RISK ANALYSIS ON THE INTRODUCTION OF EXOTIC SPECIES IN NATURE

Viseu

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1. Preamble

Introduction of exotic species in nature must be authorised by the Institute for Nature Conservation and Forests (ICNF, IP, in Portuguese) pursuant to Article 13 of Decree-Law No. 92/2019, of 10 July. This report contains a **risk analysis favourable to the introduction into the nature of an exotic species** mentioned in Article 14(1)(e) and (2) of **Decree-Law No. 92/2019, of 10 July**. This diploma implements Regulation (EU) No. 1143/2014 of the European Parliament and of the Council, of 22 October 2014, on the prevention and management of the introduction and spread of invasive alien species, in the national legal framework.

The analysis is based on the best available scientific data, especially as regards the ability of a species to integrate and disperse in the environment, under the conditions described in **Article 4(3)(b),** and includes the common elements set out in **Article 5(1) of Regulation (EU) No 1143/2014**, which are thoroughly described in **Commission Delegated Regulation (EU) No. 2018/968,** of 30 April 2018:

a) Taxonomy, ethology and ecology, in particular habitat*,* diet and interspecific relationships of the relevant species;

b) Reproductive biology, pathologies, dispersion capacity and risks of hybridization with indigenous species;

(*c*) Supporting habitat, including an assessment of the consequences of the introduction on the relevant *habitat* and its surroundings and appropriate measures to reduce or minimise negative effects;

(*d*) Risks of the envisaged introduction of species into the nature, as well as the possible measures to eliminate or control the introduced population, including the feasibility and costs of introduction, should unforeseen and harmful effects arise therefrom;

(*e*) If applicable, previous introduction of the relevant species into other locations and consequences thereof;

(*f*) Identification of the entity responsible for the envisage process of introduction in nature and description of the methods to be used

The risk analysis focuses on three hybrids produced and marketed by WeGrow®, as well as the species these hybrids derive from: 1) **Phoenix One®:** *Paulownia elongata* S.Y. Hu x *Paulownia fortunei* (Seem.) Hemsl.; 2) **H2F3®** *Paulownia catalpifolia* T. Gong ex D.Y. Hong x *Paulownia fortunei* (Seem.) Hemsl.; and 3) **H2F4®**: *Paulownia catalpifolia* T. Gong ex D.Y. Hong × *Paulownia fortunei* (Seem.) Hemsl.), for which a specific model is presented (NAPRA_EU_word_template_v1.1 -EU NON-NATIVE SPECIES RISK ANALYSIS - RISK ASSESSMENT TEMPLATE V1.0 (27-04-15). This report serves as an in-depth complement, and hence explains the consequences of introduction in nature and the probability of integration of the relevant species.

In addition, as per **Article 14(3) of Decree-Law No. 92/2019,** an independent report is submitted with the aim of analysing the ecological conditions of two test fields held of WeGrow® at *Universität Bonn. Campus-Klein-Altendorf, Germany* and at *Finca Serranillos-Toledo, Spain*. This allows for an assessment of ecological characteristics that are similar to those of Portuguese territory, where the species are intended to be introduced.

2. Genus *Paulownia*

Plants of genus *Paulownia* originate from China, where they have been recorded for approximately 3000 years. They were introduced in Japan and Korea about 1000 years ago and the first records of their existence in Europe date back to 1712, when they were introduced in Holland, France, the United States of América, Austria, Italy and Australia (Barton *et al*., 2007). The name is believed to derive from that of the Queen of the Netherlands, Ana Pavlovna (1797-1865). This genus is currently present in Argentina, Belgium, Brazil, Canada, Cambodia, Colombia, India, Indonesia, Israel, Italy, Laos, Vietnam, Mexico, New Zealand, Portugal, Taiwan, Spain and Turkey (Muñoz & Cancino, 2014).

Due to their rapid growth, their sprouting capacity and widespread use of their wood and fibres, some species of genus *Paulownia,* as well as their hybrids, have proven to be suitable for intensive short rotation cultivation (Clatterbuck & Hodges, 2004).

Species of the genus *Paulownia* are known to be the fastest growing species with sustainable production, adapting to different soil types and temperatures ranging from -22ºC (depending on the varieties) to 4ºC (WeGrow, 2020a). Under normal soil and climate conditions, a 10-year-old plant can reach 30 to 40 cm in diameter at breast height (DBH) and a wood volume of 0.3 to 0.5 m^3 (Zhao-Hua *et al*., 1986). However, under optimal conditions it can produce wood for use in 5 or 6 years, achieving reaching wood volumes of about 4 to 4.5 m^3, with annual growths of 3 to 4cm DBH (Zhao-Hua *et al*., 1986). WeGrow hybrids can produce between 0.75 and 0.9 m^3 (WeGrow, 2020a):

Yield per hectare varies according to the characteristics of the site (location, climate, irrigation, fertilisation, etc.), but the expected yield can vary from 30 to 40 ton/ha/year of dry matter or up to 80 ton/ha in a two-year rotation (Bio Tree, 2020a).

Paulownias are valuable in the production of biomass, pellets and for the processing industry, as their light wood can be used in several areas, such as the furniture industry, construction of musical instruments, yacht construction, animal feed, fertilizer, etc. (Kole *et al*., 2012; Danci *et al*., 2015). Besides, species of the genus *Paulownia* may be an alternative source of raw material for the production of pulp, despite their wood resembling more agricultural crops than pine and eucalyptus (Jiménez & Rodríguez, 2003).

Paulownia wood differs from other woods in that it is light, clear and resistant, has a low density, between 300 and 400Kg/m^3, easy to work and has a fine grain (Barja, 2009).

Another advantage over other species is their ability to generate biomass (Rodrigues *et al.* 2000). An 8-year-old *Paulownia* has a biomass proportion of 31.9%, 25.31%, 21.32%, 17.19%, 4.27% and 1.4% for trunks, leaves, branches, roots, flowers and fruits respectively, and approximately 275.4 kg of total dry matter (Zhao-Hua *et al*., 1986).

Compared to other hard- and softwood species, *Paulownias* are highly resistant to fire. Their ignition temperature ranges between 420ºC and 430ºC, which is almost twice as much as the former (Bergmann, 2003; Barja, 2009; i*Paulownia*, 2020a). This characteristic may be especially advantageous in countries that are regularly affected by forest fires, as is the case in Portugal.

Due to their rapid growth, adaptability to various types of soil and climatic conditions, resilience to pests and diseases, and production in few years, planting *Paulownias* can be an option to combat deforestation worldwide. In Mexico, the National Forestry Commission suggested planting *Paulownias* to offset the loss of forest at a rate of 678,000 ha/year (Liñán & Delgado, 2009).

Further to their capacity to tackle soil erosion and improve its structure, and their capacity to reduce groundwater pollution, *Paulownias* are great air purifiers, as they absorb 10 times more CO_2 than any other plant species. A plantation of approximately 1.62 hectares of *Paulownias* has the capacity to absorb 13 tonnes of atmospheric CO_2 per year (Bio Tree, 2020a). *Paulownias* absorb approximately 1200 tons of CO_2 per year (*Paulownia* Green E S.R.L, 2020).

These species are highly tolerant to pollution, and hence are, without a doubt, crucial in the current scenario of climate change. These plants are also useful to stabilise and control soil erosion after fires and are highly resilient to pests and diseases (WeGrow, 2020a).

3. Taxonomy, Ethology and Ecology

3.1. Taxonomic description of the species

The species of genus *Paulownia* are taxonomically classified as follows (Itis Report, 2020):

Kingdom: Plant

Infrakingdom: Streptophyta

Superdivision: Embryophyta

Division: Tracheophyta

Subdivision: Spermatophytina

Class: Magnoliopsida

Superorder: Asteranae

Order: Lamiales

Famíly: *Paulownia*ceae

Genus: *Paulownia* Siebold & Zucc.

Initially, genus *Paulownia* belonged to the Bignoniaceae family and later to the Scrophulariaceae family. However, recent molecular studies have determined that this genus should belong to its own family, the *Paulownia*ceae family (Olmstead *et al*., 2001). This genus contains six species that are globally recognised (*P. elongata*, P. *fargesii*, P. *fortunei*, *P. galbrata*, *P. tawaina and P. tomentosa)* (El-Showk and El-Showk, 2003). Some studies even report the existence of over 20 species (Barton *et al*., 2007) and, more recently, 17 species (Koman & Feher 2020).

3.2. Habitat and general characteristics

The *Paulownias* belong to the world's fastest growing group of plants (Bergmann, 2003; Minato *et al*., 2005). Their growth rate depends very much on location and age. However, trees can reach up to 50m in height and up to 2m in diameter at breast height (DBH). One year after being planted (Figure 1), these trees can measure between 4 and 6 m in height. During the fourth year, plants that are pruned can reach a height of 10 m with 5 m of clean stem and 22cm DBH (Van de Hoef, 2003).

Figure 1. Population of *Paulownias* one year after planting, in Tondela, Viseu.

The development of these plants is greatly affected by the amount of light available. More than 70% of shade can significantly affect the development of young trees and can even cause death (Zhao-Hua *et al*., 1986). These plants show great resistance to low temperatures. Some species can withstand temperatures of -20ºC during their period of inactivity. According to Muñoz & Cancino (2014), strong spring frosts can cause damage to branch and young growing buds and can affect the growth and shape of the tree. These authors also observed that persistent winds can cause permanent curvatures in the trunks, making them unsuitable for industry. Extremely strong winds can damage or even break the trunks.

Younger plants have large leaves that are susceptible to frost, wind and hail damage and, therefore, plants of some varieties located in such conditions may not resist (Bhat *et al*., 1998).

The trunk of the species of genus *Paulownia* can be grey, brown or black. They are smooth with visible lenticels[1] when young (Figure 2), and develop vertical cracks during adulthood (Zhao-Hua *et al*., 1986).

[1]**Lenticels:** porous tissues composed of cells with large intercellular spaces, located in the peridermis of the bark located in trucks and roots of dicotyledonous plants. Their function is to directly exchange gases between the internal tissues and the atmosphere through the bark.

Figure 2. Lenticels on a young *Paulownia* trunk in a settlement in Tondela, Viseu.

All species and clones of this genus are similar in appearance and their wood have similar properties (Muñoz & Cancino, 2014). *P. elongata*, *P. fortunei* and *P. kawakamii* are most used in forestry projects. The most important species from an economic and forestry perspective are *P. fortunei*, *P. elongata* and *Paulownia tomentosa*. The latter is considered an invader in Portugal as per Decree-Law no. 92/2019, of 10 June, which amends the regime established by Decree-Law no. 565/99, of 21 December.

In addition to producing high-quality wood, several species of the *Paulownia* genus are able to recover degraded soils (as they hold high amounts of nitrogen in leaves, which compares to certain legumes) (Hui-jun & Ingestad, 1984), avoid erosion due to their long (2 to 3 m) and very dense root system (Zhao-Hua *et al,* 1986), and establish high amounts of CO_2 [for example, Magar *et al*. (2018) estimated that the total carbon of biomass for a single tree in one year is 4.52 ± 0.53 Kg] and achieve high yields per unit time (Zhao-Hua *et al*., 1986; Bergmann, 2003).

