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RESEARCH ARTICLE

ECOPHYSIOLOGICAL STUDY OF *PAULOWNIA TOMENTOSA*

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ABSTRACT

This *Paulownia tomentosa* (Princesstree, Empress tree) is a deciduoustree in the familyPaulowniaceae, native to central and western China. It is an extremely fast-growing tree, and is a persistent exotic invasive in North America.This tree grows 10–25 m tall, with large heart-shaped to five-lobed leaves 15–40 cm across, arranged in opposite pairs on the stem. The very fragrant flowers are produced before the leaves in early spring, on panicles 10–30 cm long, with a tubular purple corolla 4–6 cm long resembling a foxglove flower. The fruit is a dry egg-shaped capsule 3–4 cm long, containing numerous tiny seeds. The seeds are winged and disperse by wind and water. *Paulownia tomentosa* can survive wildfire because the roots can regenerate new, very fast-growing stems. It is tolerant of pollution and it is not fussy about soil type. For this reason, it functions ecologically as a pioneer plant. Its nitrogen-rich leaves provide good fodder and its roots prevent soil erosion. It is able to grow from small cracks in pavements and walls.*Paulownia tomentosa* is cultivated as an ornamental tree in parks and gardens and is cultivated in all continents. All in all, this tree has popularity all over the world and needs to more attention. In this research, the ecophysiology of this plant has been studied. In first step, all related data were collected and then, after assessing their validity, the related data were extracted and combined and finally some suggestions are offered to improveand protect of this tree.

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INTRODUCTION

The *Paulownia* honors Anna Pavlovna of Russia (Coombes, Allen, 2012) and the *tomentosa* is a Latin word, meaning 'covered in hairs' (Harrison, Lorraine, 2012). This tree is cultivated as an ornamental tree in parks and gardens. It has gained the Royal Horticultural Society's Award of Garden Merit (RHS Plant Selector, 2013). The characteristic large size of the young growth is exploited by gardeners: by pollarding the tree and ensuring there is vigorous new growth every year, massive leaves are produced. These are popular in the modern style of gardening which uses large-foliaged and "architectural" plants. In Japan, the tree is planted at the birth of a girl (Roman, Magali, 2017). The fast-growing tree matures when she does. When she is eligible for marriage the tree is cut down and carved into wooden articles for her dowry. Carving the wood of *Paulownia* is an art form in Japan. Princesstree is native to eastern and central China (Hu, Shiu-Ying, 1961; Zhu, Zhao-Hua *et al.,* 1986) where it occurs south of the 0 °C isotherm With the exception of Antarctica, princesstree has been cultivated in every continent of the world (Csurches and Edwards, 1998; DeLoach and Jack, 1997; Donald, 1990; Hardie *et al.,*1989; Howlett, Duncan, 1975; Hu, Shiu-Ying, 1959; Hu, Shiu-Ying, 1961). It was most frequently introduced as a crop tree but also as an ornamental. Princesstree appears to be less invasive in Europe than in North America (Essl, Franz, 2007; Sand, Susan; 1992). Princess tree occurs in a variety of habitats and plant associations throughout the eastern United States that are similar to those of its native range. It may be a minor, occasional, or important component of plant communities of which it is a part. In addition, it has been cultivated at Golestan province in Iran. Thus, according to all reports, this tree has a worldwide popularity and it will be useful, conducting more researches about it. It is the reason of this paper. Figure 1 shows princess tree.

RESEARCH METHODOLOGY

The following steps were taken for the purpose of paper:

1) **Collecting data:** Given that data about this matter are a lot, hence key data were collected.
2) **Selecting valid data:** To identify and precisely evaluate characters, just valid data were used.
3) **Extract the desired and key data:** At this point, the desired and key data are extracted and integrated from all the gathered data.
4) **Suggestions:** some suggestions are offered to improve and protect of this tree according to information obtained from aforementioned steps.

