The Beginning of a New Invasive Plant: A History of the Ornamental Callery Pear in the United States

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*The Callery pear (*Pyrus calleryana Dcne. *[Rosales: Rosaceae]), an ornamental tree from China, has begun appearing in disturbed areas throughout the United States. To understand the relatively recent spread of this species into natural areas, we review its horticultural history, the traits promoting its invasiveness, and its current invasive status. Cultivated varieties (cultivars) of this species sold in the United States originate from different areas in China and represent genotypes that have been planted in high densities in residential and commercial areas in the introduced range. The species cannot self-pollinate because of a self-incompatibility system, but recent fruit set is due to crossing between different cultivars or between the scion and rootstock of cultivated individuals. Consequently, individual cultivars themselves are not invasive, but the combination of cultivars within an area creates a situation in which invasive plants can be produced. Because of the established nature of this species in urban areas, the spread of wild* P. calleryana *will most likely continue, especially as new cultivars continue to be introduced into the mixture of cultivars already present.*

Keywords: Callery pear, cultivar, intraspecific hybridization, invasiveness, Pyrus calleryana

**Invasive plant species can inflict tremendous economic and ecological costs on agriculture and on natural ecosystems (Pimentel et al. 2000, 2005), but scientists still do not fully understand why some species become invasive and others do not. Successful invasions involve introduction and establishment in a new area, followed by a lag phase and then by spread, which can lead to major ecological and human impacts (Sakai et al. 2001). Most studies have focused on invasive plant species that have already had substantial ecological or human impacts, such as purple loosestrife (*Lythrum salicaria;* Brown et al. 2002) and spotted knapweed (*Centaurea maculosa;* Suding et al. 2004). In contrast, species beginning their spread have received relatively little attention, largely because of the difficulty in locating them before they are well established as invasives. If these species could be identified at the initial spreading phase, the eventual high cost of their control and eradication (Pimentel et al. 2005) could be reduced.

A species can be introduced to a new locality in many ways, either accidentally (e.g., as contaminants in shipping) or deliberately (e.g., for medicinal use). One source of deliberate introduction is through horticulture (Burt et al. 2007), in which plant species are imported by plant explorers, various botanical gardens and arboreta, garden club seed exchanges, some plant nurseries, and the seed trade industry (Reichard and White 2001). Although most species introduced for horticulture are not invasive, a small portion have escaped from cultivation and spread into natural areas (Reichard and White 2001). Given the high cost of controlling invasive species (Pimentel et al. 2005), it is imperative to revisit the role of horticultural introductions in plant invasions today.

An introduced species that is in the early stages of spread in the United States is *Pyrus calleryana* Dcne. (Rosales: Rosaceae), an ornamental tree frequently planted in urban residential and commercial areas. This species is native to China, Taiwan, Korea, Vietnam, and Japan, where it has a broad ecological range, inhabiting slopes, plains, mixed valley forests, and thickets (Cuizhi and Spongberg 2003). Commonly known as the Callery pear, this species is sold primarily in the form of various cultivated varieties (cultivars). Each cultivar is a

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collection of identical plants propagated clonally from a single individual selected for one or more unique and desirable characteristics (e.g., abundant flowering, vibrant fall color). As such, cultivars are variants of the same species that are maintained in cultivation. Wild populations of *P. calleryana* can now be found throughout the United States (figure 1; Vincent 2005) in disturbed sites with high light, including transportation corridors, park boundaries, and restored wetland prairies. The latitudinal range of wild individuals in the United States corresponds to the range of the species in China (figure 2; Qian and Ricklefs 1999). Wild individuals grow rapidly, flower at a young age, and often generate fruit that is dispersed by birds such as introduced European starlings. The importance of *P. calleryana* in the horticultural industry over past decades has made it possible to document its history and spread. In this article we (a) review the horticultural history of *P. calleryana* to understand how it has affected the species' present distribution, (b) examine the biological traits promoting its invasiveness, and (c) document the current invasive status of the Callery pear. These are necessary first steps to control the species as it begins to exert substantial ecological and economic effects within its introduced range.

Figure 1. Typical invasive* Pyrus calleryana *individual flowering in southwestern Ohio, in early spring. Photograph: Theresa M. Culley.

