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ORIGINAL PAPER

Conundrums of a complex vector for invasive species control: a detailed examination of the horticultural industry

Jennifer Drew · Neil Anderson · David Andow

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Abstract Historically the horticultural industry has transformed the US landscape through intentional cultivar introductions and unintentional introductions of weeds, insects and plant diseases. While it has been demonstrated that the horticultural industry, in particular the ornamental subsector, is an important vector for the introduction and dispersal of invasive species, known invasive plants continue to be sold while new cultivars are introduced at an ever increasing rate. This study examines the horticultural trade as a vector for invasive species, its agents, and characterizes the complexity of the distribution channel. Numerous factors have contributed to the recent expansion in marketed cultivars, including technological, industry growth, and marketing developments. The result has been an increased and sophisticated consumer demand with a corresponding aggressive scouring of the planet for new crops, many of which are introduced into the market without sufficient testing for invasive tendencies. Traditional approaches to invasive horticultural crop control (regulation, self-regulation), which target players in the distribution channel before and/or after cultivar release, have had limited effectiveness and buy-in because these approaches do not address the industry's complexities and economic incentives. Involvement and education of consumers may provide better oversight outcomes by addressing the moral hazard problem while acknowledging the key characteristics of the industry.

Keywords Economic commons · Horticulture · Industry self regulation · Invasive species · Noninvasive · Moral hazard · Ornamental plants · Oversight · Regulation

J. Drew
Department of Applied Economics, University of Minnesota, 218G Classroom office bldg, 1,994 Buford Ave, St. Paul, MN 55108, USA
e-mail: drew0052@umn.edu

N. Anderson (✉)
Department of Horticultural Science, University of Minnesota, 286 Alderman Hall, 1,970 Folwell Ave, St. Paul, MN 55108, USA
e-mail: ander044@umn.edu

D. Andow
Department of Entomology, University of Minnesota, Room 219 Hodson Hall, 1,980 Folwell Ave, St. Paul, MN 55108, USA
e-mail: dandow@umn.edu

Introduction

The horticultural industry has had a significant impact on the American landscape, beginning with the first colonists who imported European seed and nursery plants (Mack 2003, Pauly 2007). Initially, American horticultural activities involved importing food and medicinal plants to ensure survival. None-the-less, Americans strove to change what they viewed as a hostile environment to a humanized and cultured

landscape patterned after European standards (Pauly 2007). In just a few centuries, North American biotas were dramatically altered as westward moving Euro-American pioneers cut down forests, plowed up prairies, exterminated animals to establish farms with monocultures of wheat, corn and cotton (Pauly 2007). Ironically, the American landscape was not only transformed by pioneering agricultural and horticultural efforts, but also by imported European weeds, insects, and plant diseases. These transformations were made with significant environmental and economic costs (Pimentel et al. 2005).

Many vectors introduce potentially invasive non-indigenous plants to new geographic areas but deliberate introductions, based on human preferences, are a primary pathway for invasive species. In fact, non-indigenous dispersals reach their greatest impact through the trade and distribution of horticultural plant products—primarily ornamentals (Anderson and Ascher 1993, Groves 1996, Mack 2003; Mack and Erneberg 2002, Randall and Marinelli 1996, Reichard and White 2001). Mack (1990, 1991) was the first to explicitly identify the horticultural industry as a vector for the introduction of invasive species. Mack and Erneberg (2002) give evidence that over 50% of nonnative species in the US are the result of deliberate introductions. Randall and Marinelli (1996) identified 300 invasive species in N. America and about half of these were introduced as ornamental plants. Reichard and Hamilton (1997) reported that 85% of 235 nonindigenous woody plant species found out of cultivation were once used for landscaping.

The horticultural industry, which grew out of a fundamental urge to change the American environment, has also changed dramatically since its inception especially in the past 10–20 years. In 1737, America, the first major nursery—the basic and historical form of a horticultural firm—was established in Flushing, N.Y. (Higginbotham 1990). Since then the industry has increased in complexity and in the number and speed of new introductions. These and many other characteristics of today's horticultural industry contribute to increasing the risks of introducing new invasive species into the environment and the likelihood that these invasives may naturalize (Anderson et al. 2006a, b, Galatowitsch et al. 1999).