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Figure 1. ***Paulownia tomentosa***

RESULTS

In this regard, remarkable points are: Princess tree is a deciduous tree (Hu, Shiu-Ying, 1959; Bean, Ellen, 1996) that may reach 21-32 m in height and 1.2-2.0 m DBH at maturity, although it is typically smaller (Bean, Ellen, 1996; Strausbaugh, Core, Earl, 1977; Duncan *et al.,* 1988; Gleason *et al.,* 1991; Kukadia, 1996). At maturity, it has thin, flaky bark. Princess tree tends to be branchy or multi-stemmed when grown in the open but can have a straight bole in forests (Kukadia, 1996; Tang *et al.,* 1980). Branches are stout but brittle, because the pith is chambered or hollow and markedly flattened at the nodes (Bean *et al.,* 1996; Strausbaugh and Core, Earl L. 1977; Duncan *et al.,* 1988). Leaves of adult trees are typically 15-30 cm long and 10-20 cm wide. However, leaves of juvenile plants and those of stump sprouts may be much larger; for example, juvenile leaves have been observed as long as 0.9 m (Graves, Donald H. 1989;U.S.Department of Agriculture, Forest Service, Northeastern Area, 1981), and leaves of stump sprouts may reach 50-80 cm or more in length (Radford *et al.,* 1968). Brittle branches and large leaves make princess tree prone to wind damage and as a result, twigs, seed capsules, and other debris frequently accumulate under the tree canopy (Hu, Shiu-Ying. 1959; Tang *et al.,* 1980; Beckjord *et al.,* 1983; Sand, Susan, 1992). The inflorescence is a large, erect terminal panicle 15-30 cm long with 5-6 cm long, tubular flowers. The fruit is an oval, 2-part capsule, 2.5- 4 cm long and 2.5 cm in diameter (Hu,Shiu-Ying, 1959; Bean *et al.,* 1996; Strausbaugh, Core, Earl, 1977; Duncan, 1988). Each part of the capsule has 2 compartments that contain very small (1.5-3 mm long), winged seeds (Bean et *al.,* 1996; Radford *et al*., 1968; Bonner, 2009). The capsules and large, fully-developed flower buds are conspicuous in winter (Arnold *et al.,* 1988). Roots can be relatively shallow to deep and well developed, apparently depending upon soil conditions. They are typically widely spreading without a strong taproot (Arnold *et al.,* 1988; Chong, Yinong. 1989). A clumped stand structure can result from even-aged seedling establishment after disturbance or from expansion through root sprouting (Duncan *et al.,* 1998; Miller, James H. 2003). Establishment of princess tree in streamside forest in Virginia associated with the large-scale disturbance of Hurricane Camille resulted in even-aged princess tree stands 10 years after the hurricane (Williams, Charles E. 1993). Forty-three percent of recorded princess tree populations in Austria resided within monospecific stands; this was attributed to the species' ability to invade extremely dry sites after disturbance (Essl, Franz. 2007).

Life span: Princess tree is apparently short lived. According to a review, mature princess trees are often structurally unsound and rarely live more than 70 years (Bean *et al.,* 1996). However, another review reports that its life span is over 125 years (Kukadia, 1996).

Raunkiaer life form (Raunkiaer, 1934**):** In this classification system, princess tree is in Phanerophyte and Geophyte category.

Seasonal Development: According to reviews, princess tree pollen is fully developed before winter (Hu, Shiu-Ying. 1959), and pollination occurs in spring (Bean *et al*., 1996; Orians, 1986). Flowers bloom before the leaves begin to emerge in late April or early May (Duncan *et al*., 1988; Hunter, Carl, 1989; Stearns, Joseph, 1944). Leaf expansion begins about 2 weeks after flowering. Flower buds begin to appear in the leaf axils in late July or early August (Hu, Shiu-Ying. 1961; Graves, Donald, 1989; Carpenter *et al.,* 1983). They develop through summer, mature in October, and are visible as terminal panicles after leaves fall in autumn (Graves, Donald H. 1989; Carpenter *et al.,* 1987). Leaves are retained in autumn until after the first frost (Stearns, Joseph L. 1944). Seeds mature in September, and capsules ripen and open in October (Carpenter *et al.,* 1987). The capsules may remain on the tree for long periods (Hunter, Carl G. 1989). The capsules break open and seeds are disseminated by wind throughout winter and into spring (Bonner, 1990).

Regeneration processes: Princess tree reproduces from seed and by sprouting from adventitious buds on stems and roots (Hu, Shiu-Ying. 1961; Donald, 1990). It apparently sprouts with or without top-kill (Niemeier, Jean. 1984). Both methods of reproduction are important to its reproductive success and invasiveness.

Pollination and breeding system: Flowers are pollinated by a variety of nectar- and pollen-feeding insects (Bean *et al.,* 1996) Carpenter *et al.,* 1979.

