed information on spread is lacking. Current recorded locations in the EU are mostly found in urban areas and it is unknown whether they originate from the dumping of garden waste or dispersal by berry eating birds. However, spread may accelerate as soon as fruiting improves due to the planting of a greater diversity of clones and an increase in sexual reproduction resulting from the planting of male and female cultivars side by side, a practice that is recommended to customers buying *C. orbiculatus* as an ornamental plant.

*Environment: biodiversity and ecosystems*
The criterion for effects of *C. orbiculatus* on native species, through predation, parasitism or herbivory is inapplicable. The effects on native species are scored as medium, as *C. orbiculatus* may, at worst, cause severe population declines in species that are not of conservation concern, or limited population declines in species that are of conservation concern. The species will have no effect as a result of interbreeding as there are no closely related species native to the EU. The species probably has a low impact on native species through the hosting of pathogens or parasites that are harmful to them. However, this score is assessed with a low level of confidence as there is no available information regarding this issue.

If it is assumed that the organism becomes widespread in the EU, the risk of adverse effects on ecosystem integrity by affecting abiotic properties is estimated to be high. *C. orbiculatus* causes the deformation and shading of mature tree crowns and strongly increases the risk of wind-throw. Additionally, nutrient availability (as a result of nitrogen mineralization and litter decomposition) may be increased by *C. orbiculatus.* These process changes are expected to be hardly reversible (e.g., because the root suckers produced by the plant are difficult to remove entirely) and may occur in ecosystems that are of conservation concern (e.g., alluvial and mixed riparian forests). Changes in abiotic properties due to *C. orbiculatus* establishment may result in changes in the composition and/or rate of succession of communities that share the same habitat. The species also cuts off the transport of assimilate to and from stems, branches and roots of trees.

The risk of adverse effects on ecosystem integrity due to changes to biotic properties is estimated to be medium. Information on (cascading) effects on biotic properties such as the food web and pollination is scarce. The undergrowth of the forest can become overgrown by *C. orbiculatus*. These effects cause an indirect effect on the survival of other plant species. In addition the species adversely affects the tree and herb layers in forests. The species causes hardly reversible process changes in ecosystems that are of conservation concern. However, these processes are mainly abiotic. The risk scores for the effects of *C. orbiculatus* on the abiotic and biotic properties of ecosystems are assigned with medium confidence, due to a lack of information on these issues. These risks have been mainly estimated using best professional knowledge of the expert panel.

*Plant crops*
The consequences of invasion of *C. orbiculatus* on plant crops, pastures and horticultural stock through herbivory, parasitism and interbreeding are not applicable. The experts attributed a medium risk of negative impacts to plant crops as a result of competition and on the cultivation system's integrity with a medium level of confidence. In this case, the quality or yield of plant crops is expected, at worst, to decrease by ≤ 20% within a crop stand. No further details were found in the available literature. The risk of negative effects on plant targets due to the hosting of pathogens or parasites that are harmful to the cultivated plants is classified as very low because no shared pathogens are described or known.

*Domestic animals*
Negative impacts resulting from parasitism or predation and by parasites or pathogens of *C. orbiculatus* are not applicable. The risk of effects on animal health by properties of *C. orbiculatus* that are hazardous upon contact is scored as very low with a medium level of confidence. No information regarding the effects of *C. orbiculatus* on domesticated animals was found in the available literature.

*Human health*
Effects on human health are considered to be inapplicable. No information regarding effects on humans was found in the available literature.

*Infrastructure*
Damage to infrastructure may occur when *C. orbiculatus* grows into fences or around above ground low voltage power lines and telephone wires. These structures may become more vulnerable to wind-throw (Connecticut Invasive Plant Working Group 2014). However, there is a low risk of effects because the growth of *C. orbiculatus* around structures that support power lines and telephone wires is expected to be irrelevant in large parts of the EU as much of the infrastructure is buried below ground.

*Ecosystem services*
Effects on provisioning services were scored as moderately negative overall based on the potential effects of *C. orbiculatus* on ecosystem services listed in table 2.5. The positive effect of the species on bio-chemicals, natural medicines, and pharmaceuticals was outweighed by its negative effect on timber production. The category 'regulation and maintenance services' in table 3.1 corresponds with

regulating and supporting services described in table 2.5. *C. orbiculatus* was expected to have a neutral effect on most of these services. Cultural services were also considered to be neutral. All risks are assigned with medium confidence based on the best professional knowledge of the expert panel as there was a lack of available scientific publications on *C. orbiculatus* effects on ecosystems services.

*Risk classification*

The invasion score is classified as medium due to the medium score allocated to the introduction category, and high scores allocated to both the establishment and spread categories (Table 3.2). The overall impact is scored high due to the high scores allocated to the impacts on environmental targets category. As a consequence, the overall risk score of *C. orbiculatus* is classified medium.

**Table 3.2:** Risk classifications, maximum risk scores and confidence levels per risk category for *Celastrus orbiculatus* in the European Union, calculated with the online version of the Harmonia[+] protocol. Please note that classifications and scores are the same for the current and future situations.

| Risk category | Risk classification | Risk score | Confidence | Confidence score |
|---|---|---|---|---|
| **Introduction[1]** | Medium | 0.50 | High | 1.00 |
| **Establishment[1]** | High | 1.00 | High | 1.00 |
| **Spread[1]** | High | 0.75 | Medium | 0.50 |
| **Impacts: environmental targets[1]** | High | 1.00 | Medium | 0.50 |
| **Impacts: plant targets[1]** | Medium | 0.50 | Medium | 0.50 |
| **Impacts: animal targets[1]** | Low | 0.00 | Medium | 0.50 |
| **Impacts: human health[1]** | Low | 0.00 | High | 1.00 |
| **Impacts: other targets[1]** | Low | 0.25 | High | 1.00 |
| **Invasion score[2]** | Medium | 0.38 | NA | NA |
| **Impact score** | High | 1.00 | NA | NA |
| **Risk score (Invasion x impact)** | Medium | 0.38 | NA | NA |

1: maximum score per risk category; 2: introduction x establishment x spread; NA: not applicable.

### 3.1.2 Classification for future situation

The expert team expects that climate change (2 °C increase by 2050 with unchanged management policies on alien species in the EU) will have no effects on the ecological risks of the species. Therefore, the risk scores for the current and future situations were the same (Table 3.2).

## 3.2 Risk assessment and classification with ISEIA-protocol

### 3.2.1 Classification for current situation

The expert team exchanged arguments for the risk scores of *C. orbiculatus* and came to a consensus. The experts allocated a “high” risk score for the sections: dispersion potential and alteration of ecosystem functions, and a risk score “medium” for the other sections (Table 3.3). The total score for the environmental risk of this species is 10, out of a maximum score of 12.

The species is currently present in isolated populations within the EU. Therefore, the species is classified as a B1-species in the BFIS-system for the current situation (Figure 3.1). According to the BFIS-system, *C. orbiculatus* qualifies for the watch list. The rationale for this risk classification is presented in more detail in the following paragraphs.

**Table 3.3:** Consensus risk scores and risk assessment for Staff-vine (*Celastrus orbiculatus*) for the current situation in the European Union, using the ISEIA-protocol[a].

| Current situation | | Consensus scores |
|---|---|---|
| **Dispersion potential and invasiveness** | | **3** |
| **Colonisation of high conservation value habitats** | | **2** |
| **Direct or indirect adverse impacts on native species** | | **2** |
| 1. Predation/herbivory | NR | |
| 2. Interference, exploitation competition | 2 | |
| 3. Transmission of parasites and diseases | DD | |
| 4. Genetic effects (hybridisation / introgression with natives) | NR | |
| **Direct or indirect alteration of ecosystem functions** | | **3** |
| 1. Modification of nutrient cycling or resource pools | 2 | |
| 2. Physical modifications of habitat | 3 | |
| 3. Modification to natural succession | 2 | |
| 4. Disruption to food webs | DD | |
| **Total score** | | **10** |
| **Range of spread** | | **Isolated populations** |
| **Risk Classification** | | **B1** |

[a] Information deficiency and best professional judgement is not expected to influence the total maximum possible risk score; NR: not relevant; DD: data deficiency.