The objective of this research is to focus on the distribution channel of the horticulture industry, which has been named as a primary vector for invasive species. We characterize the distribution channel, its recent changes, the industry's agents, their motivations and actions that contribute to the potential for invasion. An additional objective is to identify potential points in the distribution chain where oversight could best be implemented.

The increasing importance of the horticultural industry pathway

In the US, increased wealth of the past few decades has resulted in expanded demand for a wider variety of food, medicine and ornamental plant products. In particular, gardening has increased in popularity where average household spending for lawn and garden products reached $35.102 million in 2007 (Butterfield 2008). Household spending grew $95 (in real 2007 dollars)/household between 1983 and 2007 (Fig. 4; Butterfield 1981, 1987, 1992, 1996, 2002, 2008). This increasing consumer demand, along with interest in novel and exotic plants, drives the horticultural industry (Gagliardi and Brand 2007).

Profit motivated firms meet this demand by efficiently finding, selecting, breeding, propagating, distributing, cultivating, and promoting a wide variety plants for ornament, food, and medicine. Their objective is to introduce as many plant products with commercially desirable traits to as many buyers in as broad a market as possible. Thus, given a percentage of these marketed cultivars may be or becomes invasive—even if unintentional—the horticultural industry's primary functions serve to administer propagule pressure of invasive plants.

These basic functions of the horticultural industry increase the probability a new plant could become established as an invasive species (Mack 2000). The economics for achieving spatial cost efficiencies means these industry activities often include intensive cultivation practices. Greenhouse production, for instance, is "…the most intensive agricultural process known" (Hanan 1998). Mack and Erneberg (2002) linked plants that were naturalized with the likelihood that they were deliberately introduced. Marketing a plant correlates with the probability of it escaping cultivation (Dehnen-Schmutz et al. 2007a); the wider the distribution area, the higher the probability a plant may become established outside of cultivation (Reichard and Hamilton 1997, Reichard and White 2001,

Pyšek et al. 2009a). Market factors for a plant with invasive characteristics such as low price, offered by a large number of firms, and offered for many years also increase the probability for invasion (Dehnen-Schmutz et al. 2007b; Pyšek et al. 2009b).

Plant types that are promoted and demanded have characteristics that could contribute to invasiveness which include large flowers, attractive seeds and fruits, long bloom season or repeat blooming, easy care/low maintenance, heat/drought tolerance, wide adaptability, stable performance over years and locations (Anderson et al. 2006a, Mack 2005). Also, plant characteristics desired by the industry that contribute to invasiveness include ease of propagation, short juvenile period, and stress tolerance for 'post harvest' ease of shipping. Most importantly, novelty can produce premiums for the industry, so there is a constant pressure for breeders and plant explorers to produce new plant cultivars.

The potential for the industry to introduce an invasive species is expanding as the market becomes more international (USDA 2005) and the scope of the crop cultivars offered increases. In the US, the horticultural industry has grown in value from 27% of all crops in 1970 to 41% in 2004 (Strickland 2004, Fig. 1). Plant introduction rates are increasing, particularly towards the end of the 20th century (Groves 1996, Ruiz and Carlton 2003), and are linked with expansion in global trade (Ruiz and Carlton 2003). The number of commercially available cultivars in the US and Canada has increased from ~29,000 in 1987 to 105,000 in 2008 (Fig. 2; Isaacson 1987, 1989, 1993, 1996, 2000, 2004,; Isaacson and Allen 2008). The current number of commercial cultivars (n = 105,000), derived from a smaller number of taxa, starkly contrasts with the ~18,000 native N. American vascular flora (Kartesz and Meacham 1999).