Seed production: Princess tree produces many small, light seeds. Seeds weigh about 0.17 mg (Bonner, 1990; Cunningham *et al*., 1980; U.S. Department of Agriculture, Forest Service, Northeastern Area. 1981). A single seed capsule may contain as many as 2,000 seeds (Hu, Shiu-Ying. 1959; Bean *et al.,* 1996), so an individual tree may produce 20 million or more seeds/year (Tang *et al.,* 1980). Princess tree reaches reproductive age early. Time to maturity depends upon environmental conditions. It may flower in favorable environments in its 4th or 5th year (Niemeier, Jean. 1984; Kuppinger, Dane Mitchell. 2008); under cultivation it may flower as early as the 3rd year (Tang *et al.,* 1980).

Seed dispersal: The small, light, winged seeds of princess tree are easily transported by wind and water over considerable distances (Bean *et al.,* 1996; Duncan *et al.,* 1988). Field observations suggest that seedlings are occasionally located more than 3 km from parent trees in mountainous regions of North Carolina and Tennessee (Kuppinger, Dane Mitchell. 2008; Langdon *et al.,* 1994).

Seed banking: Although there is disagreement regarding the persistence of princess tree seeds within the seed bank, it appears that princess tree develops a transient seed bank. Seeds can survive in the soil seed bank for at least 2 to 3 years

(Kuppinger, Dane Mitchell. 2008; Hyatt, Laura and Casper, Brenda, 2000; Longbrake and Christina, 2001). They may persist longer (Longbrake and Christina, 2001; Dobberpuhl, 1980), High density of princesstree seeds within the seed bank may not indicate high rates of germination and establishment after disturbance. (Hyatt, Laura, 1999) observed that princesstree seeds "rarely, if ever, germinate" in wildlands and "when they do germinate, they rarely survive more than a year". Long-distance dispersal and prolific seed production of princesstree apparently allow it to establish a transient seed bank from on- and off-site sources.

Germination: Princesstree seed longevity appears to be relatively short. Seed germination capacity decreases from the time of dispersal even under optimal storage conditions in the laboratory (DeLoach, C. Jack. 1997; Graves, Donald, 1989; Carpenter *et al.,* 1979; Graves *et al.,* 1989). One study found that cold-stratified seeds frequently maintained high germination rates (>90%) in the laboratory even after 3 years (Bonner *et al.,* 2009). Other studies report that germination of cold-stored seeds appeared to decline sharply after 4 years, with highest germination occurring <2 years from the time of dispersal (Graves, Donald H. 1989; Graves *et al.,* 1989; Carpenter *et al.,* 1979). Unlike seeds of many native trees that commonly occur with princesstree (e.g., oak, beech (*Fagus* spp.), and aspen (*Populus* spp.)), princesstree seeds can maintain high viability despite dehydration (Baskin *et al.,* 2001). The seeds require light for germination (Borthwick *et al.,* 1964; Zhen, Liu. 1999). The light requirement for germination was considered "unusually high" when compared with other species (Cunningham *et al.,* 1980). The actual period of illumination required ranges from minutes to hours and varies with seed source, year, and storage conditions (Borthwick *et al.,* 1964; Grubisic *et al.,* 1985). Princesstree seeds are not dormant when dispersed from the mother plant (Bonner *et al*., 2009; Kuppinger, Dane Mitchell. 2008; Oung, James, Young, Cheryl G. 1992). Thus, fresh, wind-blown seeds dispersed in late summer and early fall may germinate immediately if they reach suitable habitat (Hu, Shiu-Ying. 1961). Secondary dormancy can be induced by unfavorable environmental conditions after dispersal. Seeds can be readily induced into secondary dormancy in the laboratory by moist or dry stratification at cold temperatures (approximately 4 °C) or imbibing seeds in darkness (Zhen, Liu. 1999; Grubisic *et al.,* 1985).

The effect of secondary dormancy on germination is highly variable and partially depends upon the amount of time in darkness and the duration of the low temperature exposure (Kuppinger, Dane Mitchell. 2008; Grubisic *et al.,* 1992). Secondary dormancy may alter the time to germination and the rate of germination in this species, and in some cases, it may reduce or eliminate the light requirement of the seed and expand the range of temperatures in which germination occurs (Barnhill *et al.,* 1982; Carpenter *et al.,* 1981). Seeds overwintered in the seed bank may achieve high germination rates in the spring (Barnhill *et al.,* 1982) despite low light or temperature. Seeds may acquire secondary dormancy but fail to germinate if the conditions for breaking the dormancy are not met. In the laboratory, numerous mechanisms break secondary dormancy in princess tree. Smoke was an important chemical stimulus for the germination of seeds in the laboratory (Beckjord, Peter R. 1982). According to reviews, princesstree prefers high light, exposed mineral soil, and adequate moisture for germination and establishment (Borthwick *et al.,* 1964); however, results of experimental studies are variable and often difficult to reconcile given the effect of environmental conditions on germination capacity and dormancy.