Historical overview

Although today *P. calleryana* is grown primarily for ornamental use, it was initially brought to the United States to combat fire blight in the common pear (*Pyrus communis*). This potentially fatal disease is caused by the bacterium *Erwinia amylovora,* which is spread by pollinators. In the early 1900s, the cultivated pear industry in the western United States was being decimated by fire blight, which caused the loss of more than 86% of the annual crop (Meyer 1918). Frank Reimer, at the Southern Oregon Experiment Station, began searching for resistant *Pyrus* species to use in breeding programs and as rootstock for *P. communis.* He found that *P. calleryana* was mostly resistant, but few individual plants were available. At Reimer's request, US Department of Agriculture (USDA) plant explorer Frank Meyer agreed to collect at least 100 pounds (45 kilograms [kg]) of *P. calleryana* seed in China so that enough genotypes could be examined to develop the much-needed resistant strain of *P. communis* (Cunningham 1984).

During his last trip to China, from 1916 to 1918, Meyer collected *P. calleryana* seed primarily in and near Jīngmén and also in Yíchang, where a resistant genotype had once before been collected (Meyer 1918). It was difficult to collect an adequate number of seeds because trees with substantial fruit were hard to locate, seed processing was very tedious, and contamination with *Pyrus betulifolia* (whose fruit is similar in appearance) was initially common. Small batches of seed were periodically sent to the USDA, including 18.5 pounds (8.4 kg) of a locally cultivated form of *P. calleryana* (USDA accession number SPI 45586) as well as wild seeds collected on Meyer's behalf by an American missionary in Henan Province (SPI 45594). Meyer's inability to quickly collect a substantial amount of seed was disappointing to those who hoped to begin surveying new genotypes for fire blight resistance. Consequently, Reimer traveled to Asia in 1917, first locating *P. calleryana* in southern Japan and then in southern and central Korea. He eventually joined Meyer in Jīngmén, in China's Hubei Province, where they collected *P. calleryana* fruits together before traveling to Yíchang. During their weeks together, Meyer dispatched several batches of *P. calleryana* seed back to the USDA (all recorded as SPI 45592). Reimer also collected over a hundred kilograms of fruit in the mountainous Jīngāng shān area (northwest of Yíchang).

After Meyer's death in China in 1918, additional collections of *P. calleryana* continued to be imported into the United States for fire blight testing. Most significant among these was an accession of seeds purchased in Nánjīng, China, in 1919 (SPI 47261), from which the popular ornamental cultivar 'Bradford' originated. Reimer also returned to China in 1919, making a second collection of *P. calleryana* in Shāndōng Province, much farther north than he had been in his previous visit (Westwood 1980). Unfortunately, he did not maintain his 1917 and 1919 collections separately, so the exact Chinese origin of individual seedlings from these collections (one of which became the 'Autumn Blaze' cultivar) is unknown. *P. calleryana* seeds continued to be collected several decades after these initial explorations and eventually be-

came commercially available for plant breeders and nurseries.

The screening of *P. calleryana* for fire blight–resistant genotypes in the United States involved planting large numbers of seeds and inoculating the resulting seedlings to determine their susceptibility to the disease. Many hectares of land were seeded with *P. calleryana* in Medford, Oregon, where Reimer was conducting his experiments, and in Glenn Dale, Maryland, at the USDA Plant Introduction Station. Although these initial studies focused on fire blight resistance and on overall vigor and scion-rootstock compatibility (Whitehouse et al. 1963a, 1963b), *P. calleryana*'s tolerance to a wide variety of detrimental environmental conditions, such as drought, soon became apparent. The Callery pear's hardiness eventually led to the use of the species as a common rootstock for a variety of cultivated *Pyrus* species.

It was in one of these outplantings of *P. calleryana,* in Glenn Dale, Maryland, that the ornamental potential of the species was first recognized. By 1950, there were still a few *P. calleryana* trees remaining at the USDA Plant Introduction Station that originated from the planting of seed from Meyer's SPI 47261 collection decades earlier (Santamour and McArdle 1983). In 1952, the ornamental possibilities of one particular vigorous, thornless tree were recognized, and cuttings of it were grafted onto *P. calleryana* seedlings at the USDA station (Creech 1973). These clones were then planted in a nearby treeless residential subdivision for testing as an ornamental street tree (Whitehouse et al. 1963a, 1963b). After eight years, the success of these carefully pruned test trees was apparent, and the cultivar was given the name "Bradford" in honor of a horticulturalist at the station (Whitehouse et al. 1963a, 1963b). By 1962, the tree was available commercially, and it eventually became one of the most widely planted boulevard trees in urban areas in the United States. Prized for its white spring flowers, rapid growth, compact form, and glossy, dark green leaves, 'Bradford' continues to be propagated today by grafting cuttings (scions) onto *P. calleryana* rootstock.