Technological revolutions and market innovations

Technological advances have revolutionized the way the horticulture industry generates, produces and distributes new cultivars. Advances in technologies for breeding and propagation have enabled the industry to develop increasing numbers of new cultivars, bring them to market more rapidly, as well as ensure returns to their R&D for new products (Duvick 1996, Craig 2003, Aguirre 2006). By ensuring a cultivar does not 'come true' from seed, vegetative propagation of clonal hybrids has aided breeders with built-in property rights which help secure returns to R&D investments

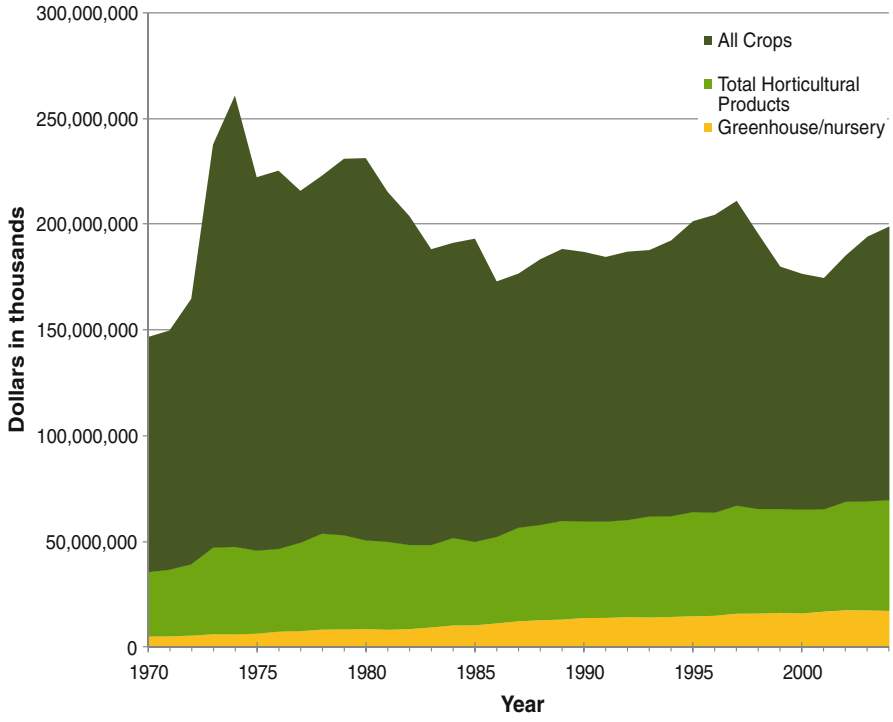

Fig. 1 Cash receipts data (1970–2004) adjusted for inflation in 2007 dollars. Source: Strickland (2004)

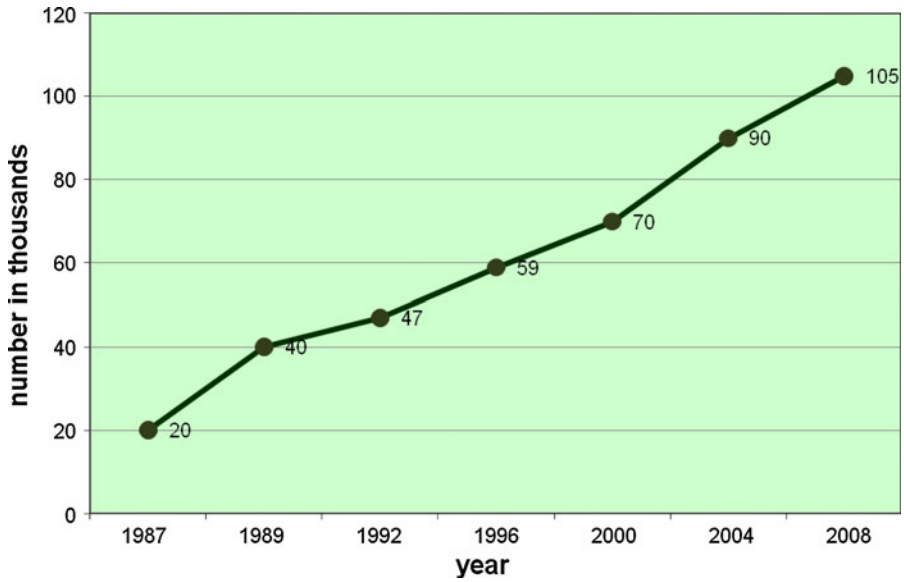

Fig. 2 Number of horticultural cultivars offered (1987–2008). Sources: Isaacson (1987, 1989, 1993, 1996, 2000 & 2004)