Seedling establishment: Princesstree seedling establishment may be infrequent and widely scattered (Hyatt, Laura A. 1999; Carpenter *et al.,* 1979). Many studies have detailed the difficulties of establishing princesstree in plantations in the United States under intense silvicultural practices and controlled environmental conditions (Stringer, Jeffrey W. 1986; Robinson *et al.,* 1993). Even so, princesstree has successfully expanded its range through seeding establishment (Miller *et al*., 2008) and may be more common than indicated in the literature. For example, princesstree was characterized as the 2nd and 5th most successful nonnative tree invading native communities in the Northeast (Orians, 1986) and Southeast (Hemmerly, Thomas, 1989) as of 1986 and 2008, respectively.

Plant growth: Once established, princesstree growth may be rapid (Duncan *et al.,* 1988; Tackett *et al.,* 1983), and survival may be high (Longbrake *et al.,* 2001) even in harsh environments, but reports are variable. Aboveground growth of seedlings is typically slow during the first year (DeLoach, C. Jack. 1997; Hu, Shiu-Ying. 1959), when seedlings invest heavily in belowground growth (Longbrake and Christina, 2001). Rapid seedling root development makes this species difficult to control. A shift in emphasis from belowground to aboveground biomass accumulation occurs between the 1st and 2nd year (Longbrake and Christina, 2001). In reviews, height increases of over 2 m/year have been reported for cultivated *Paulownia* seedlings (Donald, 1990). Light availability can impact seedling establishment, survival, and growth. Photoperiod is an important factor influencing seedling height growth, with rate and duration of height growth increasing with lengthening photoperiod in the laboratory (Carpenter *et al*., 1963; Sanderson, Kenneth, 1972; Beck, John and Van Horn, Gene, 2007). Photoperiod also influences root development. Root length of princesstree seedlings increased nearly 2-fold when the photoperiod was increased from 8 to 12 hours in the laboratory (P=0.05); increasing photoperiod beyond 12 hours further increased mean root length, but not significantly (Carpenter *et al.,* 1983).

Vegetative regeneration: Vegetative regeneration is important to princesstree's persistence and spread because sprouting may allow an individual to persist after defoliation or disturbance. Princesstree sprouts from adventitious buds on stems and roots, apparently with or without top-kill (Arnold *et al*.,1988; Chong, Yinong. 1989). Sprouts generally grow faster than seedlings. For example, root sprouts may grow to over 5 m in a single season (Bean *et al.,* 1999). Thus, coppicing is a common strategy employed by nurseries and plantation farmers to stimulate rapid growth of seedlings, which are typically slow growing initially.

Ecological characters: Little information is available on princess tree's natural habitat in China, largely because princess tree has a long history of cultivation there, and much of its native range has been altered by human activities (Hu, Shiu-Ying. 1959). In China, princess tree is a minor component of the deciduous mesophyt forest, growing chiefly in mesic ravines, open valleys, and disturbed areas associated with species of maple, ash (*Fraxinus* spp.), oak, chestnut (*Castanea* spp.), basswood (*Tilia* spp.), and pine (Hu, Shiu-Ying. 1959). In the eastern United States, princess tree occurs in a variety of

disturbed, high-light environments including forest gaps and edges, streambanks and scoured riparian areas, steep rocky slopes—particularly south slopes where solar radiation is high—roadsides, fencerows, vacant lots, and "waste" places (McDonald, Robert, Urban, Dean L. 2006; Evans *et al.,* 2006). Seed germination and seedling establishment are optimum in disturbed areas with exposed mineral soil, high light, and little to no litter (Borthwick *et al.,* 1964); thus, princess tree frequently establishes and spreads after disturbances that create these conditions, such as fire, windstorms, pestilence, floods, landslides, and anthropogenic disturbances such as construction, cultivation, mining, and logging (Hull, James and Scott, Ralph, 1982; Remaley, Tom. 2005).