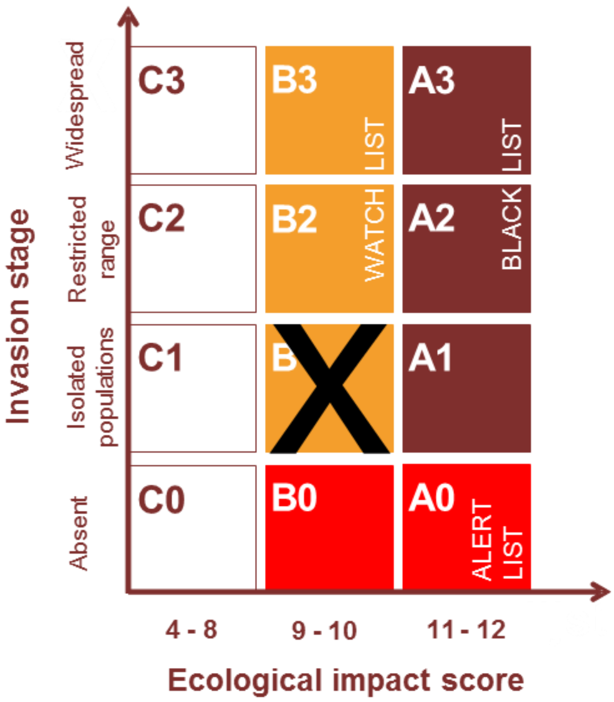



**Figure 3.1:** The risk classification of *Celastrus orbiculatus* for the current situation in the European Union according to the BFIS-list system.

*Dispersion potential or invasiveness*
Risk score 3 (**high**). The species is potentially highly fecund and individual berries are easily dispersed by birds (e.g., starling) over a distance of several kilometres (and thus more than 1 km per year). It should be noted that sexual reproduction requires that both sexes grow in close proximity. At present, this is not yet the case in the EU. However, garden centres recommend to plant female and male for fruiting.

*Colonization of high value conservation habitats*
Risk score 2 (**medium**). The species is usually confined to habitats with a ‘low or medium’ conservation value such as (peri)urban habitats, and occasionally colonises high conservation value habitats, such as riparian forests.

*Adverse impacts on native species*
Risk score 2 (**medium**). The species may cause local changes in population abundance (less than 80%) and limit the growth or distribution of one or more native plant and animal species by climbing in trees, covering parts of forests and thereby significantly altering the habitat conditions for native species. This effect is reversible if *C. orbiculatus* plants are removed. The risk assessment criteria predation, herbivory and genetic effects are not applicable. The species may hybridize with another non-native species present in the EU, *Celastrus scandens,* which is also occasionally grown in gardens. However, there is no evidence that invasiveness increases after interspecific hybridization (Zaya et al. 2015). Available information on transmission of parasites and diseases is lacking.

*Alteration of ecosystem functions*
Risk score 3 (**high**). The impact of the species on ecosystem functions is scored as high. The species likely has an impact on ecosystem processes and structure by growing in trees and over bushes. In old-growth forests, gaps that naturally form in the canopy provide *C. orbiculatus* with opportunities to invade areas which are not prone to human disturbances. Established vines that have climbed high into the trees are difficult to remove. The species forms root suckers which re-sprout after cutting. Furthermore, *C. orbiculatus* will likely affect nutrient cycling and resource pools in the invaded habitat. Establishment of the plant will result in physical habitat modifications, e.g., alteration to the vegetation structure and light interception. In addition, the plant will modify natural succession by killing native trees and bushes, and prevent natural development of the understory and tree layers. The species has the ability to suppress the regeneration of canopy trees in forest gaps. There is insufficient data to allow an assessment of potential food web disruption.

### 3.2.2 Classification for future situation

The expert team expects that climate change (2 °C increase by 2050) with unchanged EU and national policies for *C. orbiculatus* will have no effects on the ecological risk posed by the plant. However, propagule pressure exerted by *C. orbiculatus* is expected to increase if management policy remains unchanged.

Spread may accelerate as soon as 1) the fruiting improves as a result of planting of a greater diversity of clones, and 2) sexual reproduction increases due to the planting of male and female cultivars together, advice given to customers buying *C. orbiculatus* from retailers. Moreover, the expert panel expects that, in the EU, there will probably be a geographical shift in suitable habitat towards the north, and from a lower to a higher altitude in mountainous areas due to an increase in air temperature. It is reasonable to assume that areas with currently suitable habitat will remain partially suitable or become sub-optimal as a result of climate change. However, it is unknown whether these areas will become entirely unsuitable in the future. An overall increase in recorded distribution is expected from isolated populations to a restricted range owing to the combined effect of unchanged management policy and climate change. Therefore, the results of the ISEIA risk assessment for the future situation will not change compared to the assessment for the current situation, and the risk score remains B – moderate. Information deficiency and the application of best professional judgement are not expected to influence the total maximum possible risk score.

## 3.3 Other available risk classifications

The results of the risk assessments for *C. orbiculatus* obtained with Harmonia$^{+}$ and ISEIA were compared with other available risk classifications for this species (Table 3.5).

**Table 3.5:** Available risk classifications for Staff-vine (*Celastrus orbiculatus*).

| Geographical area | Assessment scheme | Context | Risk classification | References |
|---|---|---|---|---|
| European Union | Harmonia$^{+}$ | Risk assessment for decision making on listing IAS of EU concern | Medium | This study |
| European Union | ISEIA | Idem | Medium | This study |
| European Union | Workshops, discussions and consensual agreement | Prioritization for risk assessment (Horizon scanning) | High | Roy et al. (2015) |
| Hawaii, USA | Hawaii Pacific Weed Risk Assessment (HPWRA) | Development of a comprehensive ‘approved planting list’ to ensure that invasive species are not being planted in state projects or by any state contractors | High (likely to be a pest; rejected for approved planting list) | HPWRA (2013) |
| Indiana, USA | US-Weed Risk Assessment | Assessment of invasive species in Indiana’s natural areas by Invasive Plant Species Assessment Working Group | High | Casebere et al. (2005) |
| Ohio, USA | Ohio Invasive Plant Assessment Protocol | Re-assessment of previously listed invasive plant species | Invasive | Ohio Invasive Plant Council (2014) |
| New Zealand | Weed Risk Assessment (WRA) System | Testing this WRA-system for prioritization of weeds for management program | High | Williams et al. (2005) |

Other available risk classifications are higher in comparison with our assessments. Potential reasons for differences between classifications are differences in ecological context (e.g., island versus continent, and the presence of native congener in USA), different methods applied to aggregate risk scores within and between categories (total summation, averaging and maximum approaches), assessment context (e.g., detailed risk assessment versus horizon scanning or prioritization), impact rating (differences in number and threshold values for risk classes), and risk categories (e.g., inclusion or exclusion of introduction risk and the scope for effective management).

*European Union*

The EU horizon scanning for invasive alien species prioritised 250 species across five taxonomic groups (1. plants, 2. vertebrates, 3. terrestrial invertebrates, 4. marine species, and 5. freshwater invertebrates and fish) for risk assessment, using workshops, discussions a nd consensual agreement between experts species (Roy et al., 2015). This study identified 95 species that pose a potentially high or very high risk of introduction, establishment, spread and negative impact to biodiversity and associated ecosystem services across the EU over the next ten years. The overall score for the risk of *C. orbiculatus* was 500 out of 625 points, indicating a species that potentially poses high risk. The overall score was calculated as A*B*C*D with scores on a scale of 1 (Low) to 5 (High) attributed by experts for the likelihoods of A) Introduction, B) Establishment, C) Spread, and D) Potential negative impact on biodiversity within the EU. According to Roy et al. (2015), *C. orbiculatus* was not present in free nature in the EU. However, the present study revealed that the species already occurs in several EU member states (see §2.2).

*Hawaii, USA*

The Hawaii Pacific Weed Risk Assessment (HPWRA, 2013) has been used to develop a comprehensive ‘approved planting list’ to ensure that invasive species are not being planted in state projects or by any state contractors, e.g., screened by the Weed Risk Assessment (WRA) protocol (Daehler & Carino 2000, Daehler et al. 2004). According to the WRA scores, species were placed into the following categories: Accept (not likely to be a pest; WRA score < 1), Reject (likely to be a pest; WRA score > 6), or Evaluate (requires further evaluation; WRA score = 1-6). The assessment of *C. orbiculatus* resulted in a WRA score 13.5 (HPWRA, 2013), indicating that this species should be rejected for the approved plant species list because it potentially poses a high risk to biodiversity and ecosystems.

*Indiana, USA*

Casebere et al. (2005) assessed species for potential invasiveness in Indiana’s natural areas and ranked *C. orbiculatus* as a high risk species. The total score for ecological impact, potential for expansion and difficulty of management was 108 points (risk classification with score < 45: low risk; score 45-80: medium risk; score > 80: high risk).

*Ohio, USA*

In 2014, the Ohio Invasive Plant Council (OIPC) re-assessed several plant species that were listed as invasive in 2000. A working group firstly developed an assessment protocol, based on careful review of the scientific literature, existing protocols from other states and organizations, and input from OIPC members with expertise in relevant areas, especially invasive species research, land management, and the nursery industry. These species were run through the point-based protocol to determine if plants were invasive (45-80 points), not invasive (0-34 points), in an intermediate category (pending further review; 35-44 points), or could not be completely assessed due to a lack of data (insufficient data). The assessment protocol of the OIPC includes a summation of risk scores on the invasion status (local, regional and national distribution), biological characteristics (establishment and spread), and ecological importance (impacts on ecosystem processes and biodiversity). The re-assessment of *C. orbiculatus* resulted in a score 59, meaning that this species remained in the invasive species category.