Paulownia wood has the following characteristics: knot-free, extremely light and resilient to diseases (fungi), pests (insects) and high temperatures, twice the combustion temperature of many hard and softwoods, ignition temperature of approximately 400ºC, excellent insulator and good dimensional stability (i*Paulownia*, 2020a).

The shape of the crown can vary across species/varieties. The leaves are large when young (Figure 3) and decrease their size during adulthood (15 - 30 cm long by 10 - 12 cm wide) (Innes, 2009). They are usually sparse, whole, have a smooth or wavy border, long petioles, serrated border and opposite. All parts, except the old branches, are covered in hairs(Zhao-Hua *et al*., 1986).

Paulownias are C4 plants (photosynthesis type C4) with a high percentage of organic matter in their leaves (Woods, 2008).

Figure 3. Example of a leaf of a young *Paulownia* in a settlement in Tondela, Viseu

Most *Paulownia* species have pseudodichotomic[2] ramifications, which terminal buds dry out after winter. As an exception, the terminal buds of the *P. fortunei* species can sometimes grow new branches (Zhao-Hua *et al*., 1986).

The inflorescence is composed of a panicle[3] of two to five flowers, which can either be pedunculated or sub-sessile[4] and are produced in the armpits of smaller leaves, in the summer and autumn. Flowers are pedicled[5] and articulated at the terminal apex (they can measure from 15 to 30 cm and are composed of floral tubes of 5 to 6 cm). The calyx[6] is fleshy, bell-shaped and has five lobes (Figure 4). The lobes are triangular, and the upper middle lobe is slightly larger and generally densely covered in hairs. The corolla[7] is large, purple to white, with two lobes on the upper lip and three elongated lobes on the lower lip (Zhao-Hua *et al*., 1986).

[2] **Dichotomy:** Type of branching in which an axis bifurcated.
[3] **Panicle:** undefined, bunch-like inflorescence whose pedicels divide to form small bunches.
[4] **Sub-subsessile:** Virtually no petiole.
[5] **Pedicels:** It is the stem of an individual flower if it belongs to an inflorescence.
[6] **Calyx:** Set of external floral pieces (sepals).
[7] **Corolla:** Set of petals, free or joined.

Figure 4. Flowers of *Paulownia* in a settlement in the region of Viseu

The tube of the bell-shaped corolla is usually bent forward from the base about 5mm and increases either gradually or abruptly. The inside of the corolla is often covered with purple spots or stripes and yellow wrinkles. The stamens[8] measure about half the size of the corolla. The pistils[9] can either be longer or shorter than the stamens. The ovules are bilocular. The fruits have the shape of ovoid, oval or ellipsoid capsules (Zhao-Hua *et al*., 1986).

3.3. Description of the natural range and potential of the species

As mentioned above, *Paulownias* originated in from China, where they have been recorded to exist for approximately 3000 years in 23 provinces located from the north to the south of the country. The climate in China is quite heterogeneous, and hence varies among regions. The natural dispersion of various species of *Paulownias* is influenced by the minimum temperature, altitude and frosts (Zhao-Hua *et al*., 1986) (See points 3.4and **Error! Reference source not found.**). For centuries, *Paulownias* were cultivated in China and Japan. There are currently about 2.5 million hectares of *Paulownia* plantations in China alone. Over time, species of the genus *Paulownia* naturally hybridized in regions of China, sometimes forming specimens that are hard to classify. However, none of these species have ever been described as potentially invasive in the diverse soil and climate conditions present in China. The main species of genus *Paulownia* are heterogeneously distributed in their habitats of origin, according to their respective characteristics and requirements. The following sections contain information on the ecology as well as on the distribution of the species of origin of the hybrids that are analysed herein.

Paulownias grow on a wide range of soils, although they perform best in well drained, sandy soils that are slightly sloped, have a percentage of clay below 30%, deep, with porosity above 50% (well ventilated), salinity below 1% and pH between 5 and 8.9. They can grow in poorly fertile

[8] **Same**: Organ of the flower where the pollen is produced.

[9] **Pistils**: Set of the ovary, stiletto and stigma of either a single carpel or the fusion of two or more carpels.

soils when the texture and drainage are favourable (Hu, 1959; Clatterbuck & Hodges, 2004; Barton *et al.,* 2007).

It is not recommended to plant these species in clayey, rocky, podzolic[10] and soaked soils. Fertilizers, preferably nitrogenous, favour growth (Zhao-Hua *et al*., 1986).

Depending on the species/hybrids, *Paulownias* can develop at an altitude of up to 2000 m and at a latitude of up to 40ºN to 40ºS. Plant growth begins in the spring, when soil temperatures reach 15ºC or 16ºC, although optimal temperatures for development ranges from 24ºC to 33ºC. These plants require a lot of solar energy to develop (Bio Tree, 2020a).

If, in the first growing season, rainfall does not exceed 150 mm/month, then watering will be necessary. In subsequent years, irrigation is required if monthly rainfall does not exceed 50 mm. Insufficient watering slows down plant growth, but does not jeopardise its survival (Bio Tree, 2020a).

It is important to plant *Paulownias* in places with little wind (< 28 Km/h). In the case of strong gusts of wind during the first year after planting, tutors must be placed until the trunks become strong and stable. Strong wind is dangerous for young plants (Clatterbuck & Hodges, 2004) (about 45 Km/h), and hence windier areas should be avoided (Barton *et al.,* 2007). Table 1 describes the climate, soil and agronomic conditions that are necessary to obtain high yields (if wood is high-quality).

Table 1. Ideal conditions for the development of *Paulownias*

Parameters	**Boundaries**
Clay content	< 30%
pH	5.00 – 8.50
Content of water-soluble salts	< 1%
Depth of soil	> 90 cm
Humus layer depth	> 40 cm
Total porosity	> 50%
Soil density	Circa 1,3 g/cm^3
Height of water tables	> 2 m
Altitude	< 2000m
Average annual temperature	13 – 25ºC
Maximum temperature	40ºC
Minimum temperature	-20ºC
Monthly precipitation (mm) (1st year)	> 150 mm/month
Wind speed	< 28 Km/h
Light	20000 – 30000 lux[11]

Source: Hu, 1959; Barton *et al*., 2007; Bio Tree (2020a).

[10] **Podzol:** It is a type of soil with a low concentration of humidity and nutrients.

[11] **Lux:** According to the International System, it is the capacity of illuminance and light emission, measuring the luminous flux per unit area..

3.4. Species of Genus *Paulownia*

3.4.1. Paulownia elongata S.Y. Hu

This species can be over 10 m in height, has a largely conical crown (Figure 5) and most parts covered in hairs (Shu, 1998).

Its rhytidome is brown and has convex lenticels. The leaves are often ovate-sided, up to 34 cm in length, whole, sometimes irregularly angled or lobed, with a gradually acute apex as well as sessile and dendroid hairs on the lower page and glabrous on the upper page. The inflorescences are pyramidal, closely conical panicles, about 30 cm in length, with 3 to 5 flowers. The peduncle measures 0.8 to 2 cm, almost as long as the pedicels. The calyx measures 1.6 to 2 cm, with 5 lobes measuring about one thirds of the width of the calyx. The corolla is purple to pinkish white, with shape ranging for bell- to funnel-like, and measures 7-9.5 cm x 4-5 cm. The tube is slightly curved, ventrally depressed, with hairs on the outside and glabrous on the inside with purple spots; the stamens measure 2.5 cm. The ovary and stilettos are glandular; the stilettos measure 3 to 3.5 cm. The fruit is an ovoid capsule, which is rarely ovoid-ellipsoidal, measures 3 to 3.5 cm and is tomentose; the calyx is disc-shaped and persistent. The seeds measure 4 to 5 mm and are winged. Flowering occurs between April and May (Shu, 1998).

Figure 5. A specimen of *Paulownia elongata*.
Source: David's *Paulownias* (2017a)

Table 2 summarises the soil and climate and ecological preferences of this species in China, where it originated and adapted widely.

Table 2. Ecology and distribution of *Paulownia elongata* in China.

Altitude	**Temp. (ºC)**			**Rainfall (mm)**	**Soil preferences**							
(m)	Min.	Avg.	Max.	Annual Avg	Months of drought	pH	Min. Depth	Optimal Depth	Soil Texture	% Clay	Ventilation	Phreatic Level
1200	-15	12 a 17	40	600-1500	3 to 9	5 - 8,5	>0,5 m (Avg. height 4 from 4 to 5 m)	> 1m (70 to 85% roots between 0,4-1m)	Clayish loam	<10%	>30%	>1,5m. Max. waterlogging period 3 months.

Source: Zhao-Hua *et al*. (1986); DTBN (2013).

3.4.2. Paulownia fortunei (Seem.) Hemsl.

This species can reach 30 m in height and has a conical crown (Figure 6). Young branches, inflorescences and fruits are tomentose. The trunk is vertically straight, can reach 2m DBH (Diameter at Breast Height) and is greyish brown. The leaves are ovate-stimmed and grow up to 20 cm, with star-shaped hairs on the bottom. The leaves are tomentose in the adult phase and can seldom have few hairs or be glabrous. The inflorescences are straight and long, subcylindrical, measuring about 25 cm; with 3 to 8 flowers. The peduncle is practically as long as the pedicels. The pedicels are glabrous. The calyx measures 2 to 2.5 cm; the lobes are 1/4 to 1/3 the length of the calyx and are oval to triangular-oval shaped. The corolla can be white, purple, or light purple, tubular and 8 to 12 cm long; the tube widens gradually, is slightly curved forward, ventrally bandaged and with hair on the outside. The stamens measure 3 to 3.5 cm and have glandular hair. Occasionally the ovary may have hair. The fruit is an oblong to oblong-ellipsoid capsule of 6 to 10 cm in size. The pericarp is 3 to 6 mm thick. The seeds measure 6 to 10 mm and are winged. Flowering occurs between March and April (Shu,1998).

Table 3 summarises the soil and climate and ecological preferences of this species, in China where it originates and is widely adapted.

Table 3. Ecology and distribution of *Paulownia fortunei* in China.

Altitude	**Temp. (ºC)**			**Rainfall (mm)**	**Soil preferences**							
(m)	Min.	Avg.	Max.	Annual Avg.	Months of drought	pH	Min. Depth	Optimal Depth	Soil Texture	% Clay	Ventilation.	Phreatic Level
1100	-10	15 a 23	40	1200-2500	2 to 3	4,5 - 7,5	>0,5 m (Avg. height 4 to 5 m)	> 1m	Loam to clayish loam	16,3 – 23,5%	>30% (max. waterlogging 3 months)	>1,5m. Max. waterlogging period 3 months.

Source: Zhao-Hua *et al*. (1986); DTBN (2013).

Figure 6. Specimen of *Paulownia fortunei*.
Source: Van den Berk Nurseries (2020).

3.4.3. *Paulownia catalpifolia T. Gong ex D. Y. Hong*

The crown of this plant is tall and wide, and the trunk is straight (Figure 7). The leaves are mostly ovate-strung, twice as long as wide, densely tomentose on the lower side, and glabrous on the upper side, with a full or wavy border and a lit apex. The inflorescences are pyramidal or conical, usually under 35 cm. The peduncle is almost as long as the pedicels. The calyx is slightly bell-shaped, less than 2 cm long and glabrous after flowering. The lobes are 1/3 to 2/5 of the width of the calyx and are triangular to oval. The corolla is light purple, slightly tubular to funnel-shaped, 7 to 8 cm wide, less 3.5 cm wide, ventrally striated, inside with dense purple spots and the base is curved forward. The fruit is an ellipsoid capsule, 4.5 to 5.5 cm long, with star hairs when young; the pericarp is 3 mm long. Flowering occurs in April (Shu,1998).