Soil: According to reviews, princesstree tolerates a variety of soil types and conditions including low fertility, high acidity, and drought (Beckjord, Peter R. 1984) but grows best on moist, uncompressed, well-drained soils (Melhuish *et al.,* 1990). Best growth of princesstree is obtained within strongly acidic to mildly alkaline pH levels (range: 5.5-7.5) (Turner, Gregory *et al.,* 1988) High soil acidity adversely affects germination and seedling growth (Kays *et al.,* 1998). Germination, as well as seedling root and shoot growth, are typically poor at soil pH of <4.0, but seedling growth may be reduced at soil pH of <5.0 (Kays *et al.,* 1998; Turner, Gregory *et al.,* 1988). Seeds are likely killed at soil pH of <2.5. A gradual increase in seed germination was observed in the laboratory from pH 4 to pH 7, with 79% and 98% germination at pH 4.0 and 7.0, respectively. Time required for maximum seed germination was negatively correlated with acidity (r^2=0.96, P<0.05). Princesstrees in treatments with soil pH of <5.0 germinated more quickly and primary root growth occurred more slowly than princesstrees in treatments with soil pH of >6.0 (Kays *et al.,* 1998).

Soil texture may play a role in princesstree's invasiveness. In general, sandy or loamy soils with low clay content appear optimum (Melhuish *et al.,* 1990). In China, princesstree generally grows on soils where clay content is <10% (Zhu, Zhao-Hua *et al.,* 1986). In the United States, production guides recommend planting princesstree on soils with <30% clay content (Graves *et al.,* 1989). In general, survival of seedlings appears highest in disturbed soils. Nitrogen and phosphorus are essential for tree growth. Since fire may result in substantial short- and long-term changes in availability of these nutrients, knowledge of princesstree's nitrogen and phosphorus requirements may yield important information regarding its postfire establishment and spread. In general, princesstree is tolerant of low soil fertility but grows better in fertile soils, responding favorably to fertilizer by increasing growth (Robinson *et al.,* 1993). High nitrogen levels may allow princesstree to increase chlorophyll content of leaves and maintain growth in low light (Longbrake and Christina, 2001).

Climate: Cold climates may limit princesstree's establishment and spread. Early and late frosts and minimum winter temperatures apparently limit princesstree's establishment and spread in the United States (Johnson *et al*., 1983; Mitchem, David *et al.,* 2002). In China, princesstree occurs south of the 0 °C isotherm (Hu, Shiu-Ying. 1959) in areas that receive mean annual rainfall from 500-3,000 mm (Donald, 1990). In the United States, it is typically not invasive in regions where temperatures drop below 0 °C for long periods (Dong and van Buijtenen, 1994). USDA hardiness zones 7 to 10, where average annual minimum temperatures range from -18 to 4 °C (Jordan, Ramon. 2001), are considered most favorable for princesstree (Bean *et al.,* 1996). When fully dormant, mature princesstrees can withstand temperatures as low as -25 °C, but individual plants are more susceptible to frost damage when actively growing or young and are damaged by -10 °C or lower temperatures (Donald, 1990). Damage to seeds by low temperatures is unknown, but seeds can be dry-stored at -20 °C without losing viability (San Miguel Anyanz, 1985). Princesstree may be top-killed by low temperatures (Geyer, Wayne, 2000; Kuser, John and Fimbel, Robert, 1990). Following damage by cold, plants typically sprout (Mitchem *et al*., 1980). In some cases flower buds are damaged by extreme cold, as observed by Braun (Smith *et al.,* 2008) in Ohio. Thus, the reproductive potential of an individual can be greatly limited in cold climates even if individual trees survive. Predicted climate change might result in princesstree spreading beyond its current distribution, pushing altitudinal limits upwards and latitudinal limits northward of its current range (Simberloff, Daniel, 2000).

Successional status: Princesstree is an early-successional species that is intolerant of shade (Grime, 1965; Williams, Charles, 1993). It possesses many characteristics often associated with early-successional species and invasive behavior: 1) copious production of small, wind-dispersed seeds, 2) rapid growth of seedlings, 3) strong shade intolerance and "poor competitive ability", 4) early age to first reproduction (<10 years), and 5) sprouting ability (Hu, Shiu-Ying. 1961). Apparently due to growth interference by neighboring vegetation and an inability to reproduce in shade, princesstree is a transient invader following disturbance (Kuppinger, Dane Mitchell, 2008).Princesstree is frequently described as having "poor competitive ability", particularly during the first few years of age (Beckjord *et al.,* 1985). Many authors have demonstrated that treating neighboring vegetation with herbicides increases princesstree seedling survival and growth (White *et al.,* 1982). However, the influence of neighboring vegetation on princesstree is variable. If princesstree seedlings grow fast enough to remain in the canopy, survival may be high. Seedlings over 5 feet (1.5 m) tall can create sufficient leaf surface area to shade out undergrowth (Beckjord *et al.,* 1983). Longbrake (Longbrake and Christina, 2001) concluded that once princesstree establishes, "competition will not hinder its invasive potential"; instead, light availability is apparently the dominant factor influencing its growth. Seedlings can acclimate to low light; however, growth is slower (Immel *et al.,* 1980) and according to Zhu *et al.* (1986) , around 70% shade may be fatal to princesstree saplings.