*New Zealand*

The Department of Conservation of New Zealand used the weed risk assessment system for new conservation weeds (NCWR) for risk priority rankings of invading woody vegetation (Williams et al. 2005). An impact score is calculated by summarizing risk scores from four different categories: 1) the estimated volume of an individual species, 2) if the species covers native species to form a canopy, 2) if the growth appears faster than associated native species, and 4) how long the species persists in an area with optimal habitat. A spread score is calculated by summarizing scores for the invasion stage and reproduction. The combined risk score (impacts*spread) of the NCWR system for *C. orbiculatus* in an early stage of invasion of conservation land in the Nelson-Marlborough and Auckland regions was 176 and 200 out of 320 points, respectively. The species had the highest combined risk score and ranked 1 and 2 out of 21 and 12 weeds, respectively. It was most likely that the species was a candidate for control in New Zealand and was already in the 'weed-led' programme for the Nelson-Marlborough region (Williams et al. 2005).

*Compendia of weeds*

In the Global Compendium of Weeds (2016) *C. orbiculatus* is classified as a noxious weed (i.e., status: Weed ~ Quarantine Weed ~ Naturalized ~ Environmental Weed). This plant is listed by the USA federal government and several states as a noxious weed. Moreover, the species is banned or prohibited by several states because of its invasiveness, e.g., Connecticut, Massachusetts and New Hampshire (USDA 2016).

# 4. Discussion

## 4.1 Classification and rating of risks

The two assessment protocols used in this risk assessment of *C. orbiculatus* (ISEIA and Harmonia$^+$) gave similar scores. Both resulted in the risk classification “medium risk”. In risk assessments in other countries this species yielded higher risk classifications. Although the impact categories applied in the NCWR, used for the assessment of *C. orbiculatus* in the Nelson-Marlborough region of New Zealand, differ from the ones included in the ISEIA and Harmonia$^+$ protocols, the total impact score is also high (8 out of 10 points) (Williams et al. 2005). The difference of total risk scores between the NCWR and our Harmonia$^+$ assessment may be attributed to the lack of an introduction risk category in the NCWR. The application of the OIPC protocol, used for the assessment of *C. orbiculatus* in Ohio (USA) resulted in an invasion status score of 100% out of 13 points, the biological characteristics 78% out of 32 points, and the ecological importance 60% out of 35 points (Ohio Invasive Plant Council 2014). A comparison between the OIPC protocol and our assessments is difficult due to different usage of impact ratings, but the results of the biological impact category in the OIPC protocol seem to be on a similar level as the risk scores for establishment and spread (1.00 and 0.75) in the Harmonia$^+$ protocol. It is possible that the application of the summation of risk scores from the different categories rather than the maximum score caused the differences in total risk scores observed between our assessments and the USA and New Zealand assessments.

The risk of colonization of high conservation value habitats was scored as medium. A high risk would be allocated in the scoring system of the ISEIA protocol if the alien species often colonises high conservation value habitats (i.e., most of the sites of a given habitat are likely to be readily colonised by the alien species when source populations are present in the vicinity) and poses therefore a potential threat for red-listed species. The expert team expected that *C. orbiculatus* will not be able to colonise such a wide range of high conservation value habitats in the EU. However, it is not clear whether new sites in Europe originate from the dispersal of seeds by berry eating birds, or from the dumping of garden waste. Dispersal by birds (i.e., starlings) is evident in the USA.

The category adverse impact on native species was allocated a medium score. In the scoring system of the ISEIA protocol, a medium risk is allocated when the alien species causes local changes (<80%) in population abundance of one or more native plant or animal species. A high risk is allocated when the alien species often causes severe (>80%) population declines and the reduction of local species richness, which is the case when the alien species often forms dense and monospecific stands. In Europe there are no cases yet where *C. orbiculatus* causes such severe population declines. Evidence from the USA may indicate that such severe impacts may be possible in a future situation in the EU irrespective of climate change (2 °C increase). This is due to the currently suitable climate and habitat conditions in the EU. Impacts are likely to increase when *C. orbiculatus* occurs more frequently and produces more viable seeds. This situation requires the occurrence of different varieties of the species, and that male and female plants are planted side by side. The latter is recommended by garden centres to guarantee fruit set in this dioecious species. It is unknown if this scenario will develop in the EU, but in that case the ecological and economic risks will increase.

The expert panel allocated a high risk score to the category concerning potential alterations to ecosystem functions as the impact on ecosystem processes and structures is considered as high and not easily reversible. In old-growth forests naturally occurring gaps in the canopy provide *C. orbiculatus* additional opportunities to invade areas that are not disturbed by humans. Removal is difficult once the vine establishes and climbs high into the trees. The species forms root suckers which re-sprout after cutting. At this stage, only the cutting and treating of the stump with herbicides will be remove individuals. It may take a considerable amount of time before the ecosystem recovers after removal measures have been carried out. Moreover, re-infestation remains possible if nearby seed sources are not eliminated.

## 4.2 Knowledge gaps and uncertainties

It is not clear in which EU habitats *C. orbiculatus* will establish within Europe. The most likely habitats for colonisation are deciduous forest on moist (but not too wet), nutrient rich and neutral soils. 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. Here, the risk of increase in nutrient availability rises as a result of *C. orbiculatus* development.

Dispersal by birds (starlings) is evident in the USA. It is not always clear whether new sites in Europe originate from bird dispersal or the dumping of garden waste. This knowledge gap results in uncertainty in the dispersal risk classification. It is very likely that starlings, which are indigenous to Europe, will disperse seeds within Europe.

Occurrence of different clones or varieties of the species, and male and female plants side by side will result in sexual reproduction. After the initiation of sexual reproduction, the risk of spread of the species likely increases as unintentional distribution by berry eating birds will likely occur. It is assumed that the ecological and economic risks will increase if this situation will develop in the EU, but detailed information on the actual and potential risk of spread of the species by berry eating birds and subsequent establishment is lacking.

In addition, there is a lack of information on the following risk aspects:

- Transmission of parasites and diseases;
- Effects of feeding by domesticated animals;
- Disruption of food webs, especially in forests;
- Effects on nutrient cycling and resource pools in the invaded habitat;
- Control of the plant by deer.

Additionally, cost information with respect to losses of ecosystem functions, such as those relating to a decline of timber production, was not found in the available literature. Only information on the costs of management measures to control the species in New Zealand between 1999 and 2003 was found (§2.5.5).

### 4.3 Management

Effective management measures to remove or control of *C. orbiculatus* should be tailored to the traits of the species. The intact forest floor litter of an undisturbed forest will not prevent seedling establishment from elsewhere (Ellsworth et al. 2004a). However, the low survival of *C. orbiculatus* in the seed bank suggests that eradication of seedlings and adult plants prior to seed rain may be an effective control strategy. It is possible, at an early stage, to remove the young plants from the forest floor by hand pulling. Additionally, the low percentage of seed germination after the first year and fire intolerance of the seeds suggest that fires conducted in the spring (prior to green up) with temperatures higher than 140 °C may actually aid control as the year's crop of seeds would be essentially eliminated (Leicht-Young et al. 2013). Fire as a management tool, however, is not applied within the EU.

Forests should be monitored by land managers so that *C. orbiculatus* eradication can occur while invasions are still at low densities and restricted to the ground layer (Pavlovic & Leicht-Young 2011). The early stage of invasion offers a window of opportunity for control because population spread is limited due to limited light availability and the inability of the plant to reproduce sexually at this point. After the initiation of sexual reproduction, *C. orbiculatus* may spread rapidly and, in the presence of sufficient disturbance, become the dominant canopy species (Silveri et al. 2001). Eradication will be much more difficult or even impossible in situations where *C. orbiculatus* has become invasive at many sites.

# 5. Conclusions

**Current presence in the EU**

- *Celastrus orbiculatus* has been present in European botanical gardens since 1863 and is nowadays offered for sale as a garden plant in many European countries. There are records of *C. orbiculatus* naturalizing in Europe from 1980 onwards, mostly in or nearby urban areas. The species is recorded in Germany (scattered sites), Austria (several sites), Czech Republic (1 town), the United Kingdom (four 10x10 km-squares), Sweden (several sites), Poland, Belgium (4 sites), the Netherlands (2 sites), Norway (1 city) and European Russia (1 region).

- The species is used as an ornamental plant because of its colourful display of fruits and leaves in late summer and autumn. Therefore, the social and economic benefits of *C. orbiculatus* are related to the horticultural and plant trade.