for new cultivars (Aguirre 2006). For example, hybrid corn technology developed in 1908 was the foundation for the birth of the modern seed industry in the 1920s (Duvick 1996). Advances in tissue culture and vegetative propagation techniques have facilitated more rapid introductions of newly developed cultivars at the producer firm level (Fig. 3) by enabling faster production of commercial quantities of propagules for less cost (Craig 2003). Rapid introduction increases the time royalty premiums can be collected for a plant with intellectual property rights before competitive follow-on, close substitute cultivars enter the market. This could explain the increasing numbers of plants propagated this way (Anderson 2006). In addition, these clonal propagation techniques can produce increased clonal variation in some plant species (mutations) and, thus, increase the potential of discovery of new products (Craig 2003). Improvements in controlled-environment technologies such as supplemental lighting, irrigation, plugs, automated sowing and transplanting, soilless media, chemicals (herbicides, pesticides, fertilizers, growth regulators), and greenhouse technologies (aluminum frames, glazing materials, flexible use units, computerization) have increased the types of ornamental crops produced, operational efficiency and capacity, and enabled flexibility when and what crops are grown (Janick and Goldman 2003). Continued evolution of transportation systems, combined with improvements in packaging and shipping technologies, have extended the range of plant origin, availability and viability.

Mergers and acquisitions in the seed and plant industries serve to increase and consolidate market share and distribution capacity, as well as to acquire access for protected intellectual property of select, high-value crops (Fernandez-Cornejo 2004, Brennan et al. 1999). Larger firms with greater market power and national distribution (e.g., Bailey Nursery, Ball Horticultural Co., Syngenta Flowers, Henry F. Michell's and Monrovia Nursery) can produce and efficiently move large numbers of plants across the continent. This represents a new level of threat for the spread of invasive species, meaning that a new, non-exclusive plant introduction promoted by a larger firm(s) can reach high levels of propagule pressure in a disturbingly short period time. The rise in the number of invasive horticultural crops may be aided by increased propagule pressures (Anderson and Ascher 1993, Dehnen-Schmutz et al. 2007a, b, Mack 2005, Reichard and White 2001). Spread of *Phytophthora ramorum* (Sudden Oak Death), a hitchhiker invasive species on horticultural crops, demonstrates the threat large firms can also pose for dispersal of additional invasives. In 2004, this fungus was discovered on *Camellia* cultivars at Monrovia Growers, a California nursery supplying >5,000 nurseries nationwide (Dunne 2004/2005).

A recent trend towards mass merchandising (i.e., chain box store and parking lot retailing) greatly increases the quantities of plants retailed through self-service (Miller 2001) as well as contributes to