Figure 7. Specimen of *Paulownia catalpifolia.*
Source: David's *Paulownias* (2017b).

Table 4 summarises the soil and climate and ecological preferences of this species, in China where it originates and is widely adapted.

Table 4. Ecology and distribution of *Paulownia catalpifolia* in China.

Altitude (m)	Avg. Temperature (ºC)			Annual Avg. Rainfall (mm)	Months of drought	Soil	
	Min.		Max.			pH	Texture
800	-10	15-23	40	1200 - 2500	2 - 3	4,5 - 7,5	Sandy clay

Source: Zhao-Hua *et al*. (1986); DTBN (2013).

3.5. *Paulownia* Hybrids

Several *Paulownia* hybrids have been developed in China since 1970 and, as a result, 22 different hybrids suitable for large-scale planting and quality timber production (*Paulownia*.Pro, 2020a) have been produced. Nowadays, the number may even be higher.

Paulownia hybrids developed both naturally and artificially and are either unable to produce viable seeds (Silvestre *et al*., 2005) or produce very few seeds (Jensen, 2016). Artificially bred hybrids combine the characteristics of the mother plants and may be especially suited for certain locations from the perspective of adaptability, growth, resilience to pests and diseases, and yield.

Some recently developed hybrids have proven excellent behaviour by providing up to 30% more wood volume than the original species (Wenhua, 2001). Some hybrids can be planted as monocultures or inserted in mixed plantations (Ptach *et al*., 2018).

These plants adapt to a wide variety of soils, including poor soils, different temperatures and precipitation rates (Kasamaki, 2007), which makes them suitable for potential climate change scenarios.

3.5.1. Main hybrids traded in the European and world markets

Table 5 contains information on the main *Paulownia* hybrids marketed in Europe and the rest of the world, including the country of breeding, places of cultivation, name of registration, plants of origin and their respective sources.

Table 5. Main *Paulownia* hybrids marketed in Europe and worldwide.

Country of manufacture	Places of cultivation	Hybrid	Plants of origin	Source
Spain	Spain	Clone In Vitro 112®	P. elongata P. fortunei	(In Vitro SL, 2020), (Koman & Feher 2020)
Spain	Japan, China, USA	*Paulownia* Pao Tong Z07®	P. fortunei P. tomentosa P. kawakami	(*Paulownia*.pro, 2020a)
Spain	China, USA, Germany, Bulgaria, Iran, Nepal, Vietnam, Burma, Laos, Thailand, Indonesia, Uganda	*Paulownia* Shan Tong Nº3® e Nº4®	P. fortunei P. tomentosa	(*Paulownia*.pro, 2020b)
France	France	Shantong C3®	P. fortunei P. tomentosa	(*Paulownia* France, 2020)
Spain	Spain, Germany	Cotevisa2®	P. fortunei P. elongata	(I*Paulownia*, 2020b) (Pinto, 2015)
		Paulownia 9501		
Bulgaria	Bulgaria	Bellissia®	P. elongata P. fortunei P. elongata	(BioTree, 2020b)
Bulgaria	Bulgaria	Paulemia®	P. elongata P. fortunei P.kawakamii.	(BioTree, 2020c)
Bulgaria	Bulgaria	OXI®	P. elongata P. fortunei	(BioTree, 2020d)
Bulgaria	Bulgaria	T 121®	P. elongata P. fortunei P. tomentosa	(BioTree, 2020e)

Table 6. shows the hybrids marketed by WeGrow®, a German-based company. Note that **the introduction of the hybrid NordMax21® is not requested**, as this hybrid originates from *P. tomentosa* (Thunberg) Steudel, a species included in the National List of Invasive Species by Decree-Law No. 92/2019, of 10 July, which amended the regime set by Decree-Law No. 565/99 of 21 December.

Table 6. Information on four *Paulownia* hybrids.

Country of manufacture	Places of cultivation	Hybrid	Plants of origin	Source
Germany	Germany	NordMax21®	*P. tomentosa* *P. fortunei*	(WeGrow, 2020a, b)
Germany	Klein-Altendorf Toledo Italy	Phoenix one®	*P. elongata* *P. fortunei*	
Germany	Klein-Altendorf Toledo	H2F3®	*P. catalpifolia* *P. fortunei*	
Germany	Klein-Altendorf Toledo	H2F4®	*P. catalpifolia* *P. fortunei*	

The **characteristics of the three hybrids that Wegrow® intends to introduce in Portugal** and are already marketed both in Europe and internationally are described below.

The various WeGrow varieties resulted from controlled cross-pollination of different species, with subsequent selection between individuals. The selection process started in 2010 with the support of the University of Bonn. Representative genetic material has been maintained, since 2017, under controlled agronomic conditions, in the Clonal Garden at Kehn 20, 47918 Tönisvorst, Germany. The selected WeGrow hybrids are commercially planted on more than 430 hectares in Germany and Spain.

3.5.2. Description of hybrid Phoenix One® (Paulownia elongata x Paulownia fortunei)

In warm locations, this hybrid develops a thick trunk in a short period of time (WeGrow, 2020a). The bark of this hybrid's trunk is light grey and, in young specimens, lenticels and slight longitudinal cracks can be seen. It has single, opposite leaves, up to 80 cm wide, with a full margin and five lobes, which distinguishes it from other species.

The Phoenix One hybrid does not flourish in European climate conditions, according to studies carried out between 2013 and 2020 by Prof. Dr Ralf Pude, from the Institute for Plant Science and Resource Conservation at the University of Bonn, Germany, which is a characteristic to be valued, if it can continue as a sterile variety. This hybrid has been under observation since 2013 in Germany, 2017 in Spain and 2018 in Italy, and has no flowers (WeGrow, 2020a).

The environmental conditions in the natural distribution of *P. elongata* x *P. fortunei* correspond to temperatures ranging from 12 to 23ºC, average annual rainfall between 600 and 2,500 mm and an altitude between 600 and 1500 m. The optimal temperature for growth ranges between 24 and 29º C (Van de Hoef, 2003).

In addition, the Phoenix One® hybrid displays the following characteristics (WeGrow, 2020a):

- Homogeneous and compact growth;

- Recommended planting density: 4m x 3m (staggered rows);
- A planting density of 825 trees/ha can be obtained (values used in Spain);
- No technical pruning is required;
- Especially narrow cup;
- Recommended branch height: 6 m;
- Frost resistance to -10ºC;
- The first cut is possible in 5 years (0.4 m^3 of wood/tree);
- Ideal cut at 7 years (0.75 m^3 of wood/tree);
- Resists well in windy places.

3.5.3. Description of H2F3® e H2F4® (Paulownia catalpifolia x Paulownia fortunei)

Hybrids called H2F3® and H2F4® are known for their extremely rapid vertical, homogeneous growth (WeGrow, 2020a).

Because they originate from a crossing of *P. catalpifolia* and *P. fortunei*, up to present day, they are the first and only plants not (or hardly) to develop lateral branches in the first year. This strongly reduces the need for maintenance and significantly increases their final yield. During their early years, these species grows mainly vertically, rather than in trunk diameter. In fact, H2F3® and H2F4® can grow over 6 metres in one year. Due to the large size of their leaves, it is recommended that they grow in places that are well shielded from wind (WeGrow, 2020a).

These hybrids also display the following characteristics (WeGrow, 2020a):

- Recommended planting spacing of 4 m x 4 m or 4 m x 5 m triangular shaped;
- Planting density of 625 or 500 trees/ha;
- Recommended branch height: 8 to 8.5 m;
- Medium width cup;
- First cut in 8 to 10 years;
- No technical pruning is required;
- Frost resistance to -20ºC;
- 1.3 m^3 of wood/tree can be obtained.
- Due to the high size of the leaves, windy areas are not advised.

4. Reproductive biology and other remarks

4.1. Reproductive Biology

The *Paulownias* can be produced by seed and by vegetative means (root shoots or in vitro). *Paulownias* bloom in the beginning of spring and their pollination is entomophilic[12]. Differences

[12] **Entomophilic pollination**: Pollination by insects.

exist as to flower formation, e.g., *P. tomentosa* and *P. Kawakamii* usually form flowers after the second year of planting, unlike *P. fortunei* and *P. catalpifolia,* which only blooms after the fifth or sixth year. The pollen can be stored for six months or more, in places with temperatures between 15 - 20ºC and can resist over one year at low temperatures (0ºC) (Zhao-Hua *et al*., 1986). However, hybrids do not flower or are considered sterile.

4.2. Dispersibility

The amount of seed produced by *Paulownias* varies widely, depending on the species. *P. tomentosa*, in the wild and under ideal conditions, is capable of producing approximately 20 million tiny seeds that are easily transported over long distances by wind and water, and after being established in appropriate soil (it needs very specific conditions of light and humidity), can germinate rapidly (Remaley, 2005). According to Zhao Hua *et al*. (1986), a seed can travel over 1 km from its tree of origin and still be viable. However, ***Paulownia* hybrids**, which were **developed for commercial use in Europe and the rest of the world, are known to be sterile or to produce few seeds**, which reduces the risk of invasion after large-scale planting (Jensen, 2016). In addition, WeGrow Phoenix One®, H2F3® and H2F4® hybrids do not result from the crossbreeding of *P. tomentosa*. On the other hand, according to the company, in the testing grounds and commercial plantations in Europe, to date, no unwanted/uncontrolled growth from seeds has been recorded.

4.3. Risk of hybridisation with indigenous species

No information exists on the hybridisation of species of the genus *Paulownia* with indigenous species in territories where the former were introduced. According to Zhao Hua *et al*. (1986), who studied several plantations for several years, there is no record of natural hybridization between individuals of the genus *Paulownia* and other genera. The risk assessment in respect of *P. elongata* and *P. fortunei* shows that these species have a reduced capacity to hybridise naturally (PIER, 2005; PIER, 2009).

4.4. Pests and diseases

Pest and disease resilience is an important feature in fast-growing and highly productive crops (*Paulownia*. Pro, 2020b). ***Paulownias* are generally not much affected by phytosanitary problems**. However, plants can be affected at different stages of development by some organisms such as **insects, nematodes, molluscs, fungi and phytoplasma** (Barton *et al*., 2007), and other **macrofauna**, such as rats, mice, rabbits, marmots and deer, which can cause damage to the tops, trunks or roots (Clatterbuck & Hodges 2004).

There are several **insects** reported in the literature as pests of *Paulownias*, such as those listed in **Error! Reference source not found.**, and the damage they inflict varies in intensity and magnitude depending on the place and the year. Among them, only *Agrotis ipsilon*, *A. Segetum*, *Gryllotalpa africana* and *Cicadella viridis* have been referenced in the Iberian Peninsula, in other hosts ranging from horticultural, ornamental and forest species (for example, *A. ipsilon* in pines, or *C. viridis* in pome fruits). The occurrence of these insects in the Iberian Peninsula is not significant, and in Portugal, *A. ipsilon* and *A. segetum* were only referenced in coastal territories, and *Gryllotalpa africana* was not identified in the national territory.