Recovery of midsuccessional vegetation after disturbance may create unsuitable conditions for princesstree. Without repeated canopy-opening disturbance, princesstree is likely to remain suppressed in the understory (Remaley, Tom, 2005). It is rarely present in the canopy of mature forests (Evans *et al.,* 2006; Remaley, Tom, 2005). Even if it persists in the tree canopy, the requirements of high light and bare soil for seed germination may lead to reproductive failure beneath the canopy of mature trees (Remaley, Tom, 2005).

Relatively poor quality sites—for example, those with low fertility and frequent drought—may provide better survival for princesstree in the long term (Arnold *et al.,* 1988). Over time in the Linville Gorge Wilderness Area, princesstree became increasingly limited to the most xeric portions of the landscape, such as slopes and ridgetops, where native plant regeneration was low. The distribution of princesstree 1 and 4 years after fire

indicated that princesstree habitat contracted over this 4-year period; habitat losses were more concentrated on mesic sites, at relatively low elevations, and on relatively flat slopes. Princesstree was reduced mainly where fire severity was low, moisture availability was high, and native plants were regenerating well (Kuppinger, Dane Mitchell, 2008). The frequency and scale of disturbance may be important to establishment and persistence of princesstree (Longbrake and Christina, 2001). Several reviews note that princesstree invasion of native forests may be primarily facilitated by large-scale disturbances, which are more likely to result in reduced interference from other vegetation, high light, and exposed mineral soil necessary for optimal establishment (Beckjord *et al.,* 1985; Webster *et al.,* 2006). Establishment of princesstree in a streamside forest after Hurricane Camille peaked immediately following the hurricane and decreased over time. Sixteen years after the disturbance, no new individuals were recruited. The author attributed this to a lack of disturbance since the hurricane and overshading by native vegetation (Williams, Charles,1993).

Uses

Importance for wildlife and livestock: Domestic livestock and wildlife regularly consume princess tree leaves, flowers, and branches. In reviews, several authors mention the use of *Paulownia* leaves as fodder for domestic sheep, goats, pigs, and rabbits (Arnold *et al.,* 1989; Wilson, Geoff. 1985). Leaves of 3 *Paulownia* species (*P. tomentosa*, *P. fortunei*, and *P. elongata*) were highly palatable to domestic goats in experimental studies and had "adequate" nutritional value for domestic goat browse as long as minerals were supplemented (Radford *et al.,* 1968). Leaves appear to be equally palatable to wildlife.

Other uses: Princesstree is valued in eastern Asia for its medicinal, ornamental, and timber uses (Hu, Shiu-Ying. 1961; Hu, Shiu-Ying. 1959). In the United States, it has been widely planted as an ornamental (Duncan *et al.,* 1988), as a source of high-value export lumber (Preston, Dickson, 1983) and for revegetation of land disturbed by coal mining. Except for its use as an ornamental, little attention was given to princesstree in the United States until the 1970s (Tackett *et al.,* 1983). The United States began exporting princesstree wood to Japan in 1972. The logs obtained from wild-grown trees in the United States were of high quality, making prices for princesstree logs comparable to expensive native hardwoods such as black walnut (*Juglansnigra*) (Hardie *et al.,* 1989). High prices encouraged interest in cultivating princesstree for timber production and led to much research regarding its cultivation on plantations and surface-mined lands (Tang *et al*., 1980; Graves, Donald, 1989). Princesstree has since been extensively cultivated and grown in commercial plantations in the United States and throughout the world (Miller, James, 2003). The commercial market for princesstree in the United States likely peaked in the late 1970s and early 1980s (Tackett *et al*., 1983; Preston, Dickson, 1983), when it was promoted as a "magic tree" (Chong, Yinong, 1989) or as an "eco-friendly multi-purpose species" (DeLoach, C. Jack. 1997). Frequent planting and increased propagule pressure may have resulted in increased invasibility of native communities by princesstree. The 1990s marked the first time that researchers and land managers began to see princesstree establish after fire in native xeric plant communities in the southern Appalachians (Kuppinger, Dane Mitchell. 2008). Beginning in the early 1990s, focus in the literature gradually shifted from promotion to eradication of princess tree.