The Glenn Dale station was also the origin of other Callery pear cultivars (see *http://bioweb.ad.uc.edu/faculty/culley/Pyrus. htm*). For example, 'Whitehouse' was selected in 1969 and released in 1977 after it was found growing near the vicinity of the station in a population of 2500 pear seedlings that were offspring from the original set of trees planted at the station decades earlier. The original tree was an open-pollinated, thornless seedling, presumably resulting from a cross between two of the many *P. calleryana* individuals growing at the site (Cunningham 1984). The National Arboretum is credited with introducing the 'Capital' cultivar, of unknown parentage, which was developed in 1981. This cultivar has an even narrower shape than 'Whitehouse', making it ideal for use as an ornamental screening tree or in locations where space is limited (Cunningham 1984). Both the 'Capital' and the 'Whitehouse' cultivars produce more blooms than other Callery pear cultivars (Kuser et al. 2001).

Several *P. calleryana* cultivars originated in the western United States, primarily in Oregon, near Reimer's original outplantings. For example, a seedling with striking fall leaf coloration was found growing at the Lewis-Brown Horticultural Farm in Corvallis, Oregon (Westwood 1980). The seedling originated from *P. calleryana* trees introduced to the area by Reimer, who grew them from seed obtained from his Chinese expeditions (Westwood 1980). The tree was cloned by grafting onto seedling *P. calleryana* rootstock and later by budding onto *P. communis* or *Pyrus fauriei* seedlings; in the latter case, the clone exhibited a dwarf phenotype. In 1978, the cultivar was patented as 'Autumn Blaze', and it is still sold today.

As Callery pears grew in popularity, many nurseries began developing and releasing their own cultivars. For example, 'Aristocrat' was selected in 1969 from a large number of *P. calleryana* seedlings growing at a nursery near Independence, Kentucky. These seedlings originated from Chinese seed originally collected by Meyer. The selected tree had a strong central leader with horizontal branches and an early pyramidal form (Storey 1996). One of the most popular Callery pear cultivars today is 'Chanticleer', named the 2005 Urban Tree of the Year by the Society of Municipal Arborists (Phillips 2004). 'Chanticleer' was cloned from a street tree in Cleveland, Ohio (Santamour and McArdle 1983), which was originally derived from commercial seed purchased in 1946. This tree proved so remarkable that it was cloned several times, resulting in the independent development of several cultivars ('Cleveland

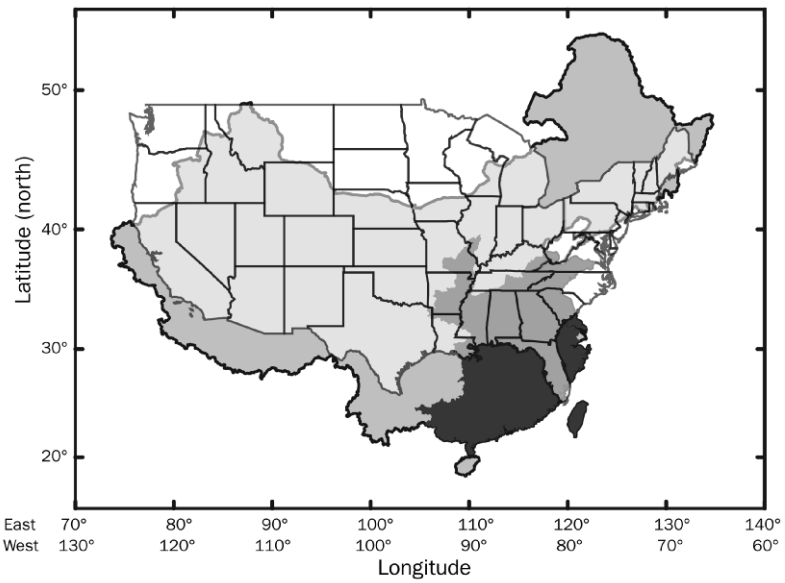

Figure 2. The United States and China are located at similar latitudes. Provinces in China where* Pyrus calleryana *are found (shown in black) are at the same latitude as areas in the southeastern United States where the species is already invasive. Source: Adapted from Qian and Ricklefs (1999).