Table 78. Main insects that attack *Paulownias*.

Order	Species
Lepidoptera	*Agrotis ipsilon*, *A. toxionis*, *A. segetum* and *Psilogramma menephron*
Coleoptera	*Maladera orientalis*, *Anomala corpulenta* and *Holotrichia diomaphalia*
Orthoptera	*Gryllotalpa unispina* and *G. africana*
Hemiptera	*Empoasca fabae* and *Cicadella viridis*

Source: adapted from Muñoz & Cancino (2014).

The presence of *A. ipsilon* and *A. segetum* is, in general, subject to natural limitation due to the occurrence of a vast set of native predators and parasitoids, in many cases of generic action, as is the case of parasitoids of the genera *Macrocentrus* spp. and *Apanteles* spp from the Braconidae family (Hymenoptera), but also from parasites such as *Metarhizium anisopliae* (Patel *et al*., 1991). Some studies report that parasitism rates can reach 69%, with natural enemies exercising significant control over the populations of these insects.

The **cicadellid *C. viridis*** has already been referenced in Europe, including in the north of Portugal, as a pest of hazel, with less importance in vines and orchards of pome fruits and stone fruits. Regarding the set of natural enemies described for this species, to date there are no records of occurrence in the Iberian Peninsula. There are also records that this cicadellid is a vector of ***Xylella fastidiosa***, a lethal bacterium in vines that constitutes a quarantine disease in Europe (Snare 2006; Alford, 2012; EFSA, 2019), **but that has not been referenced to date in plants of the genus *Paulownia*** (Baldi & Porta, 2017; EU, 2019; EPPO, 2021). However, given the polyphagous character of this bacterium, it is important that *Paulownia* plants are always tested for this phytopathogenic agent.

During the greenhouse growing process (4 to 6 weeks), according to tests conducted by WeGrow® (2020a), plants can be affected essentially by insects of the *Sciaridae* family (Order Diptera), when there are high levels of humidity in the substrate. **However, these insects can be**

easily controlled through biotechnical control means, such as the placement of yellow chromotropic traps, or biological means, for example the introduction of entomopathogenic nematodes (*Steinerma feltiae*).

Some species of pathogenic nematodes have been reported in *Paulownia* plantations in Poland, such as *Meloidogyne hapla* (Chitwood, 1949), *Trichodorus viruliferus* (Hooper, 1963), *Rotylenchus buxophilus* (Hooper, 1963), *Pratylenchus fallax* (Steinhorst, 1968), among others, with occurrence records that may go up to 38% of the analysed plants (Skwiercz *et al*., 2020). All these species have a wide worldwide distribution and are referenced in Portugal or the Iberian Peninsula (EPPO, 2018; GBIF.org, 2020; CABI, 2020). If necessary, some natural enemies usually found in soils, such as bacteria and fungi, can act as biological control agents to control disease-causing **nematodes** in *Paulownias* (Ferraz & Santos, 1995). The use of nematophagous fungi are some sophisticated strategies for infecting or capturing nematodes, as shown by several studies (Mankau, 1980; Jatala, 1986; Stirling, 1991; Ferraz & Santos, 1995; Siddiqui & Mahmood, 1996). The propagation of plants in vitro and the use of sterile substrates in nurseries are practices that allow to ensure the production of nematode-free plants.

In very young plants and during the first weeks of like, attacks by **snails** may occur. In these cases, which occur essentially in nurseries, control can be made by the following means: **i) hand-picking**; **ii) attractive traps** consisting of placing fabrics soaked in beer or milk next to the affected crop at dusk and collected the following day early enough to be destroyed manually or in boiling water; **c) lime or ash**, in 20 cm-wide strips around the crop to make it difficult for slugs and snails to gain access, repeating the procedure when it rains or weekly (Zorzenon & Campos, 2009).

There are records of **damage caused by macrofauna** in other growing sites, e.g., in Spain, rabbits and mice, or in the US, deer, rats and marmots, in particular in young plants (Muñoz & Cancino, 2014). **The placement of individual protections in the first years after planting is sufficient to prevent these attacks.**

Certain **fungi** can cause diseases to *Paulownias* (**Error! Reference source not found.**). The *Sphaceloma spp*. and, in particular, *S. Paulowniae* **have not been reported to date in the Iberian Peninsula** (GBIF Secretariat, 2019).

Table 910. Main diseases caused by fungi that can affect *Paulownias*

Causal agent	Damage
Phytophtora ssp.	Rotting tissue in the neck of the root.
Armillaria sp. (root disease)	Rotting at the base of the trunk.
Rhizoctonia solani	Rotting collar, wilting and death of aerial parts.

Fusarium sp.	Withering leaves die and fall.
Sphaceloma spp. and *S. Paulowniae*	Trunks, leaves and buds are affected, especially on young trees.

Source: Liñán & Delgado (2009)

In addition, more **fungi** can affect these plants, even if they do not cause severe damage: *Cercospora Paulowniae, Mycosphaerella corylea, Phyllactinia imperialis, Septobasidium tanakae, Uncinula clintonii* and *Valsa Paulowniae,* (Muñoz & Cancino, 2014). Barton *et al*. (2007), refer in New Zealand to *Fusarium merismoides* and *Phoma macrostoma.* **None of these species has been found to date in the Mediterranean region** (GBIF Secretariat, 2019; Farr and Rossman, 2021).

The occurrence of these diseases is more common in soils that with waterlogging or poor drainage. Therefore, the first steps to reduce the presence of fungi in the soil is to adopt good cultural practices, such as proper irrigation (not soaking the soil), soil mobilization, spacing between plants and fertilization. Should fungi appear in the soil after adopting these measures, additional techniques such as solarization, among others, should be applied to eliminate them. The propagation of plants in vitro and the use of sterile substrates in nurseries are practices that allow to ensure the production of nematode-free plants.

Among the phytopathogenic organisms that affect *Paulownia*s, most have not yet been detected in Europe, particularly with regard to parasitic bacteria and fungi. The only exception refers to the phytoplasma "*Candidatus* Phytoplasma *asteris*" PaWB strain (PaWB), the causal agent of ***witch's broom***, which has already been reported in Europe and the Iberian Peninsula (CABI, 2021). The main vectors of this phytoplasma, associate with Paulownias plantations, are sap-sucking insects (bed bugs) belonging to order Hemiptera (e.g., ***Cicadella viridis*** (Linnaeus, 1758), ***Halyomorpha halys*** **(**Stål, 1855) (=mista) and ***Halyomorpha picus*** **(**Fabricius, 1794)) (*See* Kawada and Kitamura (1983); Sun Zhi-qiang *et al*. (1999); Medal *et al.* *(*2013); Rice *et al.* *(*2014); Kriticos *et al.* (2017), GBIF Secretariat (2019) and CABI (2020)), as the specimens in **Error! Reference source not found.**. Of these species, only *Cicadella viridis* and ***Halyomorpha halys*** have been reported in Europe and the Iberian Peninsula (GBIF Secretariat, 2019), although **no case of severe attack on WeGrow cultivation fields has yet been recorded** (WeGrow, 2020).

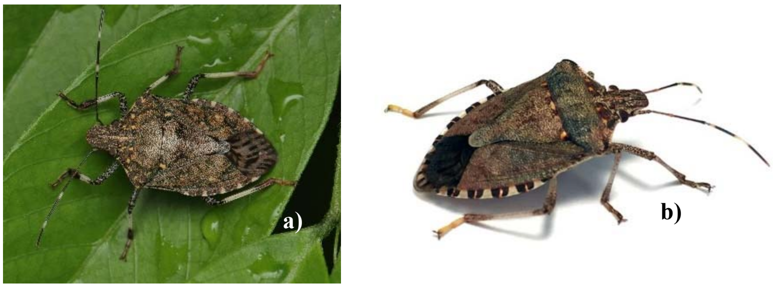

Figure 8. Insects vectors of the witch's broom disease: (a) *H. halys* and (b) *H. picus*
Source: (a) https://inaturalist.ca/taxa/81923-Halyomorpha-halys
(b) https://indiabiodiversity.org/biodiv/observations//14d59e37-1065-41bc-81a5-21535b46b79b/7176.JPG;

This disease occurs during the growth phase in the field, particularly in the countries where the species is original (Hiruki, 1999), having also been detected in the USA (Liñán & Delgado, 2009). This disease results from the phytoplasma infection and the symptoms appear on the trunk, branches, leaves, flowers and roots, varying according to the host species (Yue *et al*., 2008). Phytoplasma propagation also occurs through contaminated propagation material (roots, stakes, etc.).

Controlling ***witch's broom,*** based on the monitoring and capture of vector insects with chromotropic traps, may involve the use of **biological, bio-technical, physical, cultural and chemical means**. Vector insects can also be capture by using light traps (Shah *et al.,* 2019), which are more effective in areas with low insect populations.

Other forms of health control to prevent the spread of the disease include analysis of vegetative propagating material, the use of sowing techniques as opposed to planting (since the seeds do not transmit the disease) and cutting off infected branches and healthy close branches by covering the wounds with terramycin (CABI, 2020b).

The marmorated brown sucker, ***Halyomorpha halys,*** *a* vector insect of the ***witch's broom*** phytoplasm, has already been identified in Portugal and poses a threat to some agricultural crops (Naves, 2019, and Gaspar, 2020). An insecticide spray, based on pyrethroids and neonicotinoids, has been used abroad as **biological control** of this insect. Recently, the use of the *Trissolcus* wasp has been tested (Lee *et al*., 2013). Parasitic organisms and entomopathogenic predators are also used in the biological control of this pest, and are described in Lee *et al*. (2013), as well as the results of their use.

Due to the fact that most of the abovementioend pests and diseases have not been reported in Portugal and that Paulownias are quite resistant to their action, its introduction has positive and negative aspects in terms of risk of invasion. On the one hand, these agents have not yet been introduced, but culture is well-established, thus creating conditions for the development of populations of any of the abovementioned species, which could always pose a risk to other plant species. On the other hand, the presence of agents that are enemies of *Paulownia* (insects, nematodes, molluscs, fungi and phytoplasmas) is a **natural way of controlling this species, thus hindering a potentially invasive behaviour**. Therefore, it is important to ensure plant multiplication practices, from in vitro propagation to nurseries, as well as phytosanitary analyses when exiting the nursery, for the various groups of enemies of the species, which ensure the marketing of plants free from pests and diseases. WeGrow ensures that plants grow in controlled environments and are tested when exiting nurseries.

5. Support habitat

5.1. Means of introduction and dispersion

As per Article 5(1)(c) of Regulation (EU) No. 1143/2014, of 22 October 2014, and Commission Regulation (EU) 2018/968, of 30 April 2018, which complements the former, risk assessments for invasive alien species should consider all **relevant pathways of introduction and dispersion,** based on the classification of pathways developed by the Convention on Biological Diversity (CBD, 2014).

According to this classification, the means of introduction are included in ***Category 1 - Introduction to Nature, Subcategory - Other intentional uses*** (**Error! Reference source not found.**). Intentional introduction reflects the fact that the purpose of these species is the production of wood, although it can also be used for ornamental functions.

Table 1112. Categorisation of entry routes for exotic species.