Wood products: The characteristics of princesstree wood make it suitable for a diversity of uses, and many reports have touted the unique physical and mechanical properties of princess tree wood (Dong and van Buijtenen, 1994). Its wood is used to make plywood and other house construction wood (other than for structural timber), paper, veneer, hand-carvings, clogs, musical instruments, furniture, and kitchen items such as rice pots, water pails, bowls, and spoons (Graves, Donald, 1989; U.S. Department of Agriculture, Forest Service, Northeastern Area. 1981).

Reforestation and reclamation: Princesstree invades open, disturbed areas and often tolerates the harsh environmental conditions of surface mines (Cunningham *et al.,* 1980). Several studies have advocated using it for reclamation (Carpenter, Stanley, 1977). It has been planted on surface-mined lands throughout the eastern United States, including West Virginia, Kentucky, Tennessee, and Alabama (Vogel, Willis G. 1981). However, several authors describe it as having limited importance for use in revegetation on coal-mined sites due to the frequent difficulties of establishing princesstree relative to other species (Vogel, Willis G. 1981).

Agroforestry and cropping systems: The Chinese have developed intercropping and agroforestry systems for *Paulownia*, including princesstree, which have been evaluated extensively in the literature (Yin and He, 1997). Species of *Paulownia* other than princesstree are apparently preferred for these practices (Kays *et al.,* 1998).

Impacts and control

Impacts: Princesstree is a moderate to severe threat to native plant communities in many eastern states. In general, it is considered moderately invasive in native communities of the northeastern United States (U.S. Department of Agriculture, Forest Service, Eastern Region. 2004). In the Southeast, it is typically considered a substantial or severe threat to native communities (Alabama Invasive Plant Council, 2007; Georgia Exotic Pest Plant Council, 2006; Kentucky Exotic Pest Plant Council. 2008; Southeast Exotic Pest Plant Council, Tennessee Chapter, 2001). Princesstree is considered moderately invasive in Virginia (Virginia Department of Conservation and Recreation, Division of Natural Heritage, 2003). In a study using the Southern Research Stations Forest Inventory and Analysis database, cover estimates of princesstree totaled over 20,000 acres in 12 southeastern states (Hemmerly, Thomas E. 1989). Many studies report princesstree is of minor importance in intact forest and undisturbed environments (Donald, 1990). For example, in New London County, Connecticut, it had increased in disturbed areas but had not spread to more mature plant associations; the remaining native terrestrial flora had not seriously declined despite a high percentage of nonnative species (Hill, Steven, 1996). In western North Carolina and eastern Tennessee, there was no significant correlation between princesstree's presence or cover and native species cover or diversity; however, the author cautioned about the stability of this condition if princesstree cover were to increase (Kuppinger, Dane Mitchell. 2008). Princesstree was not considered an "aggressive invader" in eastern forests lacking large-scale disturbance due to its habit of forming "small scattered populations in much the same way that it does in its

natural environments in China" (Williams, Charles E. 1993). In China (Hu, Shiu-Ying. 1961) speculated that the requirement for high light for germination and the small size of the seed - with little food reserve - probably contribute to the isolated occurrence of princesstrees there.

Control: Princesstree control requires persistence due to its strong sprouting ability, rapid growth, and prolific seed production. Posttreatment monitoring and retreatment are essential. Treated areas should be checked once or more a year, with any new sprouts or seedlings retreated (cut, sprayed, or pulled) as soon as possible so that roots do not have time to build up carbohydrate reserves and grow larger. Princesstree's rapid root growth and sprouting ability underscore the need to eradicate seedlings when they are small and before they become established. In all cases where invasive species are targeted for control, no matter what method is employed, the potential for other invasive species to fill their void must be considered (Matthew and Pyke, David, 2001). Bean *et al*. 1996 review application methods for many of the control methods discussed below; however, the information provided herein is not intended to be either comprehensive or prescriptive in nature.