Select', 'Stone Hill', 'Select', and 'Glenn's Form'), all of which are genetically identical to 'Chanticleer'.

As Callery pear cultivars were being developed and released, the original and highly popular 'Bradford' cultivar was found to have a major structural flaw. The narrow crotch angles of the branches eventually caused individual trees to split under their own weight after approximately 15 to 20 years of growth. Consequently, urban arborists began to promote other Callery pear cultivars with improved branching patterns, such as 'Aristocrat' (Kuser et al. 2001) and 'Chanticleer'. 'Bradford', however, is still preferred in many areas of the United States because it has better resistance to fire blight than other cultivars (Gilman and Watson 1994). All commercially available trees continue to be formed by grafting the desired scion onto different *P. calleryana* rootstock or by budding. Ornamental pear trees planted in urban areas are now a mix of different cultivars, in which 'Bradford' still retains a significant role. Consequently, many of the cultivars sold today in the United States contain genotypes, whether scion or rootstock, that represent different parts of the native Chinese range of *P. calleryana.*

Species biology

Pyrus calleryana possesses many traits that contribute to its ability to spread into a variety of environments. These includes reproductive characters, a self-incompatibility system that promotes outcrossing, resistance to disease and herbivory, and tolerance of different environmental conditions. These biological attributes are found in the native range of the species and enhance *P. calleryana*'s ability to spread and persist in new locations.

Reproduction. *Pyrus calleryana* is a perennial tree that begins flowering at approximately three years of age. It is one of the first trees to leaf out in the early spring and one of the last to retain its leaves in late autumn. Flower buds of this species are produced in early spring before leaf formation, and typically appear grouped together in approximately 6 to 12 flowers per inflorescence (Cuizhi and Spongberg 2003). Individual flowers are protandrous, about 2 to 2.5 centimeters (cm) in diameter, and consist of five sepals, five petals, two sets of 10 anthers each that differentially dehisce, and two to five carpels (Cuizhi and Spongberg 2003) with two ovules per locule. This produces a maximum seed number of 10, although the actual number is usually between 2 and 6. The flowers are strongly malodiferous and are highly attractive to insect pollinators, including generalist honeybees (*Apis mellifera* L.), bumblebees (*Bombus terrestris* L.), other introduced bees, and hoverflies (*Syrphidae*) (Farkas et al. 2002). Fruits take several months to develop and remain on the tree until they mature in early to late autumn (August to October). The fruits are consumed and the seeds dispersed in late fall by a variety of animals, such as European starlings and American robins (Gilman and Watson 1994, Swearingen et al. 2002). A prominent seed bank is likely for *P. calleryana* because its seeds possess secondary dormancy if exposed to warm temperatures in late winter (Huxley 1999). The species is diploid ($2n = 34$; Zielinski and Thompson 1967, Cuizhi and Spongberg 2003).

Self-incompatibility. Like other members of the Rosaceae, *P. calleryana* is self-incompatible (Zielinski 1965) and thus cannot produce fruits through self-pollination. Such self-incompatibility is due to the genetically controlled system in *P. calleryana,* known as gametophytic self-incompatibility. In this system, pollen tubes begin to grow down the styles of both compatible and incompatible mates, but if the haploid pollen grain shares the same self-incompatibility allele as the diploid maternal tissue, the pollen tube is prevented from reaching the ovule (de Nettancourt 2001). Compatible crosses can occur only between haploid pollen and diploid maternal tissue with no self-incompatibility allele in common, but fruit set can still occur in crosses between parents that share one self-incompatibility allele (a semicompatible cross). The gametophytic self-incompatibility system is present in fruit species such as apple, cherry, almond, and some plum and apricot cultivars, as well as other *Pyrus* species (Tomimoto et al. 1996, Zuccherelli et al. 2002).