Category	Subcategory
"INTRODUCTION INTO NATURE" (1)	Biological control Erosion control / dune stabilization (windbreaks, hedges, etc) Nature fishing (including sport fishing) Hunting Improvement of landscape / flora / fauna in nature Introduction for conservation or wildlife management purposes Release in nature for use (different from above, e.g., skin, transport, medical use) **Other intentional introductions**
"INVASION OF THE PLACE OF CONFINEMENT (2) "	Agriculture (including raw material for biofuels) Aquaculture / Mariculture Botanical garden / Zoo / Aquaria (excluding domestic aquaria) Pets / Aquaria / Terrarium species (including live food for such species) Farmed animals (including animals left under limited control) Forestry (including afforestation or reforestation) Hide farming Horticulture Ornamental use other than horticulture *Ex-situ* research and creation (on site) Live food and live bait Another escape from confinement
"TRANSPORT - CONTAMINANT (3) "	Polluting nursery material Polluted bait Food pollutant (including live foods) Pollutant in animals (except parasites, species carried by host / vector) Parasites in animals (including species carried by host and vector) Pollutant in plants (except parasites, species carried by host / vector) Parasites in plants (including species carried by host and vector) Seed pollutant Wood trade Transport of habitat material (soil, vegetation, etc.)
"TRANSPORT - CLANDESTINE" (4)	Hook Fishing/Fishing Equipment Container cargo Flight or voyage by clandestine boat (excluding ballast water and hull inlay) Machinery / equipment, people and their luggage / equipment (in particular tourism) Biological packaging material, especially wooden packaging Ship / boat ballast water Dirt on the hull of the ship / boats, vehicles (car, trains, etc.) Other means of transport
"CORRIDOR (5)	Waterways / interconnecting basins / seas Tunnels and land bridges
"NO HELP" (6)	Natural dispersion across borders of invasive alien species introduced through pathways 1 to 5

Source: CBD, 2014

The distribution of WeGrow® hybrids is directly made by the manufacturing company to the final producer or plant retailer. Plants are multiplied only by in vitro laboratory techniques and developed from clean material previously tested in the greenhouse. These are transported from the company's greenhouses, properly packaged, still young, i.e., with a height of 15 - 20 cm and with 4 to 6 pairs of well-developed leaves (WeGrow, 2020a).

At this early stage of development, these plants have no flowers or seeds and therefore do not spread seminally. On the other hand, without proper ground preparation for planting and the absence of regular watering (in hot and dry seasons), these plants cannot survive or spread naturally.

In order to assess **the possible consequences of the introduction in nature** in the specific habitat and its surroundings, as well as the appropriate measures to reduce or minimise their negative effects, the habitats of origin where these plants have already been introduced are described below.

5.2. Geographical distribution of the species

Plants of genus *Paulownia* have been planted in Europe for ornamental purposes, approximately, over the past 200 years. There are records of these plants in the United Kingdom since 1830 (Hu, 1959), the Netherlands and Belgium since 1838 (Hu, 1959), Denmark (Copenhagen University, 2016) and Ireland (TROBI, 2016). The geographical distribution of WeGrow® hybrids is shown in Figure 9.

Hybrids marketed by WeGrow® for over 7 years have already been introduced in several countries, both for scientific purposes and production, in Europe (Germany, Austria, Latvia, Croatia, Spain, Italy, United Kingdom, Greece) and outside Europe (Latin America and Africa). Clones are expected to be introduced in France, Slovakia, Serbia, Belgium, the Netherlands, Turkey and other regions of Asia by 2021.

Figure 9 shows the Phoenix one® records in northern Italy, central Spain (Toledo) and Rheinbach in Germany and H2F3® and H2F4® in central Spain (Toledo) and Rheinbach in Germany (WeGrow, 2020a).

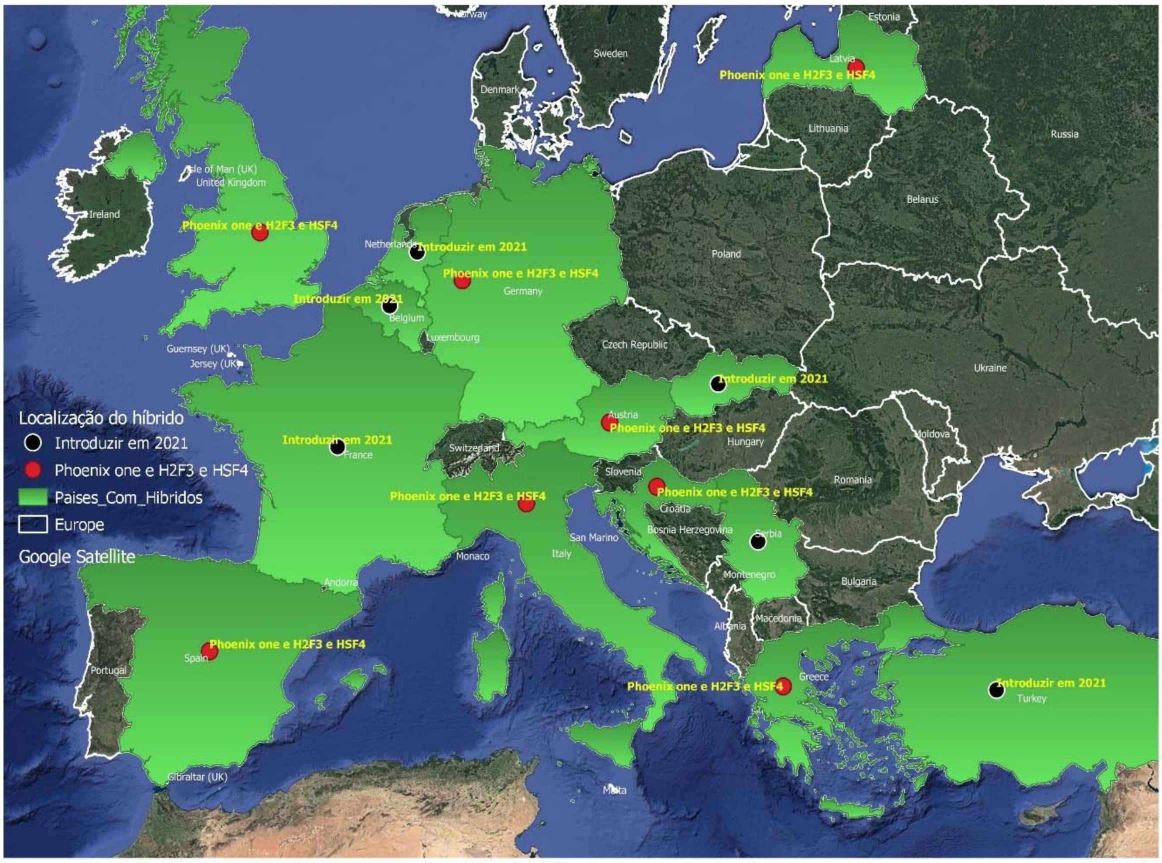

Figure 9. Distribution of WeGrow® hybrids in Europe.

5.2.1. *Geographical distribution of Paulownia fortunei*

Although this species, which originated in China, is less widespread than *P. tomentosa,* records exist in the USA, South America (Brazil) and some European countries (Figure 10). Some studies reveal the presence of this species in India (Misra *et al.,* 2001), Iran (Kiaei, 2013) and Brazil (Stuepp *et al*., 2016), albeit for scientific purposes.

Figure 10. Records of location of the *Paulownia fortunei* species worldwide
Source: GBIF Secretariat, (2019).

5.2.2. *Paulownia elongata*

This species, originating in China, is less widespread than *P. tomentosa* and *P. fortune.* There are only records of this species in China and Japan (Figure 11). Some studies mention that this species is present in Turkey (Birinc *et al.,* 2017; Kaymakci *et al.,* 2013), Serbia (Markovic *et al*., 2013) for scientific purposes. There are also records of plantations in Tetuan and Agadir, Morocco (Neres, 2020) and some isolated plantations and trees scattered in several countries of this species, although not documented (Neres, 2020).

Figure 11. Records of location of the *Paulownia elongata* worldwide
Source: GBIF Secretariat, (2019).

5.2.3. *Paulownia catalpifolia*

This is the least widespread species worldwide. It is used as a mother plant in hybridization. Little is known about its worldwide distribution (Figure 12).

Figure 12. Records of location of the *Paulownia catalpifolia*.
Source: GBIF Secretariat, (2019).

5.3. Interest for the culture of *Paulownias*

5.3.1. Soil-climate boundaries

The correct choice of species/hybrid for a specific location is the key success factor of a plantation, and hence it is important to respect soil and climate needs.

The optimal *Paulownia* species can only be selected after assessing local climate, topography, orography and soil type. **Error! Reference source not found.** shows the main soil and climatic characteristics of these hybrids (*see* 3.5.2and 3.5.3).

Table 1314. Main soil and climate characteristics of WeGrow® hybrids

Phoenix One®	H2F3® and H2F4®
Crossing: Fr. elongata and *Fr. fortunei*	*Crossing: P. catalpifolia* and *P. fortunei*
• It develops in a noticeably short time a trunk with a large diameter in hot climates; • Altitudes from 600 to 1500 mm; • Average annual precipitation of 600-2500 mm; • Resistant to temperature of -10ºC; • Optimum temperature from 24 to 29ºC (Van de Hoef, 2003); • Suitable for windy spots.	• Due to the huge leaves, it is advised not to plant in windy areas; • Resistant to temperature of -20ºC;

Source: WeGrow (2020a)

5.3.2. Productivity and profitability

The expected yield per hectare varies according to various factors, such as the planting site, climatic conditions, irrigation facility, density, etc. The expected yield for *Paulownias* ranges between 30 and 40 ton/ha/year (dry matter), or 80 ton/ha in a two-year rotation cycle (Bio Tree, 2020a).

In several regions, productivity and yield figures are noteworthy:

- In Yinjang, Szechuan Province in China, under normal soil and climatic conditions, a 10-year-old plant can reach 30 to 40cm DBH and a wood volume of 0.3 to 0.5 m^3. Under optimal conditions, it can produce wood for use within 5 or 6 years. Under these conditions, wood volumes of about 4 to 4.5 m^3 can be obtained, with annual growths ranging between 3 to 4 cm of DBH m^3 (Zhao-Hua *et al*., 1986);
- In Brazil, yields in volume were observed from 11 to 30 m^3/ha/year (Barton *et al*., 2007);
- In the United States of America, increases of 5.5 m (height) in 16 months were recorded, with biomass yields of up to 84 ton/ha/year of dry matter, with low irrigation and fertilization applications (Woods, 2008). In rotational plantations, with 3-year cycles, yields ranged between 30 and 45 tons/ha/year (Zhang *et al*., 2010);

5.3.3. Characteristics of the biomass of Paulownia

At present, satisfying the demand for alternative raw materials that can be used as biomass in energy production is a major challenge to achieve sustainable growth based in a bio-economy model (Mendes *et al*., 2009). In this context, lignocellulosic biomass is one of the most promising raw materials for biofuel production due to its high availability and low prices (Favaro *et al*., 2013). Lignocellulosic materials, such as wood, provide abundant and renewable raw materials that do not compete with food crops (Palmqvist & Hahn-Hägerdal, 2000).