Prevention: Managing to maintain the integrity of the native plant community and mitigate the factors enhancing ecosystem invasibility is likely to be more effective than managing solely to control the invader (Howlett, Duncan. 1975). Maintaining high plant species richness in native communities is likely to decrease the invasibility of plant communities by princesstree because interference from neighboring vegetation may decrease princesstree's growth and survival. Due to princesstree's preference for open, disturbed habitat, its establishment may be prevented by minimizing loss or disturbance of native communities (Moore, James E. 2006; Pearson *et al.,* 1999). Successful control of princesstree requires prevention of propagation and planting by restricting the sale and use of princesstree and increasing public education about its impacts on native communities. In 2006, Webster *et al.* (2006) stated that "a quick review of the forestry extension web sites of 24 land grant universities in the eastern United States revealed that 7 institutions still offer publications that promote invasive exotic woody plants for plantations, wildlife habitat improvement, and ornamental plantations". Another method of preventing princesstree infestation is by developing and using a risk assessment model (Ding *et al.,* 2006). A risk assessment model combines information regarding current infestations with what is known about the species' biology. Land managers can then use the model to identify the probability of occurrence and areas at risk of invasion. Weed prevention and control can be incorporated into many types of management plans, including those for logging and site preparation, grazing allotments, recreation management, research projects, road building and maintenance, and fire management (U.S. Department of Agriculture, Forest Service, 2001).

Physical and/or mechanical: Mechanical methods can be an effective initial control measure for princesstree. Cut mature trees at ground level. To prevent seed production, cutting is most effective at the onset of flowering. Because princesstree spreads by suckering, root sprouts are common after treatment, and additional control methods such as repeated cutting for sprouts or an herbicidal control to prevent sprouting may be required (Bean *et al.,* 1996). Repeated cutting eventually exhausts the roots and kills the plant, but this may take several years (Leck *et al.,* 2005). Girdling kills the top of a tree but sprouts are common and may require a follow-up treatment with a foliar herbicide such as glyphosate or triclopyr. Seedlings can be controlled by hand-pulling; however, the entire root must be removed because broken root fragments may sprout (Bean *et al.,* 1996).

Biological: Biocontrol could potentially reduce the invasiveness of princesstree in the United States (Ehrenfeld, Joan G. 2008), but no biocontrol methods are available as of this writing (2009). Ding and others (Ding *et al.,* 2006) prioritized princesstree and 9 other species as targets for future biological control efforts based on information on their importance in introduced areas, availability of their host-specific insects or pathogens in China, and their potential biological control risk to introduced ecosystems. According to this study, princesstree has no congener species in the United States, making the potential biological control risk to introduced ecosystems low. Of 128 natural enemies in China, 19 may be potential biological control agents for use in the United States due to their narrow host ranges. Biological control of invasive species has a long history that indicates many factors must be considered before using biological controls. In the United States, native and nonnative invertebrates, fungi, and diseases are known to adversely affect princesstree. Several studies have reported mortality of seedlings due to root rots (U.S. Department of Agriculture, Forest Service, Northeastern Area, 1981; Stearns, Joseph L. 1944).

Chemical: Herbicides may provide initial control of a new invasion or a severe infestation but are rarely a complete or long-term solution to invasive species management (Bussan *et al*., 1999). Herbicides are more effective on large infestations when incorporated into long-term management plans that include replacement of weeds with desirable species, careful land use management, and prevention of new infestations. Following stem control, total elimination requires surveillance and treatment of root sprouts and plant germinants that originate from the soil seed bank (Miller, James H. 2003). Control with herbicides is temporary because it does not change conditions that allow infestations to occur (Outie, Berta; Soll, Jonathan, 1990). According to reviews, systemic herbicides (e.g., triclopyr and glyphosate), which kill roots, currently provide the best chemical control for princesstree (Bean *et al*., 1996) although results may vary depending upon environmental conditions. These herbicides risk damage to non-target species. When princesstree is interspersed with non-target species, the foliage, stumps, or basal bark of individual trees can be treated with herbicides (Bean *et al.,* 1996).

Integrated management: Princesstree can be controlled most effectively using integrated management. Cutting or girdling trees may prevent seed production. However, princesstree readily sprouts and repeated cutting or an herbicide treatment following cutting may be necessary (Tu, Mandy. 2002).

DISCUSSION AND CONCLUSION

1. Ecological spectrum of this tree is wide and it can adapt to various ecological situation.
2. In addition, biological spectrum of this tree is wide too, and it causes more spread of this plant all over the world.
3. Magic beauty of princess tree causes its world popularity among common people.

4. Usages of this plant lead to its more popularityamong users of its products.
5. It is notable which princess tree exists in few cultures specially in far East countries.
6. As a result, pay attention to princess tree is common and it causes its spread more and more, all around the world.
7. But, the most important matter for improvement and spread of princess tree is that cultivating and entrance of this tree in new land scape, must be based onspecific ecological study of land scape and ecosystem situation. In a lot of data about princess tree, refer to invasive power of it which can be related to wide ecological and biological spectrum and its adaptation power.
8. According to mentioned matters, princess tree needs to more studies for development and cultivating over the world.

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