The occurrence of self-incompatibility in *P. calleryana* is consistent with the observation decades ago that Callery pear trees (originally composed primarily of the 'Bradford' cultivar) only rarely produced viable fruit (Zielinksi 1965, Swearingen et al. 2002) and that these fruit were very small, with few seeds. More recently, however, abundant fruit set has been detected in many cultivars growing in urban areas (Swearington et al. 2002). Furthermore, fruits almost always form after hand pollinations between cultivars. This increase in *P. calleryana* fruit formation probably reflects the diversity of different cultivars planted today within crossing distance of one another. Because individual trees within each cultivar are clones, all individuals of a cultivar contain the same self-incompatibility genotype, thereby causing incompatibility in self-crosses and within-cultivar crosses. There is an exception: if the rootstock of a cultivated tree is allowed to sprout, it may cross with a scion that is genetically different. Fruits are often produced by crosses between cultivars that differ by at least one self-incompatibility allele; this may explain recent fruit set in urban areas where a mix of cultivar types typically occur, especially those that have different Chinese ancestry and are therefore more likely to contain different self-incompatibility genotypes.

Disease and herbivory. One reason the Callery pear is so popular is that it is more resistant to disease and pests than many other ornamental trees. Although all *P. calleryana* cultivars have some degree of resistance to fire blight, 'Bradford' has consistently higher resistance (Gilman and Watson 1994), whereas 'Whitehouse' is more susceptible to the disease (Gerhold 2000), especially in warm and humid southern states where fire blight is more common. 'Bradford' is highly resistant to the Japanese beetle (*Popillia japonica;* Keathley et al. 1999) but is susceptible to the pearleaf blister mite (*Eriophyes pyri*)—a species that also feeds on leaves of

'Chanticleer', 'Redspire', and 'Whitehouse', causing significant foliar injury (Gill 1997). *P. calleryana* resists wood-boring beetles (*Anoplophora glabripennis*), apparently by producing chemical compounds that interfere with normal beetle growth and development (Morewood et al. 2004).

The Callery pear is susceptible to several herbivores. Damage from white-tailed deer has been observed in cultivated varieties of *P. calleryana* (e.g., 'Bradford', 'Chanticleer', and 'Aristocrat') and in other ornamental *Pyrus* cultivars (Kays et al. 2003). The susceptibility of wild trees to deer damage remains unknown, although herbivory may be deterred in some wild plants by the production of thorns along stems and branches, a condition often seen within *P. calleryana*'s native range in Asia. The thorns are not typically lost in mature shoots of wild *P. calleryana,* as they are in several other *Pyrus* species that also possess this phenotype. In the case of wild *P. calleryana,* protective thorns may enhance individual fitness by reducing herbivory.

Environmental tolerance. Callery pear cultivars are known for their ability to tolerate a wide range of environmental conditions, including moisture, disease, and pollution. Consequently, these cultivars are ideal street trees for urban locations, where such conditions often prevail. Such tolerance reflects the wide habitat variation of the species in its native range, as Meyer (1918) noted while in Yíchang:

> *Pyrus calleryana* is simply a marvel. One finds it growing under all sorts of conditions; one time on dry, sterile mountain slopes; then again with its roots in standing water at the edge of a pond; sometimes in open pine forest, then again among scrub on blue-stone ledges in the burning sun; sometimes in low bamboo-jungle...and then again along the course of a fast flowing mountain stream or on the occasionally burned-over slope of a pebbly hill. The tree is nowhere found in groves; always as scattered specimens, and but very few large trees were seen. (p. 91)

The ability of *P. calleryana* to persist in variable and adverse soil conditions is also a reason for its success as rootstock for *Pyrus* species that are cultivated for fruit consumption (e.g., *P. communis*) or ornamental use. In China, young *P. calleryana* saplings are commonly used for rootstock if they are found naturally growing in a suitable location, where they could be grafted *in situ.*

Callery pears in general adapt well to different soils (including clay) of variable pH and also tolerate restricted root zones, pollution, drought, and heat. Consequently, many cultivars grow well in tree islands located in paved parking lots or planted along residential streets, often under utility wires (e.g., Gerhold 2000, Kuser et al. 2001). Despite these harsh and constricted environments, Callery pear cultivars exhibit rapid growth and establishment and, if pruned properly, can eventually become established shade trees.

Despite their general tolerance, Callery pear cultivars are limited in two respects. First, *P. calleryana* cannot tolerate extreme cold and will not survive where temperatures fall lower than –28 degrees Celsius (Phillips 2004). Consequently, cultivars do not perform well in the northern United States, where very cold winter temperatures predominate. The species is currently recommended for planting only in USDA Plant Hardiness Zones 5–9 (Gilman and Watson 1994), but its ability to invade new habitats, and therefore its potential invasive range, may expand northward as a result of global warming. Second, *P. calleryana* and its cultivars do not tolerate shade well, preferring instead high-light environments. Wild *P. calleryana* are rarely found in the understory of larger trees; they prefer open or disturbed habitats where they may form dense, monocultural stands.