Paulownias are advantageous in the production of biomass, due to their rapid growth, harvesting between 1 and 3 years, regeneration after coppicing, among other reasons. A plantation can last 20 to 25 years, and 10 to 12 biomass crops can be harvested (Bio Tree, 2020a).

Error! Reference source not found. presents some chemical components of *P. tomentosa* and *P. fortunei* species as compared to other species.

Table 1516. Comparison of chemical components (% dry basis) between two species of *Paulownia* and other materials.

Material	Cellulose content (%)	Hemicellulose content (%)	Holocellulose content (%)	Lignin content (%)
P. tomentosa1	41,7 ± 0,5	19,8 ± 0,3	61,5	20,5 ± 0,8
P. fortunei2	34,2	22,7	56,9	27,2
Eucaliptus globulus3	34	18,2	52,2	33,3
Olive pruning4	24,5 ± 0,2	18,8	43,3	22,2 ± 0,2
Bamboo wood5	39,36 ± 0,76	18,01 ± 0.06	57,37	20,83 ± 0,13
Wheat straw6	35,19 ± 0,29	22,15 ± 0,21	57,34	22,09 ± 0,31

[1] (Ye *et al*., 2016), [2](Caparros *et al.*, 2008) [3](Ishiguro & Endo, 2015), 4(Silva-Fernandes *et al., 2015),* 5(Xin *et al*., *2015)*, 6(Toquero & Bolado, 2014).

As per above, the hemicellulose[13] and lignin[14] content of *Paulownia* material is greater to that of other materials, although its structure is simpler. Holocellulose[15] is identical across species of *Paulownia* and eucalyptus and is higher, for example, to that of olive pruning remains. These figures indicate that *Paulownias* are an excellent source for bioethanol production (Ye *et al*., 2016).

Error! Reference source not found. shows the physical and chemical properties of the biomass of *Paulownia* and other lignocellulosic species.

[13] **Hemicellulose:** Polysaccharides and together with cellulose, pectin and glycoproteins form the cell wall of plant cells.

[14] **Lignin:** It is a three-dimensional amorphous molecule, in association with cellulose in the cell wall, in order to confer rigidity, impermeability and resistance against biological attacks to plant tissues.

[15] **Holocellulose: The** total polysaccharide fraction of wood or substrate, composed of cellulose and hemicelluloses, is obtained by removing extractives and lignin from the original natural material.

Table 1718. Physicochemical and calorific properties of biomass from *Paulownia* and other lignocellulosic species.

Species	**Normal density (Kg/dm^3)**	**% Ash**	**Gross calorific value (KJ/Kg)**	
			Madeira	**Bark**
P. tomentosa	0,245-0,290	2,88	19895	20034
P. elongata		1,53	19623	19876
P. elongata x fortunei	0,265-0,319	1,12	19558	19881
Populus versus Euro-American	0,400-0,290	1,55-1,36	18870-19748	
Populus deltoides	0,375-0,310		18615-19251	
Populus trichocarpa	0,325		18615-19251	
Eucaliptus globulus	0,55			
Pinus pinaster	0,52			
Pinus radiata	0,49			

Source: DTBN (2013).

The calorific value of biomass from *Paulownia* is approximately 19,500 KJ/Kg, much higher than that of other forest and agricultural residues and similar to the calorific value of other fast-growing energy species such as poplar and eucalyptus (Martinez *et al*., 2009).

The normal density (12% humidity) of the biomass of *Paulownia* sp. (0.245 - 0.319 Kg/^{dm3} at 10% humidity) is low compared to the biomass of poplar (0.29 - 0.47 Kg/dm^3) or maritime pine (0.55 - 0.65 Kg/dm^3) and, therefore, transportation costs are high (Martín *et al*., 2009).

The waste generated after combustion is extremely low (carbonates and corrosive chlorides), and hence the yield and average life of the boilers are not be affected (Martinez *et al*., 2009). Some authors (e.g., Marcos *et al*., 2009) show that waste can vary between 1.1% and 3%, while Kawasaki (2007) calculated a waste value between 1.1 and 1.5% (DTBN, 2013).

The humidity of the plant material at cutting is low, as it reaches 46% on a dry basis (**Error! Reference source not found.**). Humidity is lower, between 28 and 30% on a wet basis, as registered in laboratory calorific power tests. For economic reasons, it is convenient to reduce the humidity of the biomass of *Paulownia* sp. to a minimum of 25% on a wet basis (Monteagudo & Martínez, 2009).

Table 1920. Density and moisture content of *Paulownia* biomass.

Species	**Moisture content (%)**				**Density *Paulownia* sp. on wet basis**		
	Water / Wet weight		**Water / Dry weight**				
	Madeira	**Bark**	**Madeira**	**Bark**	**10%**	**12%**	**15%**
P. tomentosa	30,84	31,24	44,78	45,79			
P. elongata	30,16	29,45	43,53	41,76	0,26	0,24	0,26-0,33
P. elongata x fortunei	28,46	28,76	39,82	41,09			

Source: DTBN (2013).

5.3.4. Uses and applications of Paulownia wood

Planting *Paulownias* may serve several objectives, such as recovery of ecosystem (through soil fixation, nutrient uptake and habitat creation), rapid biomass or wood production, paper production (Ates *et al*., 2008), animal food production (Olson & Carpenter, 1985) or soil bioremediation (through the creation of a compound based on P. *fortunei) (*Madejón *et al.,* 2016). In Japan, *Paulownia* wood is used in several products as it is attractive, strong, light, fast drying, versatile and with good resonance qualities. It is an easily workable wood and the ends do not break or crack when drying (Clatterbuck & Hodges 2004).

The wood of *Paulownia* can be used for interiors of boards, frames, pallets, boxes, cages and other materials where the appearance is more important than the resistance. Its wood is great for aeroplane transportation due to its lightness (low density, 300 - 400Kg/m^3). It is also used for filters, packaging such as food (fruit, coffee etc.), hives, fishing net accessories and as floor covering (Barja, 2009).

According to Liñán & Delgado (2009), forests have been planted in *Paulownia* in Australia, the United States (Carolina, California, Indianapolis and Kentucky), Canada, Central and South America, where production is mainly for furniture manufacture, thus avoiding excessive imports. Wood can also be used in the construction of non-structural elements such as frames, doors, slabs, furniture, shoes and aircraft models and as construction material applied in ships, aircraft, cars or wind power systems, boats and in the "kitesurf" sector. Due to its good resonance, it is also used for the production of music instruments (Li *et al*., 2010).

Wood from *Paulownia* also has good potential for pulp production or for pulp production jointly with other species (Ates *et al*., 2008; Liñán & Delgado, 2009).

The leaves and flowers of *Paulownia* are rich in nitrogen and other nutrients and are therefore an excellent natural fertilizer (Wang & Shogren, 1992). As the leaves have a rich in nutrients, they can be used in ruminant feed (Bodnár *et al*., 2014) and be inserted into forages. Their leaves are an alternative to conventional fodder as they have 20% crude protein and 60% digestibility (Liñán & Delgado 2009). The leaves can also be used as feed for pigs and rabbits (Wang & Shogren, 1992; Zhao-Hua *et al,* 1986).

Medical researchers have identified some interesting properties of plants of the genus *Paulownia*, such as antibacterial, anti-inflammatory, diuretic, antihypertensive, as an insecticide agent, etc. (Qu *et al*., 2011).

6. Risks of introduction in nature

Biological invasions are among the main factors in biodiversity loss, extinction of specifies (Bellard *et al*., 2016), and reduced resilience of natural habitats, making them more vulnerable to the impacts of climate change. Thus, it is important to be aware of the potential risks of introducing alien species outside their place of origin.

6.1. *Paulownia* as an invasive plant

In Portugal, **only *P. tomentosa*** (Thunb.) Siebold & Zucc. ex. Steud, known as *kiri,* is considered an invasive plant under Decree-Law no. 92/2019, of 10 July, which, as already mentioned, is not part of the crossbreeding of the WeGrow hybrids (Phoenix One and H2F3/H2F4).

P. Tomentosa is native to China and is widely distributed in the central and northern regions, especially Shaanxi, Shanxi, Gansu, Henan, Hebei, Shandong, Anhui, Hubei, Jiangsu and the Liaoning peninsula. It is present in Japan and South Korea, although some Japanese taxonomists believe that these populations, which are accepted as natural, are the result of previous introduction and cultivation (USDA-NRCS, 2020). The three varieties of *P. tomentosa* have distinct distributions: *P. tomentosa* var. *lucida* is mainly present in northern China, var. *lanata* is present in the northern region of the Yangtse River and var. *tsinlingensis* is present in central and southwestern China.

The database on global biodiversity (GBIF - Global Biodiversity Information Facility), and CABI - Invasive Species Compendium register more than 25 countries and islands where this plant was introduced *(P. tomentosa* Steud. in GBIF Secretariat, 2019). Its invasive character has already been recorded in different locations around the globe, as per Figure 13. Portugal is not yet included in this map.

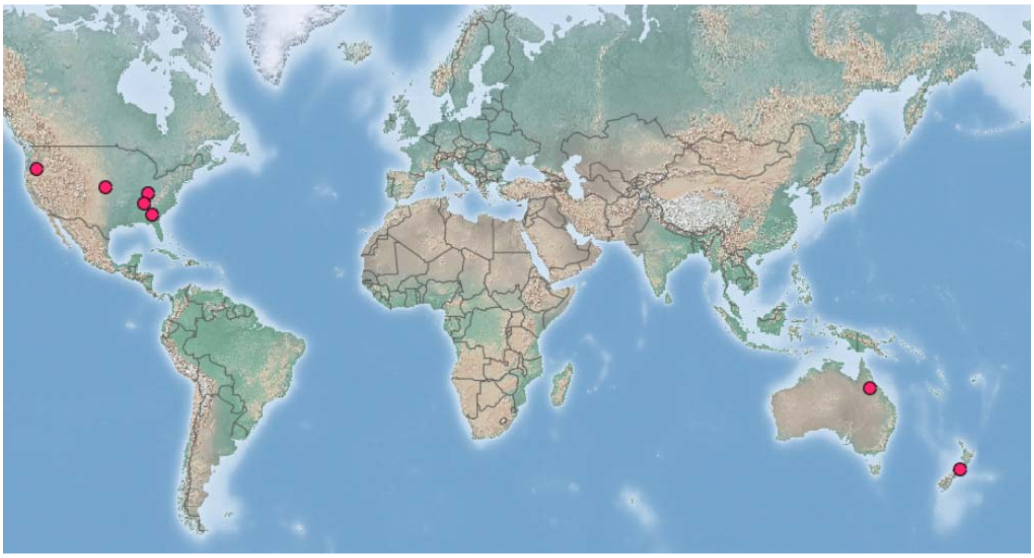

Figure 13. Geographical distribution of the places where *P. tomentosa* was considered invasive
Source: CABI (2020).

The following map shows the current distribution of this species and the places where it is most abundant.