**Probability of introduction**

- The species was intentionally introduced in the EU for cultivation in the 19th century. New introductions are likely to occur, as *C. orbiculatus* is offered for sale as a garden plant in nurseries and web shops. However, the probability that the species will be introduced into the EU's wild from outside the EU by intentional human actions is scored medium. This score is based on the historical introductions and present-day occurrence of *C. orbiculatus* in EU member states. There is no evidence of intentional introductions of *C. orbiculatus* into the wild of the EU.

- The probability that *C. orbiculatus* will be introduced into the EU's wild from outside the EU by unintentional human actions or via natural pathways within the time span of a decade is scored as low. It is more likely that introductions via natural pathways will occur due to the recorded occurrences of *C. orbiculatus* in eight EU member states.

- The risk of introduction of the species is expected to be unaffected by foreseeable changes in climate conditions.

**Probability of establishment**

- The species is highly fecund and produces many berries. The lack of reports of sexual reproduction in the period 1860-1980 is probably due to dioecious plants that were grown as a single male or female specimen. Nowadays there is a greater diversity of clones available and gardeners are advised to plant male and female cultivars side by side to achieve a better fruiting which encourages regeneration and potentially leads to greater sexual reproduction.

- Climatic and habitat requirements of *C. orbiculatus* are expected to be fully met in the EU. The species' native range and the EU feature similar climate zones. The entire Atlantic, Continental and southern Boreal biogeographical regions of Europe are likely to be suitable for the establishment of the species. The Mediterranean biogeographical region and some (sub) montane regions do not match the climate requirements of *C. orbiculatus*.

- It is uncertain in which EU habitats *C. orbiculatus* will establish. Suitable habitats are most likely to be forests on moist, fertile, neutral soils, such as alluvial forest and riparian mixed forest (Natura 2000 codes 91E0 and 91F0). In its native range, *C. orbiculatus* grows in mixed forests, forest margins and thickets on grassy slopes at altitudes between 400-2200 m. The species grows in a very wide number of different habitats ranging from sand dunes and open fields to wet and dry forests in its non-native range in the USA. It thrives best in recently disturbed and edge habitats.

- The risk of establishment of *C. orbiculatus* is most likely highest in locations with alluvial or riparian mixed forest in climate regions that match the native and non-native ranges of the species located in north-eastern USA, south-eastern Canada, northern Japan and New Zealand (Köppen-Geiger regions Dfb and Cfb). Climate regions matching these classifications in the EU are areas at possible risk of *C. orbiculatus* establishment (endangered areas).

- The risk of establishment in the EU is high considering *C. orbiculatus'* fecundity and the habitat and climate match.

- The future climate change is expected to have little effect on the risk of establishment, although some (sub) montane regions may gain more suitable habitat for *C. orbiculatus* if the temperature increases.

**Probability of spread**

- The risk of spread within the EU is expected to be high, considering the climate match, the wide range of habitat conditions in which the species can occur and thus the availability of suitable habitat in the EU. As soon as the species is established and the requirement of multiple clones to guarantee fruit set in this dioecious species is met, the number of locations where the species grows will increase. After the initiation of sexual reproduction, *C. orbiculatus* may spread rapidly and unintentional distribution by berry eating birds will likely occur. The propagule pressure will likely increase over time in the event of unchanged management policy.

- The unintentional distribution of plants from gardens into the wild, caused by berry eating birds and the improper disposal of (bonsai) trees or decorations outdoors or in compost, can contribute to the spread of *C. orbiculatus*.

- Climate change (2 °C increase) will not change the risk of spread of *C. orbiculatus* within the EU. There will probably be a geographical shift in suitable habitat in the EU towards the north and from a lower to a higher altitude in mountainous areas. It is reasonable to suggest that current areas with potential suitable habitat will remain partially suitable or sub-optimal after climate change. Therefore, in the event of unchanged management policy and climate change, an increase in distribution from isolated populations to a restricted range is expected with respect to the current situation.

**Probability of impact**

- *C. orbiculatus* adversely affects the tree and herb layers in mature forests. In the presence of sufficient disturbance and light *C. orbiculatus* may become the dominant canopy species. The species causes the deformation and shading of mature tree crowns and severely increases the risk of wind-throw. *C. orbiculatus* also cuts off the transport of assimilate to and from stems, branches and roots of trees. Additionally, nutrient availability (nitrogen mineralization and litter decomposition) may be increased by *C. orbiculatus.* These process changes are expected to be hardly reversible (e.g., due to the difficulty to remove root suckers entirely) and may occur in ecosystems that are of high conservation value (e.g., alluvial and mixed riparian forests).

- The impact of *C. orbiculatus* on ecosystem functions, such as the physical modification of habitat, is expected to be high. The species may limit timber production. *C. orbiculatus* suppresses regeneration of young trees in forest gaps and young trees can be totally overgrown on forest plantations.

- The effects of *C. orbiculatus* on human health and safety are not applicable. No information regarding effects on humans was found in the available literature.

**Risk classification**

- The expert team allocated *C. orbiculatus* the total risk score "**medium**" for ecological risks posed by the species in the endangered area of the EU using the Harmonia$^+$ protocol. The classification of *C. orbiculatus* by experts based on the available knowledge resulted in the following risk scores in the Harmonia$^+$ protocol:
  - Introductions risk: **medium**
  - Establishment risk: **high**
  - Spread risk: **high**
  - Environmental impact risk: **high**
  - Risk effects plant cultivation: **medium**
  - Risk effects domesticated animals and livestock: **low**
  - Risk effects public health: **low**
  - Other risk effects: **low**

- The expert team allocated a “**medium**” total risk score for the ecological risks of *C. orbiculatus* in the endangered area in the EU using the ISEA protocol. This species is currently present in isolated populations within the EU, therefore, the species is classified as a B1-species in the BFIS-system and thus qualifies for the **watch list**. The species also qualifies with a medium risk (watch list) in the future situation in the EU, but propagule pressure is expected to increase with unchanged management policy and a geographical shift in suitable habitat in the EU may be caused by climate change.

- Climate change (2 °C increase by 2050) combined with unchanged EU and national policies for *C. orbiculatus* will have no effects on the plants ecological risk.

- Available risk classifications for *C. orbiculatus* in the USA and New Zealand are higher in comparison with the Harmonia$^+$ and ISEIA assessments for the EU.

**Knowledge gaps**

- Several knowledge gaps were encountered during this risk assessment and classification. Data are lacking on costs of (recurrent) control measures and potential losses of income from timber production. In addition, the risk of spread was scored with medium confidence because detailed information on the actual risk of spread of the species by berry eating birds and subsequent establishment is lacking. Furthermore, it is not clear in which EU habitats *C. orbiculatus* will establish within Europe. Also little information was found on the effectiveness of eradication and control measures. Research on these issues is required on either an EU wide scale or in individual member states in order to generate more data that will form a basis for management actions.

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| | |
|---|---|
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| | http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/naturschutz/Neobiota_Engl.pdf |
| | http://www.umweltbundesamt.at/umweltschutz/naturschutz/natur_aktuell/aktionsplan_neobiota |
| Belgium | http://alienplantsbelgium.be/search/site/Celastrus%20orbiculatus |
| | http://waarnemingen.be/soort/view/136664 |
| Bulgaria | http://eea.government.bg/bg/soer/2010/biodiversity-nem/biologichno-raznoobrazie-natsionalna-ekologichna-mrezha-1 |
| Croatia | NA |
| Cyprus | NA |
| Czech Republic | http://www.preslia.cz/P122Pysek.pdf |
| Denmark | http://ign.ku.dk/formidling/publikationer/rapporter/filer-2014/pathways-for-non-native-species-in-DK.pdf |
| Estonia | https://www.riigiteataja.ee/akt/12828512 |
| Finland | http://vieraslajit.fi/ |
| France | http://www.tela-botanica.org/bdtfx-nn-14946-synthese |
| Germany | http://floraweb.de/pflanzenarten/artenhome.xsql?suchnr=11929& |
| Greece | NA |
| Hungary | http://www.termeszetvedelem.hu/_user/downloads/invazios_fajok/invazivfajok.pdf |
| Ireland | NA |
| Italy | http://www.minambiente.it/sites/default/files/archivio/biblioteca/protezione_natura/dpn_flora_alloctona.pdf |
| Latvia | NA |
| Lithuania | http://www.corpi.ku.lt/nemo/ |
| Luxemburg | NA |
| Malta | NA |
| The Netherlands | http://waarneming.nl/soort/view/136664 |
| | http://www.verspreidingsatlas.nl/8152 |
| Norway | http://data.artsdatabanken.no/Search?q=japanfr%C3%B8busk |
| Poland | http://www.iop.krakow.pl/ias/gatunki |
| | http://www.wigry.org.pl/ros_obce_cz1a.pdf |
| Portugal | http://invasoras.pt/ |
| Romania | NA |
| Slovakia | http://www.preslia.cz/P122Medvecka.pdf |
| Slovenia | NA |
| Spain | http://www.magrama.gob.es/es/biodiversidad/temas/conservacion-de-especies/especies-exoticas-invasoras/ce_eei_flora.aspx |
| | http://www.anthos.es/index.php?lang=en |
| Sweden | http://www.artdatabanken.se/en/ |
| United Kingdom | http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=691 |
| | http://www.nonnativespecies.org/ |
| **Other European countries** | |
| Switzerland | https://www.infoflora.ch/de/assets/content/documents/neophytes/neophytes_divers/Schwarze%20Liste_Watch%20Liste_2014.pdf |
| | https://www.infoflora.ch/de/flora/neophyten/ |