Current spread and invasion

In recent years, Callery pear seedlings have begun to appear in many natural areas in the eastern United States (Stewart 1999, Swearingen et al. 2002, Haldeman 2003, Vincent 2005). As documented by herbarium records (Vincent 2005), the earliest escaped plants were identified in 1964 in eastern Arkansas and in 1965 in Talbot County, Maryland. Collections of wild *P. calleryana* increased over time, with 2% of herbarium specimens dated 1964–1979, 17% dated 1980–1989, 31% dated 1990–1999, and 50% dated 2000–2003 (Vincent 2005). In 1994, 'Bradford' and related cultivars were considered to have little invasive potential (Gilman and Watson 1994), but more than 10 years later, wild *P. calleryana* is found in natural areas in at least 26 states (figure 3; Vincent 2005). The 'Bradford' cultivar is currently listed by the US Fish and Wildlife

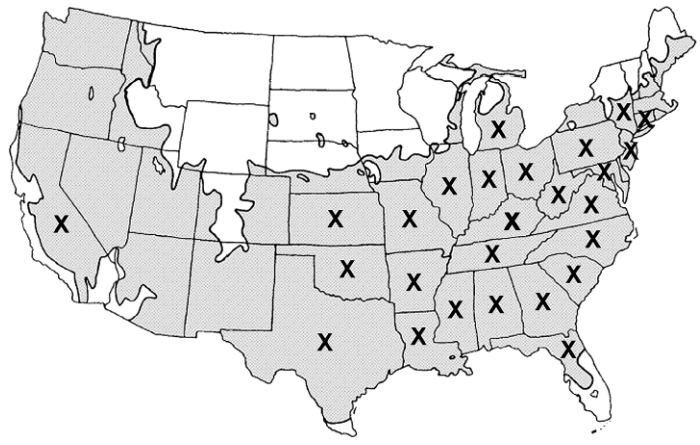

Figure 3. The recommended planting range of the 'Bradford' Callery pear (shown in gray) in the United States. The "x" denotes the 26 states in which wild* Pyrus calleryana *has been collected or observed. This consists of the 23 states found by Vincent (2005) and the states of Virginia (M. Becus, voucher #103031 and #10306b, CINC), Oklahoma (Taylor et al. 1996), and Connecticut (L.J. Mehrhoff, #124627 CONN). Source: Adapted from Fact Sheet ST-537 from the University of Florida, Institute of Food and Agricultural Sciences (November 1993).

Service as a plant invader of mid-Atlantic natural areas (Swearingen et al. 2002). *P. calleryana* itself or the cultivar 'Bradford' is listed as invasive on plant lists in six states (Alabama, Georgia, North Carolina, Maryland, New Jersey, and Pennsylvania) and is on watch lists in four others (Tennessee, New York, South Carolina, and Oklahoma). Callery pears are also spreading from cultivation in Delaware and Arkansas, and in southwestern Ohio, Callery pear saplings and trees have been found in several urban parks that adjoin residential areas where cultivated ornamental pears are widely planted. In Australia, Callery pear is considered a potential environmental weed (Csurhes and Edwards 1998).

Reasons for the spread. The ornamental use of *P. calleryana* in the United States and certain life history traits have been instrumental in affecting the species' expansion within its introduced range. Because of the popularity of Callery pear cultivars, the species has been planted at high densities in many urban areas across the United States, where the trees are cultivated to maximize growth. In contrast, Meyer (1918) wrote that trees in China "are often quite small," and "altho' not rare in the hills around here, the trees are very widely scattered." Because cultivars commonly planted in the United States typically originate from different regions of China, they represent genotypes that would normally never encounter one another within the native range. By transporting these genotypes to another country, cloning them in large quantities, and planting them together in mixed combinations supplied with resources, a situation has been created in which cultivars with different self-incompatibility genotypes can now readily cross with one another and produce fruit. Such intraspecific hybridization between cultivars, and possibly interspecific hybridization with other escaped *Pyrus* species, has been suggested as an explanation for the recent expansion of the Callery pear (Stewart 1999, Vincent 2005).