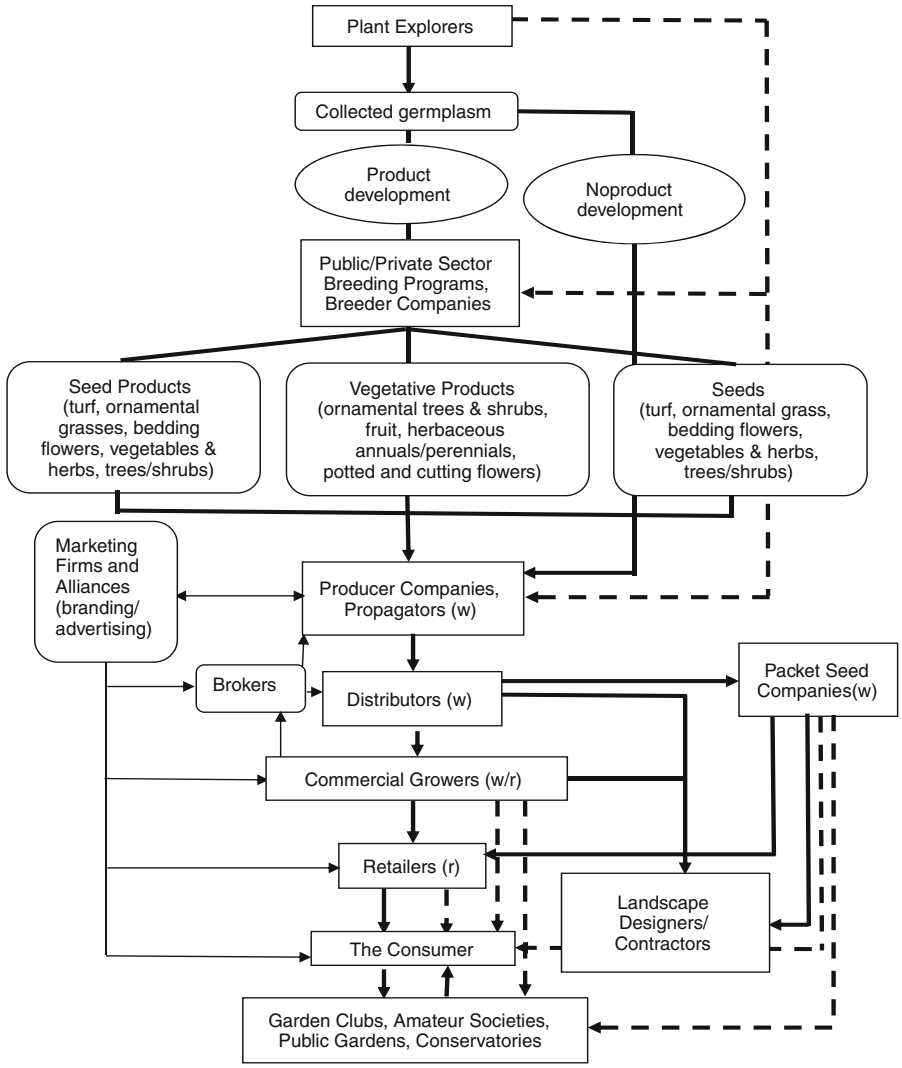

Fig. 3 International horticultural plant distribution chain. Key: *r* retail, *w* wholesale, *thick solid line* traditional marketing conduits, *thin solid line* information conduits, *broken line* web based marketing conduits. Source: adapted from Anderson et al. (2006a, b)

upstream industry consolidation (Hall et al. 2005), and so makes the dangers of increased propagule pressure more acute. This pressure is, in part, due to lack of knowledgeable personnel which limits the dissemination of consumer information. The potential for customers to unknowingly purchase plants with invasive potential is compounded because chain store retail plant choices, which are made centrally, often result in plants unsuitable for a region. This problem can be somewhat mitigated with increased use of point-of-purchase information, plant tags, and color-coded containers used for brand recognition.

Asymmetrical information between the producer and buyer is typical for horizontally differentiated products in the modern ornamental plant industry. The higher the numbers of products differentiated by characteristics, e.g. color and texture, the greater the buyer demand for information about these differences. Thus, advertising that provides information (i.e., catalogs—virtual or electronic, websites, brochures, plant tags, pots, and point-of-purchase signage) serves to match consumers to products. In addition, branding and advertising can create an increased desire for and confidence in new cultivars. For instance, the introduction and marketing of 'Purple Wave'® petunia in 1983 with its own website (http://www.wave-rave.com) broke from the horticultural industry's conservative grower marketing traditions. This savvy marketing innovation cultivated high levels of consumer demand for a higher priced product (http://www.seedquest.com/flowers/from/panamerican/expo/petuniawave.htm). Consumers requested 'Purple Wave' by name forcing