| Global and European sites | |
|---|---|
| BHL | http://www.biodiversitylibrary.org/name/Celastrus_orbiculatus |
| CABI | http://www.cabi.org/isc/datasheet/12009 |
| DAISIE | http://www.europe-aliens.org/speciesFactsheet.do?speciesId=10089 |
| EOL | http://www.eol.org/pages/396516/overview |
| EPPO | https://gd.eppo.int/taxon/CELOR |
| EU LIFE projects | http://ec.europa.eu/environment/life/publications/lifepublications/lifefocus/documents/life_ias.pdf |
| Flora of China | http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=200012786 |
| Flora of China | http://flora.huh.harvard.edu/china/PDF/PDF11/Celastrus.pdf |
| GBIF | http://www.gbif.org/species/3169169 |
| GISIN | http://www.gisin.org/cwis438/Websites/GISINDirectory/GISIN_ScientificName_List.php?WebSiteID=4 |
| GRIN | https://npgsweb.ars-grin.gov/gringlobal/taxonomydetail.aspx?id=9719 |
| ISSG | http://www.issg.org/database/species/ecology.asp?si=156&fr=1&sts=sss&lang=EN |
| IUCN | http://www.iucngisd.org/gisd/species.php?sc=156 |
| NOBANIS | https://www.nobanis.org |
| Observado | http://observado.org/soort/view/136664?from=2000-01-01&to=2016-02-16 |
| Plant list | http://www.theplantlist.org/tpl1.1/record/kew-2707630 |
| Q-bank | http://www.q-bank.eu/Plants/ |
| USDA | http://plants.usda.gov/core/profile?symbol=CEOR7 |
| USDA Forest service | http://www.fs.fed.us/database/feis/plants/vine/celorb/all.html |

NA: not available

# Glossary

| Term | Description |
|---|---|
| Acuminate | Tip of the leaf gradually tapering to a sharp point |
| Allelopathic | Secreting chemicals which suppress competitors |
| Apex | Tip |
| Aril | Fleshy or hairy outgrowth of a seed or fertilized ovule |
| Axillary | Arising in the axil of a bract or leaf |
| Carnose | Fleshy |
| Ciliolate | Covered with minute hairs |
| Crenate | With blunt or rounded teeth, scalloped |
| Cuneate | Wedge-shaped with straight sides converging a base |
| Cupuliform | Nearly hemispherical, shaped like a cupole or dome |
| Cuspidate | Tipped with a cusp |
| Cyme | A flower cluster with a central stem bearing a single terminal flower that develops first, the other flowers in the cluster developing as terminal buds of lateral stems |
| Deciduous | (of a tree or shrub) shedding its leaves annually |
| Deltoid | Shape like the Greek letter Δ |
| Dioecious | Plant species whose individuals are either male or female |
| Erose | Appearing as if gnawed |
| Fecund | Producing or capable of producing an abundance of offspring or new growth; highly fertile |
| Filliform | Thread-like |
| Glabrous | Without hairs |
| Glandular | Furnished with glands |
| Inflorescence | The complete flower head of a plant including stems, stalks, bracts, and flowers |
| Lenticels | Typically lens-shaped (lenticular) porous tissue in bark (exchange of gases with atmosphere) |
| Monoecious | (of a plant or invertebrate animal) having both the male and female reproductive organs in the same individual; hermaphrodite |
| Non-native | Species not native, originating from elsewhere |
| Obovate | Ovate with the narrower end toward the base |
| Orbicular | Rounded, with length and breadth about the same |
| Ovate | Egg-shaped |
| Ovoid | Egg-shaped and flat, with the broad end toward the base |
| Panicles | A loose branching cluster of flowers, as in oats |
| Pedicel | Stalk of a single flower |
| Peduncle | The stalk of an inflorescence or partial inflorescence |
| Petals | Member of inner series of perianthal leaves if differing from outer series (often brightly coloured) |
| Phloem | Tissue conducting food produced by photosynthesis to plant parts (parenchym, sieve tubes, fibres) |
| Petiole | Stalk of a leaf |
| Pistil | A single carpel when the carpels are free or a group of carpels when united and fused |
| Pollen | The microspores of a flowering plant or conifer |
| Polygamous | Having male, female and hermaphroditic flowers on the same or different plants |
| Sieve tubes | A tube through which food is conducted in angiosperms, formed by a series of such joined tubes |
| Seed bank | The natural storage of seeds, often dormant, within the soil of most ecosystems |
| Sepals | A number of outer series of perianthal leaves, especially when green and leaf-like |
| Serrate | Toothed like a saw |
| Spinose | With stiff sharp structures (lateral branches, stipules, thorns) |
| Stamens | The male fertilizing organ of a flower, typically consisting of a pollen-containing anther and a filament |
| Staminodes | Often rudimentary, sterile or abortive stamens (not producing pollen) |
| Stipules | A small leaf-like appendage to a leaf, typically borne in pairs at the base of the leaf stalk |
| Subglobose | Not quite, nearly, globose |
| Temperate | Relating to or denoting a region or climate characterized by mild temperatures |
| Xylem | The tissue of a vascular plant that conducts water and minerals and provides support (tracheary elements, parenchyma, woody tissue) |

# Appendix 1 – Materials and methods

## A1.1 Risk analysis components

The present risk assessment of Staff vine (*Celastrus orbiculatus*) in the European Union includes analysis of the probability of introduction, establishment and spread within the EU. Also the available literature on the ecological and socio-economic effects, impact on public health, and availability of cost-effective options for risk management were analysed. The background information and data collected in the risk inventory are presented in chapter 2 and used as basis for the risk assessments and classification in chapter 3.

Subsequently, an ecological risk assessment and risk classification of the species in the EU was made using the Harmonia$^+$ protocol (D'hondt et al. 2014, 2015). The novel internet version of this protocol includes criteria for an ecological risk assessment as well as modules for the assessment of (potential) impacts on human health, infrastructure and ecosystem services, and a module to assess effects of climate change on the risks posed by alien species. The earlier version of Harmonia$^+$ was nearly compliant with criteria for risk assessment of IAS of EU-concern derived from Regulation 1143/2014 on the prevention and management of the introduction and spread of IAS (Roy et al. 2014). We assumed that the current internet version of Harmonia$^+$ is compliant with these criteria due to the addition of modules concerning the impacts on ecosystem services and the potential effects of climate change on future impacts of alien species.

In addition, a risk assessment was performed using the Invasive Species Environmental Impact Assessment (ISEIA) protocol (Branquart 2009a, b; Vanderhoeven et al. 2015).

## A1.2 Risk inventory

An extensive literature review was carried out to compile a science based overview of the current knowledge on taxonomy, habitat preference, introduction and dispersal mechanisms, current distribution, ecological impact, socio-economic impact and consequences for public health of the species. In addition, data on the current distribution in EU member states were acquired. In this risk inventory internationally published knowledge in scientific journals and reports was described. If relevant issues mentioned in the format for this risk inventory could not sufficiently be supported by knowledge published in international scientific literature, 'grey literature' or 'best professional judgement' was used. In the latter case, this has been indicated in the report to clearly identify which arguments may be open to discussion. Uncertainties and knowledge gaps are also addressed in the discussion. A glossary was added to the report with an explanation of botanical terms.

### A1.2.1 Literature review

The internet was searched for information concerning *C. orbiculatus*. Consulted websites are listed in the references section and contain information on invasive species including information on their distribution at a global or national scale. The Web of Science was searched using the official scientific species name (The Plant List 2016) as a search term (Table A1.1). A quick-scan of the title or summary of all the articles was made to estimate their relevance. Google and Google Scholar were used to find references not accessible by the Web of Science. A combination of the scientific name "*Celastrus orbiculatus*" and "buy plants" in several languages (i.e., Dutch, English, French, German and Spanish) were used as search queries in Google in order to estimate the scale of trade in *C. orbiculatus*. As soon as availability in a country was ascertained the search was stopped.