Propagation of the Callery pear by grafting cultivar scions onto *P. calleryana* rootstock could also contribute to the spread of the species in the United States when trees are not properly maintained. There are cases of Callery pear infestations at abandoned nurseries (e.g., Taylor et al. 1996) where the rootstock has sprouted and flowered, potentially allowing it to cross with the genetically distinct scion. Thus a single cultivated tree can produce fruit under the proper conditions. Rootstock sprouting may occur at random or when roots near the soil surface are nicked by lawn machinery.

Many life history traits of *P. calleryana* have also contributed to its ability to spread, especially in disturbed sites associated with human settlement. These include a generalist pollination system which, along with self-incompatibility, promotes outcross fertilization and thereby maximizes reproductive output and genetic variation in founding populations. Seed dispersal into natural areas is promoted by indiscriminant and abundant birds, and a seed bank enables the species to persist in areas after adults have been removed. Furthermore, some traits of the Callery pear that were specifically selected during its development as an ornamental tree could also promote invasiveness. These include rapid growth, abundant flowering, and wide environmental tolerance. Many of these characteristics of *P. calleryana* are typical of an ideal weed (Baker 1974, Newsome and Noble 1986, Roy 1990, Shiffman 1997, Sakai et al. 2001).

Impact on the environment. The environmental and ecological effects of *P. calleryana* have yet to be thoroughly examined, but evidence thus far points to several detrimental impacts. Because of its rapid growth and preference for high-light environments, *P. calleryana* can potentially impede the establishment of late- to middle-stage successional species in disturbed sites. *P. calleryana* can also form dense, thorny thickets, especially from the root sprouts of abandoned trees. These thickets, which are impenetrable to humans, may provide cover for birds and small mammals. *Pyrus calleryana* fruit is also consumed by birds, albeit mostly by introduced European starlings. Wild pears are an unwanted addition in newly restored wetland prairies, where they sprout readily and compete with planted native species. The removal of wild *P. calleryana* is often hampered by the thorny phenotype of some individuals.

From a horticultural standpoint, *P. calleryana* also exhibits some undesirable traits that offset its widespread popularity. The susceptibility of certain Callery pear cultivars to breakage has led some towns and cities to stop planting them, or even to remove them along streets, to avoid liability from falling limbs (Fulcher 2002). Callery pears can also drop soft fruits on the ground in some areas, causing unsightly litter and posing a danger to foot traffic (Fulcher 2002). The widespread planting of Callery pears in some areas also results in unpleasing aesthetic effects because of their overuse in the urban landscape (Dirr 1998).

Removal and control. There are few documented management strategies for the Callery pear. The most effective control practice for wild trees is complete removal (Swearingen et al. 2002). For large trees that have been cut down, an appropriate systemic herbicide, such as concentrated glyphosate or triclopyr, must be applied immediately to all parts of the freshly cut trunk to prevent regrowth (Swearingen et al. 2002). Trees can also be girdled about 15 cm above the ground during spring and summer, if complete removal is not possible. Mowing of saplings and small trees is ineffective, because the species readily sprouts from any existing trunk or root system. Seedlings and shallow-rooted plants can be pulled up with care if the soil is moist (Swearingen et al. 2002).

To prevent the formation of wild *P. calleryana* plants, homeowners and landscape designers should consider alternative tree species (Jones 2004, Burrell 2006). These include the Allegheny serviceberry (*Amelanchier laevis*), fringe tree (*Chionanthus virginicus*), green hawthorn (*Crataegus viridis*), and two-winged silverbell (*Halesia diptera* var. *magniflora*). If landowners wish to retain established cultivated Callery pear trees, a control method to prevent fruit production is to spray the tree during full bloom with the

chemical ethephon, which is 95% effective at preventing fruit set while preventing premature blossom drop (Perry and Lagarbo 1994). Sucker growth at the base of the tree trunk should also be removed promptly to prevent possible growth, flowering, and cross-pollination with the scion. Additional research is needed on the effectiveness of different herbicides and control treatments.

Implications of invasion

Pyrus calleryana demonstrates the importance of the horticultural pathway in the invasion process. Consumer demand for unique and novel plant species facilitates the introduction of nonnative species, which are then mass-produced, transported, and distributed locally to gardeners and landscapers. This greatly accelerates the natural process of introduction, especially given increased global commerce and the availability of plants for purchase over the Internet. Although most plant species introduced for horticulture, agriculture, or forestry are not invasive, a small proportion of introduced species do spread into natural areas (Reichard and White 2001). Most woody invasive plant species, such as *P. calleryana,* were originally introduced into the United States for horticultural or agricultural purposes. For example, Reichard (1997) reported that 82% of 235 woody invasive species were originally used for landscaping, 14% were used for agriculture, 3% were introduced as ornamentals but used primarily for soil erosion control, and 1% were introduced accidentally.