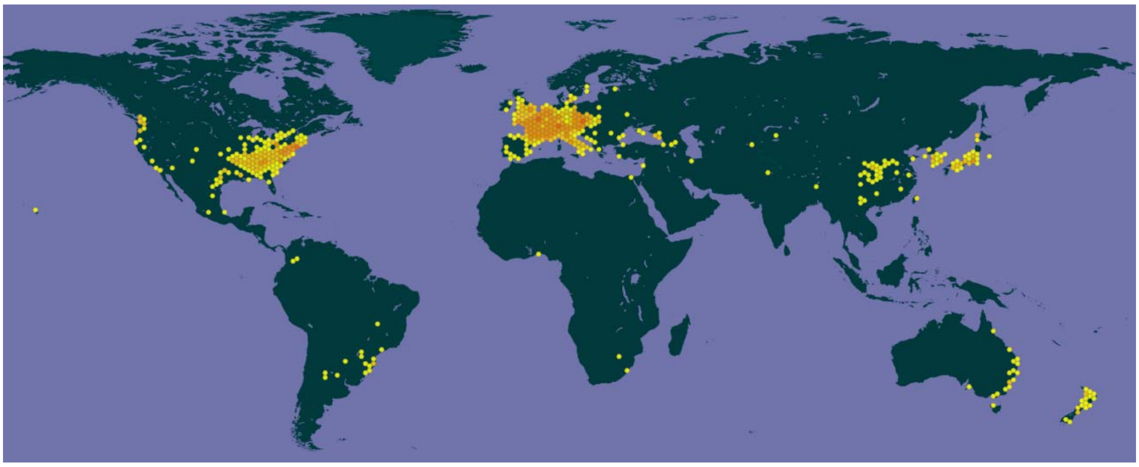

Figure 14. Distribution of *Paulownia tomentosa*.
Source: GBIF Secretariat (2019).

P. tomentosa is considered invasive in some US states (e.g., Georgia, Kentucky, Oregon, Tennessee, etc.) (USDA-NRCS, 2020; Kraus *et al.* , 2020) and is included in the list of potentially invasive species in the north-eastern region of the US, New England, Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont) (Hear.org, 2020).

Indeed, some studies (e.g., Innes, 2009 and Black *et al*., 2018) on plant behaviour after fire found that the higher the severity of fire, the higher the likelihood of invasion by *P. tomentosa*. This behaviour of *P. tomentosa* in areas affected by fires had previously been reported in China by Zhao-Hua *et al*. (1986).

In a Practical Guide to the culture of *Paulownia* in the South-eastern USA, Clatterbuck & Hodges (2004) also report that P. *tomentosa* is an invasive plant. However, they note the difficulty of this species to germinate by seed, as well as to colonise large open areas, unless in sterile soils, such as recently burnt areas, construction areas, etc. Kuppinger *et al.* (2010) also observed the spread of this species in the southern Appalachian Mountains of the USA but found that the predicted habitat of *P. tomentosa* reduced by 63%, 4 years after the fire, and by 73%, 6 years after the fire.

In Australia and New Zealand, *P. tomentosa* is considered an invasive species. An Australian risk assessment conducted by *Pacific Island Ecosystems at Risk* (PIER, 2012) scored 7 and recommended “reject[ing] the plant for importation (Australia) or species likely to become a pest (Pacific)" (PIER, 2012; GISD, 2020). In Hawaii and other Pacific islands, a risk assessment of *P.*

tomentosa by Dr Curtis Daehler (UH Botany) scored 9 and stated: "Likely to cause significant ecological or economic damage". (HEAR, 2008; PIER, 2012).

In Colombia, in 2019, *P. tomentosa* was declared invasive by the ICA (Instituto Colombiano Agropecuario) due to the high risk of invasion it presented in the USA and Australia (Liévano, 2018; Salazar, 2020).

As mentioned above, in Portugal, *P. tomentosa* was included in the list of invasive species by Decree-Law No. 92/2019, of 10 July, although no study has demonstrated its potential for invasion. In fact, Viana and Gaião (2019) considered the results of two test fields of this species, with specimens of four years of age, located in Viseu and Tondela, Portugal, and concluded that it is sensitive to frost and grows in an irregular manner. They also did not observe any seed germination in the soil. However, this species should be monitored for longer periods so as to obtain reliable results.

Despite the problems with *P. tomentosa,* several species and hybrids of *Paulownia* are cultivated in the US (Snow, 2015) and other countries, with no record of potential invasion. **To date, other species and hybrids of *Paulownia* have no record of being invasive and, in the case of hybrids, the absence or low seed production contributes to this. However, certain concern remains as regards hybrids originating from *P. tomentosa,* because it is the only invasive species in some countries.**

6.2. Preventive and control measures

In cases of invasion, eradication is necessary before new populations of non-native species can be established or reproduce. In the case of the only known invasive *Paulownia*, *P. tomentosa*, according to Innes (2009), control requires persistence due to its strong germination capacity, rapid growth and prolific seed production.

Control methods can be mechanical and chemical (GISD 2020 *cit.* Remaley, 1998; PIER, 2012):

Mechanical: Manual grubbing can be effective in the case of young plants. Plants should be extracted as soon as they are large enough. The entire root should be removed, as broken fragments can burst again. Cutting is most effective when the trees have begun to flower to avoid seed production. New sprouts may appear after cutting, and hence the use phytocides may be necessary.

Chemicals: cutting should be considered an initial control measure, which requires subsequent cutting of new shoots or herbicide treatment. Girdling is effective on large trees where the use of herbicides is impractical. This method causes the tree crown to die, but not the shoots, which may require follow-up treatment with foliar herbicide. Applying herbicides to the stump soon after cutting should also be considered when other nearby species must be protected and could be affected by foliar herbicide application.

In Portugal, few large-scale forests with species of genus *Paulownia* exist. Given that no invasion problems have been reported so far, no control measures are known for *Paulownias*. Webpage "invasoras.pt" describes invasive species in Portugal and control methodologies and, in fact, does not include any control measures applied to *P. tomentosa* species nor the control measures in place to eradicate or prevent the dispersion of these plants.
Portugal does, however, have experience in controlling certain invaders, such as the *Acacia genus,* and these control techniques are well established (e.g., Campos *et al.* 2002).

According to the company "*Paulownia* em Portugal®" (*Paulownia*, 2020), the seeds of the *P. elongata* species require specific conditions to germinate (temperatures of 24ºC; humidity greater than 80%; exposure to sunlight and, at least, daylight of 4 hours) during a period of three to four consecutive weeks, which is only possible in a controlled environment (e.g., greenhouse) and makes this species safe in Portuguese territory.
A risk assessment in Australia/New Zealand for *P. elongata* (Result = -1) and *P. fortunei* (Result = 1) shows that the species neither poses a threat nor is invasive (PIER, 2005) in local conditions.

6.3. Potential costs of control measures

As no reference costs for the control of *Paulownias* exist in Portugal, an estimate for the control of areas invaded with other tree species is hereby provided. Based on the experience of control of the invaders of the genus *Acacia spp.* and the reference costs set out in Ordinance No. 111-A/2018, of 27 April, a realistic simulation is contained in **Error! Reference source not found.** should be it be necessary to control an area populated by *Paulownias*.

Table 2122. Estimated unit costs (hectare) of controlling an area invaded with *Paulownia* spp.

Operation	**Year of control 1**	**Year of control 2**	**Year of checks 3**
1. *Paulownias* are cut by hand and removed. Immediate after, a concentrated chemical solution is applied in the cut area. In order to preserve the surrounding area from possible contamination, a non-selective, post-emergency, biodegradable, toxicologically free, non-harmful product should be applied.	EUR 932.40	EUR 932.40	
2. Controlling invaders is an arduous task, and hence the concentrated chemical solution should be applied whenever plants grow again and reach 15 to 20 cm in height. These chemicals are applied by spraying the plants' tender shoots, twice per year.	EUR 830.40	EUR 830.40	EUR 830.40
	EUR 1762.80	EUR 1,762.80	EUR 830.40
			EUR 4,356.00 €

Note that the relevant plant protection products may no longer be authorised and that less harmful alternatives to the environment are recommended.

7. Introduction of *Paulownias* in Portugal

In recent years, *Paulownia* spp. has been introduced in several places in Portugal. As reported, P. *tomentosa* (which is now forbidden) and *P. elongata* are most common.

In 2017 an experimental field with species P. *tomentosa* was created in Tondela, Portugal, as part of Project: "***CarboEnergy and Biomas Coppice - PROJ/CI&DETS/CGD/008***". At the time (and up until 10 June 2019), this species was not considered invasive. Since 2017, the plot has been monitored and no record of invasion has been observed within the plot or adjacent lands (Figure 15-17).

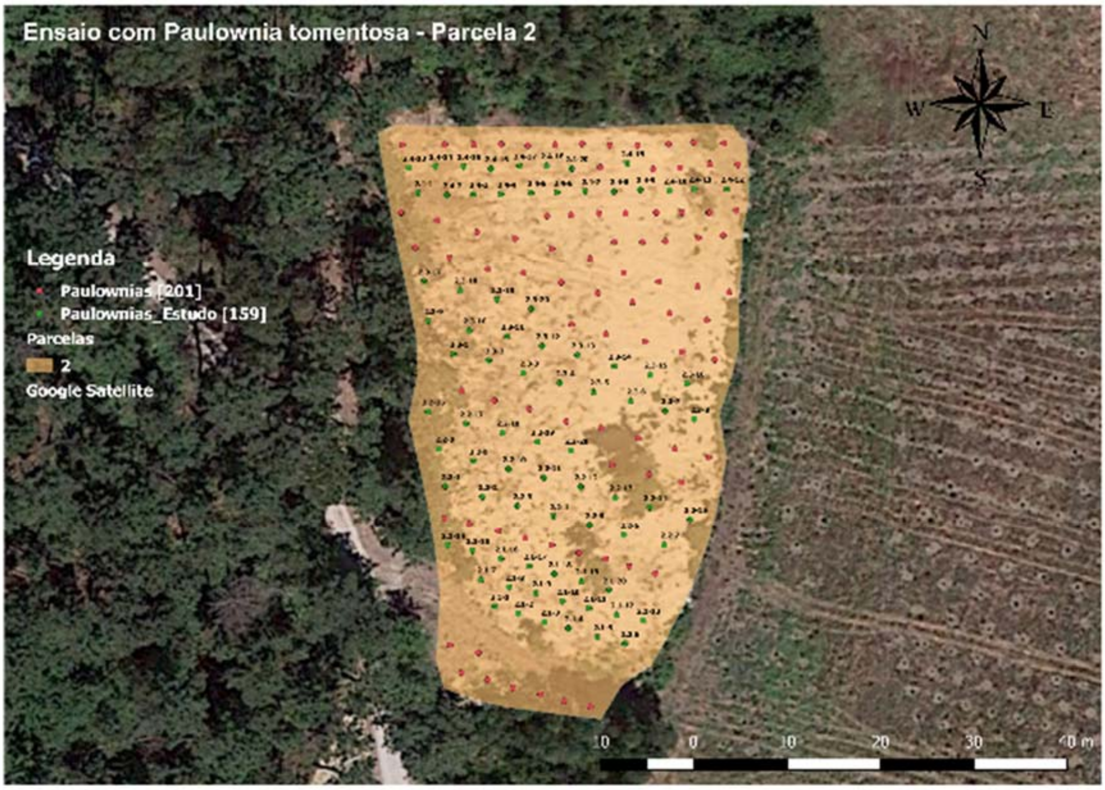

Figure 15. Location of the *Paulownia tomentosa* test field in Tondela, Portugal.