**Table A1.1**. Literature search strategy.

| Search engine | Search terms | Search date |
|---|---|---|
| Web of Science | *Celastrus orbiculatus* | February 2016 |
| Google Scholar | *Celastrus orbiculatus* | February 2016 |
| Google | *Celastrus orbiculatus* buy plants | February 2016 |
| Web of Science | *Celastrus orbiculatus* risk assessment | June 2016 |
| Google Scholar | *Celastrus orbiculatus* risk assessment | June 2016 |

### A1.2.2 Data acquisition on current distribution

Several online databases were used to acquire data on the current distribution of *C. orbiculatus*. These databases are reported in the reference section ('Websites consulted') and Appendix 3. Records in these databases are validated by photos or herbarium specimens. In addition, data on actual distribution in European countries were obtained from several experts: F. Verloove (Botanic Garden of Meise, Belgium), G. Fried (Anses, Laboratoire de la Santé des Vegetaux, Unité Entomologie et Plantes invasives, Montferrier-sur-Lez Cedex, France), M. Vilà (Estación Biológica de Doñana, CSIC, Sevilla Spain) and P. Carmo (Instituto da Conservaçâo de Natureza e das Florestas, ICNF, Lisbon, Portugal).

## A1.3 Risk assessment and classification

### A1.3.1 Selection of risk assessment methods

One of the aims of this project is to provide insight into the risks of *C. orbiculatus* to biodiversity and ecosystems in the EU. Assessments of ecological risks were therefore required and it was decided to apply both the Harmonia$^+$ and the ISEIA protocol for this purpose. In the current study, the Harmonia$^+$ protocol was used as it includes the assessment of impacts on socio-economic aspects, public health, infrastructure and ecosystem services, as well as the effects of climate change on the establishment, spread, and impacts of alien species. Moreover, the Harmonia$^+$ protocol complies with the criteria of the EU regulation 1143/2014. The ISEIA protocol requires less detailed information on impacts to obtain a risk classification than Harmonia+ and focuses on ecological impacts only. Additionally, this protocol was used to allow comparisons of our risk classification of *C. orbiculatus* with those of other alien species assessed for the Netherlands. The ISEIA protocol has been most frequently used for the risk classification of alien species In the Netherlands.

Harmonia+ and ISEIA are protocols for risk screening and are primarily developed for assessing the negative effects of alien species. They do not consider positive effects, except the module on ecosystem services in the Harmonia+ protocol. However, available information on positive effects of alien species has been included in the risk inventory (Chapter 2).

### A1.3.2 Harmonia+ ecological risk assessment protocol

The Harmonia+ protocol includes procedures for the risk assessment of potentially invasive alien plant and animal species. This protocol stems from a review of the ISEIA protocol and incorporates all stages of invasion and different types of impacts. The online version of the Harmonia+ protocol (D'hondt et al. 2014, 2015) was used for the risk assessment of *C. orbiculatus*. All risk scores were calculated using this online version. This risk assessment method comprises 41 questions grouped in the following modules:

A0. Context (assessor, area and organism);
A1. Introduction (probability of the organism to be introduced into the area);
A2. Establishment (does the area provide suitable climate and habitat);
A3. Spread (risks of dispersal within the area);
A4. Potential impact on the following subcategories:
- A4a. Environmental effects: wild animals and plants, habitats and ecosystems;
- A4b. Effects on cultivated plants;
- A4c. Effects on domesticated animals;
- A4d. Effects on human health;
- A4e. Effects on infrastructure;

A5a. Effects on ecosystem services;
A5b. Effects of climate change on the impact of the organism.

Each module contains one or more risk assessment questions and provides options for risk scores in each question. The protocol provides guidance for all questions and includes explanations and examples that serve as a reference for attributing risk scores.

Table A1.2 shows the formulas used for the calculation of various risk scores. The protocol allows the assignment of various weighing factors to impact categories (i.e., weighing risks within and between categories). In order to prevent averaging of risks and to keep the highest score of each risk category visible, the highest score was always used to calculate final effect scores for a specific impact category. This 'one out all out' principle has also been used in other risk assessments of alien species (e.g., in ISEIA and the EPPO prioritizing schemes) and other policy domains (such as ecological status assessments of water bodies according to the European Water Framework directive). The default value 1 was always used for weighing between various impact categories (i.e., equal weighing). The product of the introduction, establishment and spread was used to calculate the invasion score. The maximum of the different impact scores was used to calculate the aggregated impact score.

**Table A1.2:** Concepts and definitions for risk assessments and classifications of non-native species with the Harmonia[+] protocol (D'hondt et al. 2014).

Conceptual framework

**Invasion**= *f*(*Introduction*; *Establishment*; *Spread*; $Impact_{a\text{-}g}$)

**Risk** = *Exposure* x *Likelihood* x *Impact*

Invasion = risk?

*Exposure* ≡ $f_1$(*Introduction*;*Establishment*;*Spread*) = ***Invasion score***

*Likelihood* x *Impact* ≡ $f_2$($Impact_a$; $Impact_b$; $Impact_c$; $Impact_d$; $Impact_e$; $Impact_f$; $Impact_g$) = ***Impact score***

a: environment (biodiversity and ecosystems); b: cultivated plants; c. domesticated animals; d. human health; e: other; f: ecosystem services; g: climate change

**Total risk** = *Exposure* x *Likelihood* x *Impact* ≡ $f_3$(*Invasion score*; *Impact score*) = **Invasion**

Mathematical framework

$f_1$ : (weighed) geometric mean or product

$f_2$ : (weighed) arithmetic mean or maximum

$f_3$ : product

The degree of certainty associated with a given risk was scored as a level of confidence. The level of confidence of risk scores has been consistently reported using low, medium and high, in accordance with the framework of Mastrandrea et al. (2010, 2011). Harmonia[+] attributes values of 0, 0.5 and 1 to low, medium and high confidence, respectively, to calculate confidence levels for various impact categories. The cut-off values for risk scores and confidence levels used for the risk classification of *C. orbiculatus* in the EU are summarized in Table A1.3.

**Table A1.3:** Cut-off values for risk scores and confidence levels used for the risk classification of the Staff-vine (*Celastrus orbiculatus*) in the EU, using the Harmonia[+] protocol.

| Colour code risk | Risk classification | Risk score (RS)* | Colour code confidence | Confidence | Confidence score (CS)* |
|---|---|---|---|---|---|
| | Low | <0.33 | | Low | <0.33 |
| | Medium | 0.33 ≤ RS ≤ 0.66 | | Medium | 0.33 ≤ CS ≤ 0.66 |
| | High | >0.66 | | High | >0.66 |

*: Arbitrairy cut off values for distribution of risk scores between 0 and 1

### A1.3.3 ISEIA ecological risk assessment protocol

The ISEIA protocol assesses risks associated with dispersion potential, invasiveness and ecological impacts only (Branquart 2009a). Definitions for risk classifications relating to the four sections contained within the ISEIA protocol are presented in Table A1.4.

The ISEIA protocol contains twelve criteria that match the last steps of the invasion process (i.e., the potential for spread establishment, adverse impacts on native species and ecosystems). These criteria are divided over the following four risk sections: (1) dispersion potential or invasiveness, (2) colonisation of high conservation habitats, (3) adverse impacts on native species, and (4) alteration of ecosystem functions. Section 3 contains sub-sections referring to (i) predation / herbivory, (ii) interference and exploitation competition, (iii) transmission of diseases to native species (parasites, pest organisms or pathogens), and (iv) genetic effects such as hybridization and introgression with related native species. Section 4 contains sub-sections referring to (i) modifications in nutrient cycling or resource pools, (ii) physical modifications to habitats (changes to hydrological regimes, increase in water turbidity, light interception, alteration of river banks, destruction of fish nursery areas, etc.), (iii) modifications to natural successions and (iv) disruption to food-webs, i.e., a modification to lower trophic levels through herbivory or predation (top-down regulation) leading to ecosystem imbalance.