Horticultural introductions of plant species have the potential to promote invasiveness in several different but not mutually exclusive ways. First, cultivars themselves may escape and form invasive populations. For example, invasive populations of fountain grass (*Pennisetum setaceum*) contain a single genotype identical to that found in commercially available seed (Poulin et al. 2005). Invasive populations of ivy (*Hedera* spp.) also contain commercial cultivars in addition to putative hybrids (Clarke et al. 2006). Second, cultivars may cross-fertilize with related native or introduced species nearby, as is already documented for different taxa (Ellstrand and Schierenbeck 2000). Third, genetically distinct cultivars may cross-fertilize with one another, resulting in viable offspring in which genetic recombination creates novel genotypes (intraspecific hybridization). This occurs not only in *P. calleryana* but also in *L. salicaria,* in which self-sterile cultivars can successfully cross-fertilize with one another (Anderson and Ascher 1993; James Amon, Department of Biological Sciences, Wright State University, Dayton, Ohio, personal communication, 29 August 2007). Fourth, the rootstock of grafted individuals can potentially sprout and reproduce by crossing with the upper scion (as described for *P. calleryana*) or related species. Alternatively, the rootstock itself can become invasive, as is the case for the multiflora rose (*Rosa multiflora*), which was originally used as rootstock for cultivated roses and planted as a living fence. Finally, some cultivars may be preadapted for invasion because of horticulturally desirable traits selected during their development (e.g., abundant flowering, environmental tolerance) as well as innate traits developed in their native habitat (e.g., allelopathy). In the evergreen shrub *Ardisia crenata,* for example, selection for showy appearance and dense foliage has resulted in slower growth but greater competitive ability in invasive populations (Kitajima et al. 2006).

Reducing the number of invasive or potentially invasive plant introductions will require participation at all levels of the horticultural pathway. Plant breeders and growers need to identify potentially invasive species and cultivars before they are released. To this end, scientists must develop accurate predictive models (e.g., Reichard 1997) to pinpoint informative traits with which breeders can screen their stock for invasiveness. In some cases, cultivars are already being assessed in trials for invasive traits such as abundant seed set and high seed germination (Lehrer et al. 2006, Wilson and Knox 2006). Future tests should measure competitive ability (Anderson et al. 2006), incorporate environments that mimic conditions where spread could occur, and include pollinations between cultivars to determine compatibility and relative fecundity. Ideally, breeders would develop suitable and profitable alternatives to potential invaders, such as completely sterile cultivars of highly popular species (Li et al. 2004). Voluntary initiatives should also be encouraged for the horticultural industry, including growers, local plant nurseries, and home improvement stores, to encourage self-regulation to minimize plant invasions (Burt et al. 2007). Finally, because consumer demand drives much of horticultural development, it is crucial to educate the general public about the impacts of invasive plants and to offer examples of noninvasive alternatives. Ultimately, scientists, plant breeders, nursery personnel, land managers, and the general public all must work together to prevent the introduction of invasive plant species through the horticultural pathway.

Conclusions

In the United States, *P. calleryana*'s status is that of an early invader that is spreading across many areas of the country. As such, individual cultivars themselves are not invasive, but the combination of cultivars within an area can create a situation in which invasive plants are produced. There is an urgent need to monitor the impact of *P. calleryana* on ecosystems and to determine effective methods of control. Because Callery pear cultivars are already established as landscaping trees in the urban environment, it is unlikely that the species will decline; in fact, the spread of wild *P. calleryana* will most likely continue in the next few decades, especially as new cultivars continue to be introduced. It remains to be seen whether the species will ultimately subsist as a minor nonnative component of the ecosystem or whether it will become an economically costly problem (Pimentel et al. 2005). By monitoring *P. calleryana* over the next decade, scientists may better understand certain plant traits as well as the role of intraspecific hybridization in promoting invasiveness (Ellstrand and Schierenbeck 2000). Ultimately, the Callery pear system may provide valuable insight into the evolution of invasiveness,

particularly as it is influenced by the widespread popularity of ornamental plant species introduced into the United States.

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