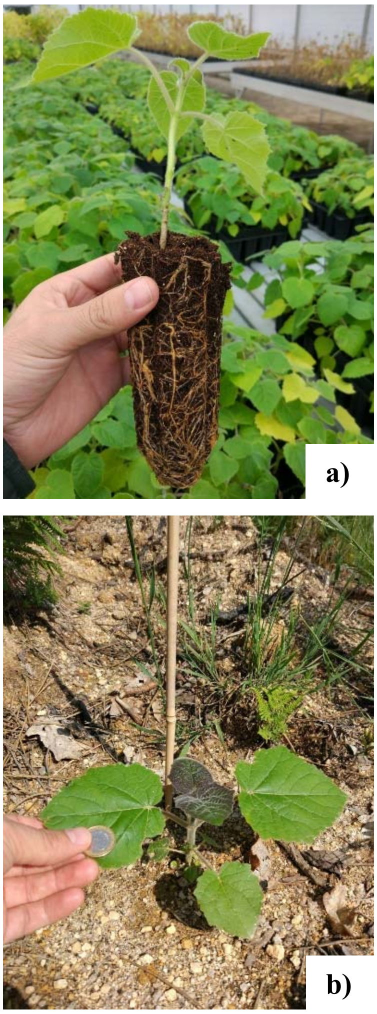

Figure 16. Specimens of *P. tomentosa* at the test field in Tondela, a) in nursery b) two months after planting

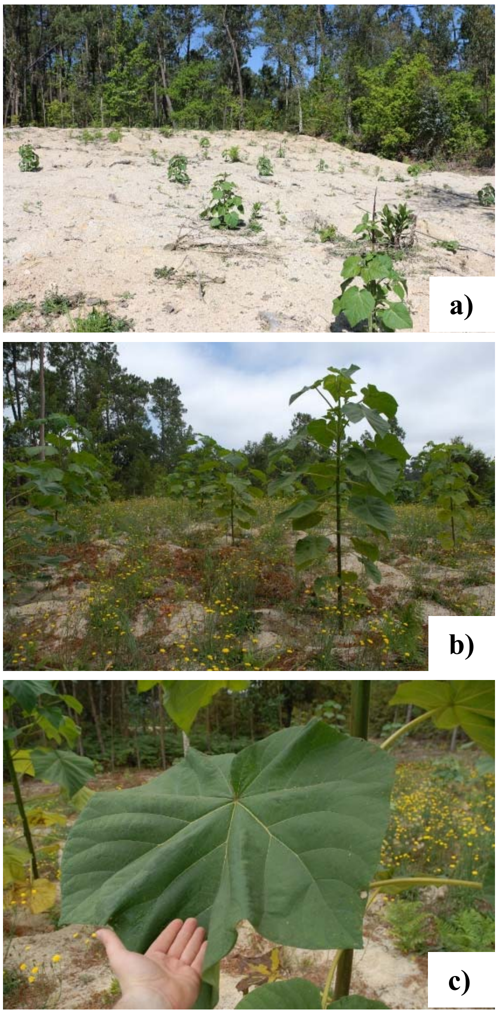

Figure 17. Specimens of *P. tomentosa* at the test field in Tondela, Portugal: a) about 8 months after planting; b) about 1 month after planting; c) close-up of leaf

Figure 18. Specimens of *P. tomentosa* at the test field after 30 months

In 2018, a second experimental test field was installed with *P. tomentosa* on the *campus* of the School of Agriculture of Viseu (Figure 19-20).

The evolution of these plants was rather unsatisfactory, as only about 20% of the plants survived. Exposure to frost is a limiting factor for this species. **In fact, there is no record of invasion in either the test field or the adjacent land.**

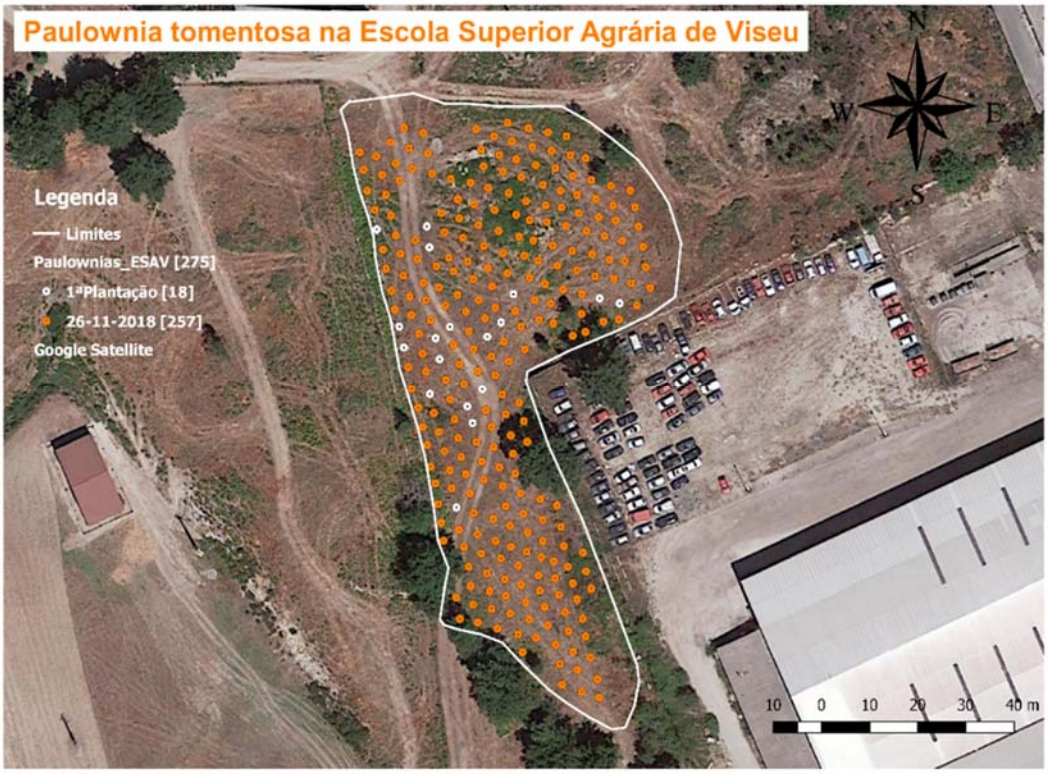

Figure 19. Location of the test field with *Paulownia tomentosa*, in Viseu, Portugal.

Figure 20. Specimens of *P. tomentosas* at the time of planting (2018) in the Viseu experimental field.

In 2018, a plantation of *P. elongata* was created in Montemor-o-Novo, in association with other forest and agricultural species. Results were positive one year after planting (Figure 21). Moreover, there are records of a plantation dated 2019 in Cadaval with the species *P. elongata*. Figure 22 shows the appearance of plants after the first technical cut.

Figure 21. *Paulownia elongata* plantation in Cadaval, one year after planting.
Source: A. Ribeiro - Quinta do Prazo in: *Paulownia* (2020).

Figure 22. *Paulownia elongata* plantation in Montemor-o-Novo, one year after planting.
Source: Montado do Freixo do Meio (2019).

In Figueiró, Viseu, there is a plantation of *Paulownia* sp. that is over 10 years old. These plants already bloomed, have a regular behaviour and there is no record of invasion within the plot or adjacent land (Figure 23).

Figure 23. Plantation of *Paulownias* in Figueiró, Viseu, that is over 10 years old.

8. Entity responsible for introducing new varieties into nature

WeGrow®, a company with headquarters in Germany, (https://www.wegrow.de) was founded in 2009 as a spin-off research company for renewable raw materials at the University of Bonn. The company lies at the intersection of science and practice and aims to actively shape the future of sustainable timber production. The company relies on innovative and ecologically sustainable technologies to produce high-quality wood.

The company also focuses in *in vitro* production of *Paulownia* hybrids, through specialized laboratory techniques. The first hybrid to be marketed in Germany was NordMax21® (*P. fortunei* (Seem.) Hemsl. X *P. tomentosa* Steud.). In addition, it markets Phoenix One®, H2F3® and H2F4® hybrids, upholding high-quality and sustainability standards.

Hybrids are produced in the laboratory located in the city of Tönisvorst by pathogen-free mother plants. The entire germination process is carried out under strict nutritional and climate control (WeGrow, 2020a).

The company has production areas installed in Rheinbach, Germany, and Todelo, Spain, to cater customer needs.

The main missions currently include the areas of KiriFonds® Germany, KiriFonds® II Germany, KiriFonds® III Spain and KiriFarm® Spain, with a volume of orders above 20 million euros.

In producing *Paulownia* wood, the company links economic and ecological knowledge and supports competent, dynamic customers as long-term reliable partners.

9. Conclusion

This risk analysis report on the introduction of exotic species into nature describes the hybrids produced by WeGrow® and the species they give rise to: Phoenix One®: *P. elongata* S.Y. Hu x *P. fortunei* (Seem.) Hemsl.; 2) H2F3® *P. catalpifolia* T. Gong ex D.Y. Hong × *P. fortunei* (Seem.) Hemsl; and 3) H2F4®: *P. catalpifolia* T. Gong ex D.Y. Hong × *P. fortunei* (Seem.) Hemsl.), according to the best scientific data available, in particular those relating to the ability of a species to adapt and disperse in the environment, under the conditions described in Article 4(3)(b), and addresses the common elements set out in Article 5(1) of Regulation (EU) No. 1143/2014 and Article 14(1)(e) and (2) of Decree-Law No. 92/2019, of 10 July.

The presence of *Paulownia* plantations in Portugal is relatively recent and marginal. The most used species was *P. tomentosa,* until prohibited by Decree-Law 92/2019, of 10 July. Although it has invasive features and has been declared invasive in other parts of the globe, no similar problem situations have been reported in Portugal. As for other species, *P. elongate* has been planted and does not reveal invasive characteristics. Thus, to date, no control measures are known for these species.

The plantations of *Paulownias* mentioned in this report, which exist in Portugal, including *P. tomentosa*, show that they have noteworthy productivity rates in certain regions. However, in others, such as in the region of Viseu, climate is a determining factor for the success of these plants. In all abovementioned cases, there is no record of uncontrolled invasion of the plants in adjacent lands.

It should be noted that **most of the pests and diseases affecting this species have not been reported to date in the Portuguese territory.** Thus, the introduction of the plantations may create conditions for the development of populations of the abovementioned species, which may pose a risk to other plant species. **It should be guaranteed that plants to be introduced are free from pests and diseases,** and that monitoring methodologies are implemented to prevent the introduction and spread of such agents. The material produced in vitro, as in the case of WeGrow hybrids, can be obtained with a Phyto certificate. On the other hand, pests of Paulownia or other crops will also depend on the agronomic techniques applied to the crop. The pests described in the literature or present in other cultures will rarely be specific to Paulownia, which already has high resistance to pathogens.

This report, which is based on the scientific and practical knowledge available at a global level, proves that WeGrow® hybrids and original species (*P. elongata*, *P. fortunei* and *P. catalpifolia*) are not invasive. **Thus, there should not be any objections to the introduction of this species in ecologically similar places to those where it has already been introduced.**

A complementary, **independent report on the analysis of the ecological potential of these plants** is issued. As concluded in this report, Portugal has sites with soil, climatic and ecological conditions that are similar to other places in Europe, where these hybrids have already been planted. However, it **may be advisable to set up test fields in Portugal, at ecologically different locations, so as to monitor these hybrids and original species.**

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