**Table A1.4:** Definitions of criteria for risk classifications per section used in the ecological risk assessment protocol (Branquart 2009a).

| | |
|---|---|
| **1. Dispersion potential or invasiveness risk** | |
| Low | The species does not spread in the environment because of poor dispersal capacities and a low reproduction potential. |
| Medium | Except when assisted by man, the species does not colonise remote places. Natural dispersal rarely exceeds more than 1 km per year. However, the species can become locally invasive because of a strong reproduction potential. |
| High | The species is highly fecund, can easily disperse through active or passive means over distances > 1km / year and initiate new populations. Are to be considered here plant species that take advantage of anemochory, hydrochory and zoochory, insects like *Harmonia axyridis* or *Cemeraria ohridella* and all bird species. |
| **2. Colonisation of high conservation habitats risk** | |
| Low | Populations of the non-native species are restricted to man-made habitats (low conservation value). |
| Medium | Populations of the non-native species are usually confined to habitats with a low or a medium conservation value and may occasionally colonise high conservation habitats. |
| High | The non-native species often colonises high conservation value habitats (i.e., most of the sites of a given habitat are likely to be readily colonised by the species when source populations are present in the vicinity) and makes therefore a potential threat for red-listed species. |
| **3. Adverse impacts on native species risk** | |
| Low | Data from invasion histories suggest that the negative impact on native populations is negligible. |
| Medium | The non-native species is known to cause local changes (<80%) in population abundance, growth or distribution of one or several native species, especially amongst common and ruderal species. The effect is usually considered as reversible. |
| High | The development of the non-native species often causes local severe (>80%) population declines and the reduction of local species richness. At a regional scale, it can be considered as a factor for precipitating (rare) species decline. Those non-native species form long standing populations and their impacts on native biodiversity are considered as hardly reversible. Examples: strong interspecific competition in plant communities mediated by allelopathic chemicals, intra-guild predation leading to local extinction of native species, transmission of new lethal diseases to native species. |
| **4. Alteration of ecosystem functions risk** | |
| Low | The impact on ecosystem processes and structures is considered negligible. |
| Medium | The impact on ecosystem processes and structures is moderate and considered as easily reversible. |
| High | The impact on ecosystem processes and structures is strong and difficult to reverse. Examples: alterations of physicochemical properties of water, facilitation of river bank erosion, prevention of natural regeneration of trees, destruction of river banks, reed beds and / or fish nursery areas and food web disruption. |

Each criterion of the ISEIA protocol was scored by six experts (§1.3.4). The scores range from 1 (low risk) to 2 (medium risk) and 3 (high risk). Definitions for low, medium and high risk, according to the four sections of the ISEIA protocol are given in Table A1.2. If information obtained from the literature review was insufficient for the derivation of a risk score, then the risk score was based on best professional judgement and / or field observation leading to a score of 1 (unlikely) or 2 (likely). If no answer could be given to a particular question (no information) then a score of 1 was given (DD - deficient data). This is the minimum score that can be applied in any risk category. In cases with data or knowledge limitations, periodical review of new literature and updates of risk scores will be recommended. Finally, the highest score within each section was used to calculate the total ISEIA risk score for the species.

Consideration was given to the future situation assuming no changes in management measures that will affect the invasiveness and impacts of this invasive plant. The risk assessment and classification of *C. orbiculatus* for the future situation was performed, with the assumption of a temperature increase of 2 °C in 2050, which reflects the IPCC scenarios for Climate Change (IPCC 2013) and unchanged policies on alien species in the EU member states.

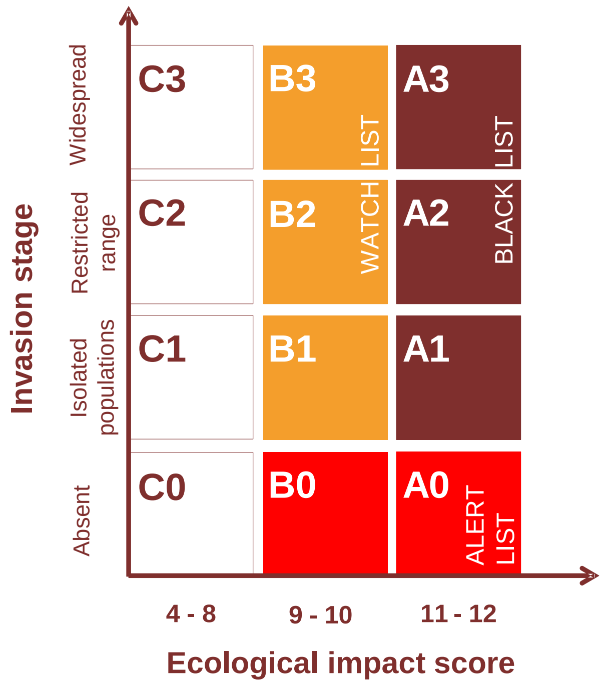


**Figure A1.1:** BFIS list system to identify species of most concern for preventive and mitigation action (Branquart 2009a; score 4-8: low risk; score 9-10: medium risk; score 11-12: high risk).

Subsequently, the Belgian Forum Invasive Species (BFIS) list system for preventive and management actions was used to categorise the species of concern (Branquart 2009a). This list system was designed as a two dimensional ordination (Ecological impact * Invasion stage; Figure A1.1). The BFIS list system is based on guidelines proposed by the Convention on Biological Diversity (CBD decision VI/7) and the European Union strategy on invasive non-native species.

Ecological impact of the species was classified into a group represented by the letters A, B or C, which was based on the total ISEIA risk score: low ecological risk score 4-8 (C), moderate ecological risk score 9-10 (B - watch list) and high ecological risk score 11-12 (A - black list) (Figure A1.1). This letter was then combined with a number representing the invasion stage: (0) absent, (1) isolated populations, (2) restricted range, and (3) widespread. A cross was used to indicate the risk classification of the assessed species within the BFIS system.

#### A1.3.4 Expert meeting on risk classification

The risk assessments of *C. orbiculatus* have been performed by a team of six experts (Ir. R. Beringen, Dr. G.A. van Duinen, Dr. R.S.E.W. Leuven, Drs. B. Odé, Dr. G. van der Velde and Dr. Ir. J.L.C.H. van Valkenburg), using the ISEIA and Harmonia$^+$ protocols. Each expert thoroughly reviewed the risk inventory (knowledge document). Subsequently, experts independently assessed and classified current and future risks of *C. orbiculatus*, using both protocols. Future risks were determined with respect to the potential effects of climate change on the introduction, establishment, spread and impacts of the species.

Following the individual assessment of experts, the entire team met, elucidated differences in risk scores, discussed diversity of risk scores and interpretations of key information during a risk assessment workshop. Discussion during the workshop led to agreement on consensus scores and a risk classification relating to both protocols. The consensus scores, risk classifications and justifications for the scores were described in a draft report that was reviewed by the project team, assuring full agreement with the outcomes of the risk assessments.

#### A1.3.5 Other available risk assessments and classifications

A specific literature search using Web of Science and Google (Scholar) was performed to retrieve other available risk assessments and classifications of *C. orbiculatus*. Search terms applied were the scientific species name and English name combined with the following terms: risk, risk assessment, risk analyses and risk classification. The outcomes of these risk assessments and classifications were included in this report and compared for consistency with our risk classifications.

### A1.4 Peer review by independent experts

The quality of this risk assessment was assured by an external peer review procedure. The final draft of this report was reviewed by two independent experts:

1. Drs. R. Pot (Roelf Pot Research and Consultancy, Oosterhesselen, the Netherlands).
2. Dr. F. Verloove (Botanic Garden of Meise, Belgium).

Both experts critically reviewed the available data and information described in the risk inventory as well as the outcomes of the risk assessments. Special attention was focused on the justification of the risk classification and relevant scientific uncertainties. Appendix 4 summarizes how the remarks and suggestions of the reviewers were dealt with.

# Appendix 2 – Risk assessment for the Netherlands

Het deskundigenpanel heeft de risico's van de boomwurger (*Celastrus orbiculatus*) voor Nederland en de gehele EU identiek geclassificeerd met behulp van het ISEIA protocol (Tabellen A2.1 en A2.2).

**Tabel A2.1:** Risicobeoordeling van de boomwurger (*Celastrus orbiculatus*) voor de huidige situatie in Nederland met behulp van het ISEIA protocol[a].

| Risicocategorie | | Consensus scores |
|---|---|---|
| **Dispersie potentieel en invasiviteit** | | **3** |
| **Kolonisatie van waardevolle habitats** | | **2** |
| **Directe en indirecte negatieve effecten op inheemse soorten** | | **2** |
| 1. Predatie/begrazing | NR | |
| 2. Verstoring en competitie | 2 | |
| 3. Overdracht van parasieten en ziektes | DD | |
| 4. Genetische effecten (hybridisatie / introgressie met inheemse soorten | NR | |
| **Directe of indirecte verandering van ecosysteem functies** | | **3** |
| 1. Modificatie van nutriëntencycli of hulpbronnenvoorraad | 2 | |
| 2. Fysieke modificatie van habitat | 3 | |
| 3. Modificatie van de natuurlijke successie | 2 | |
| 4. Ontwrichting voedselketens | DD | |
| **Totaal score** | | **10** |
| **Verspreiding** | | **Geisoleerde populaties** |
| **Risicoclassificatie** | | **B1** |

a De kennishiaten hebben volgens de beoordelaars waarschijnlijk geen invloed op de totaal score; DD: data deficiëntie; NR: niet relevant.

Het risico op verspreiding en invasiviteit is als hoog (Score 3, Tabel A2.1) geclassificeerd, vanwege de hoge potentiële vruchtbaarheid, de gemakkelijke verspreiding van bessen over meerdere kilometers door vogels, het hoge kiemingspercentage en de potentiële groeisnelheid van de soort.

Het risico op kolonisatie van waardevolle habitats wordt als matig (Score 2) geclassificeerd, omdat de soort in Europa gewoonlijk wordt gevonden in bebouwd gebied en habitats met een lagere waarde voor het natuurbehoud en zich relatief weinig in waardevolle habitats vestigt. Dit laatste is echter niet onmogelijk en kan in de toekomst bij een toenemend aantal groeiplaatsen vaker gaan optreden.

De risico's van negatieve effecten op inheemse soorten door verstoring en competitie worden eveneens als matig geclassificeerd, omdat ervan is uitgegaan dat de boomwurger voornamelijk lokale effecten heeft en lokale afnamen van populatiedichtheden van inheemse soorten van minder dan 80% worden verwacht. Echter, er is niet genoeg data om te beoordelen of *C. orbiculatus* voedselwebben verstoort.

De risico's van negatieve effecten op ecosysteemfuncties worden als hoog geclassificeerd, omdat de overwoekering van andere planten door *C. orbiculatus* fysieke modificatie van het habitat veroorzaakt. Daarnaast neemt mogelijk de nutriëntenbeschikbaarheid toe door de soort. De effecten zijn echter niet makkelijk om te keren door het verwijderen van de plant, omdat na het omhakken weer nieuwe planten uit de wortels groeien.

Klimaatverandering zal naar verwachting niet tot veranderingen in de ecologische risico's leiden en de risicoscores voor de toekomstige situatie zijn daarom identiek aan de scores voor de huidige situatie (Tabel A2.2). De soort kan zich in de toekomst mogelijk wel uitbreiden van enkele geïsoleerde populaties naar een beperkt gebied. De soort is in Nederland recent bekend van twee locaties: bij Gasselte (provincie Drenthe) in 2014 en bij Abcoude (provincie Utrecht) in 2015.

# Appendix 3 – Trade and presence in the wild in the EU

| No. | Country | Abbreviation | Local name | Present | Source | Trade | Source |
|---|---|---|---|---|---|---|---|
| | *European Union* | | | | | | |
| 1 | Belgium | be | | Yes | waarnemingen.be, DAISIE, GBIF | Yes | http://www.directplant.nl/boomwurger-celastrus-orbiculatus.html/ http://www.palmhunters.be/detail/679778-celastrus-orbiculatus-celastrus-orbiculatus-bourreau-des-arbres-50-60-c |
| 2 | Bulgaria | bg | | ND | | ND | |
| 3 | Cyprus | cy | | ND | | ND | |
| 4 | Denmark | dk | Træmorder | ND | | Yes | http://kridtvejsplanter.dk/traemorder/4561-celastrus-orbiculatus-traemorder.html |
| 5 | Germany | de | Rundblättriger Baumwürger | Yes | GBIF, Adolphi et al. (2013), Adolphi (2015) | Yes | http://www.fassadengruen.de/?id=245 |
| 6 | Estonia | ee | Ümaralehine tselaster | ND | | Yes | http://www.hortes.ee/est/ouetaimed/ronitaimed/umaralehine-tselaster |
| 7 | Finland | fl | Japaninkelasköynnös | ND | | Yes | http://www.rengontaimitarha.fi/Japaninkelaskoeynnoes |
| 8 | France | fr | Bourreau des arbres | No | F. Verloove, G. Fried | Yes | http://www.jardindupicvert.com/4daction/w_partner/bourreau_des_arbres_celastrus_orbiculatus.1744 |
| 9 | Greece | gr | | ND | | ND | |
| 10 | Hungary | hu | Keleti Fafojtó | ND | | Yes | http://www.botanikaland.hu/celastrus-orbiculatus/keleti-fafojto/ |
| 11 | Ireland | ie | | ND | | ND | |
| 12 | Italy | it | | ND | | Yes | http://www.venditapianteonline.it/shop/piante/celastrus-orbiculatus/ |
| 13 | Croatia | hr | Okruglolisni drvoguš | ND | | Yes | http://www.pjardino.com/hr-HR/Pflanzen/Details/254062/Celastrus-orbiculatus?returnUrl=%2Fhr-HR%2FSuche%2FIndeks%3FPlantGroupType%3D371 |
| 14 | Latvia | lv | Apaļlapu kokžņaudzējs | ND | | Yes | http://www.baltezers.lv/?atvert=par-augiem&id=vitenaugi |
| 15 | Lithuania | lt | Smaugikas apskritalapis | ND | | Yes | http://www.augalai.lt/news/augalas/309 |
| 16 | Luxembourg | lu | | No | F. Verloove | ND | |
| 17 | Malta | mt | | ND | | ND | |
| 18 | Netherlands | nl | | Yes | waarneming.nl | Yes | http://plantago.nl/plantindex/plant/BO/C/1/celastrus-orbiculatus/10101.html |
| 19 | Austria | at | Rundblättriger Baumwürger | Yes | GBIF, Sauberer & Till (2015) | ND | |
| 20 | Poland | pl | Dławisz okrągłolistny | Yes | ISSG | Yes | http://www.clematis.com.pl/en/vines-in-garden/other-plants/375-celastrus-orbiculatus |
| 21 | Portugal | pt | | No | P. Carmo | ND | |
| 22 | Romania | ro | | ND | | Yes | http://www.pepinieracobadin.ro/liane/celastrus-articulata/ |
| 23 | Slovenia | si | Navadni davilec | ND | | Yes | http://www.rtvslo.si/slike/tag/Navadni+davilec |
| 24 | Slovakia | sk | | ND | | ND | |
| 25 | Spain | es | | No | M. Vilà | Yes | http://es.aliexpress.com/store/product/Top-Grade-New-Seeds-Oriental-Staff-Vine-Seeds-Celastrus-Orbiculatus-Oriental-Bittersweet-Herb/1683137_32488473141.html |
| 26 | Czech Republic | cz | Jesenec okrouhlolistý | Yes | DAISIE, Červinka & Sádlo (2000) | Yes | http://www.katalog-rostlin.cz/popinave-rostliny/Celastrus-orbiculatus-Zimoker-okrouhlolisty.html |
| 27 | United Kingdom | en | Staff-vine | Yes | CABI, DAISIE, GBIF | Yes | http://www.burncoose.co.uk/site/plants.cfm?pl_id=972 |
| 28 | Sweden | se | Japansk träddödare | Yes | ISSG, GBIF | Yes | https://www.blomsterlandet.se/Vaxter-och-tillbehor/Ute/Klangvaxter/Ovriga-klangvaxter/Japansk-Traddodare/ |

# Appendix 4 – Quality assurance by peer review

The quality of this risk assessment was assured by an external peer review procedure. The independent experts Drs. R. Pot (Roelf Pot Research and Consultancy, the Netherlands) and Dr. F. Verloove (National Botanic Garden, Belgium) reviewed the final draft of this report. They assessed the available information used for the risk assessments and the outcome of the assessments, including the justifications for the risk classifications and scientific uncertainties.

The external reviewers emphasised the thoroughness of the literature search and stated that, where applicable, the expert judgement was performed well by the expert panel.

The reviewers delivered useful comments and suggestions for improvement of the risk inventory and assessment. All remarks and suggestions of the reviewers were implemented in the final version of this report. Textual inconsistencies were corrected (e.g., country names, scientific names) and all references were correctly addressed in the reference list. We used Staff-vine as a vernacular name instead of Oriental bittersweet because Staff-vine is more widely used according to hits on the internet. According to the EPPO Global Database, Staff-vine is the common English name and Oriental bittersweet the US English name.

Two points require further attention: 1) the decision of choosing maximum risk scores to calculate the final effect scores for impact categories in the Harmonia$^+$ protocol, and 2) the consistency between the ecosystem services listed in the risk inventory and those analysed in the risk assessment.

According to one reviewer, we made one rather questionable decision with regard to the aggregation in the Harmonia$^+$ protocol. He argues that maximizing the score within every module would be a fundamental error since maximizing in both steps would result in an overestimation of the total risk. We therefore clarified our choices in the text. After consultation with the Office for Risk Assessment and Research of NVWA, the maximum risk scores per module were applied to maintain transparency. In order to prevent the averaging of risk scores and to keep the highest score within each risk category visible, the highest score was always used to calculate final effect scores for a specific impact category. This 'one out all out' principle has also been used in other risk assessments of alien species (e.g., in ISEIA and the EPPO prioritizing schemes) and other policy domains (such as ecological status assessments of water bodies according to the European Water Framework directive).

In response to the external reviewers comments, the consistency between the ecosystem services listed in the risk inventory and the risk assessment has been improved. As a result, the regulating and maintenance risk score in the Harmonia$^+$

risk assessment changed from moderately negative to neutral. The overall risk score of the Harmonia$^+$ protocol changed from medium to high following improvements applied to the risk inventory on the effects of *C. orbiculatus* on ecosystems.