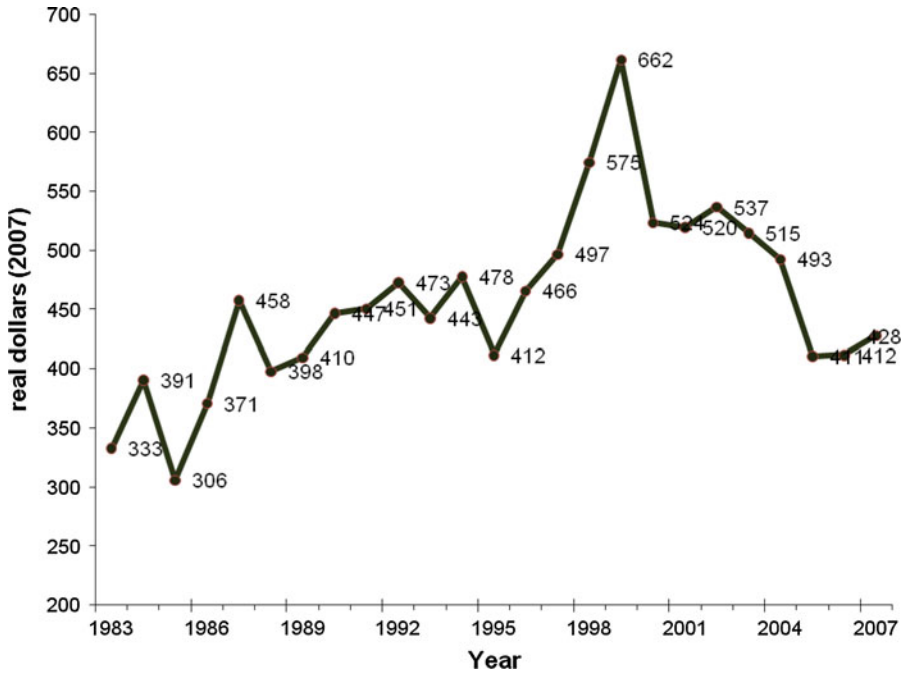

Fig. 4 Average household spending on lawn and garden activities (1991–2007) adjusted for inflation in 2007 dollars. Source: Butterfield (1981, 1987, 1992, 1996, 2002, 2008)

retailers, growers, and distributors to carry the product. Likewise, the garden guru phenomenon (e.g., Martha Stewart, Deb Brown and Rebecca Cole) has increased demand for particular plant cultivars. Additionally, garden gurus increase plant demand for gardening styles, such as water, "wild flower" and prairie style gardens, that may have greater potential to use plants with invasive attributes.

The international horticultural plant distribution chain

Growth and change in the horticulture industry, particularly the ornamental subsector, have resulted in increased propagule pressure—that is, increased units propagated for the growing numbers of cultivars (Fig. 2) and faster movement of seeds/plants through the distribution channels (Anderson et al. 2006a, b, Dehnen-Schmutz et al. 2007a, b). In the past, the horticultural industry was easily defined by breeder/producer firms specializing in breeding and producing particular seed or vegetative plant groups (Fig. 3). Particularly in the last 20 years, the roles and distinctions between firms have increasingly blurred as the industry matures and its distribution channel becomes more complex (Fig. 3; Anderson et al. 2006a). Increased vertical specialization of the ornamental industry has improved the efficiency and potential to produce and distribute ever greater volumes and variety of ornamentals. Specialized ornamental plant introduction firms, marketing firms and organizations (e.g., Proven Winners®, Flower Fields®, Plant Haven® and Blooms of Bressingham®, Chicagoland Grows, Inc.) as well as royalty administration firms (e.g., Royalty Administration Int'l.®) may have contributed to the increased rate of introductions and filings of intellectual property rights for both for cultivars and cultivar names. Their use of advertising and branding speeds adoption rates by the growers, retailers and consumers for the new crops. Emergence of propagule (seed, vegetative) and finished product brokers facilitates the sale and movement of information, seeds, cuttings, and plants through the complex wholesale market channels (Fig. 3; Craig 2003). The efficiency of this highly specialized distribution channel means that perishable horticultural products, once propagated, flow mostly unregulated at a rapid pace through the industry channels. Wholesale growers can be one of a succession of several growers (e.g., plug, pre-finisher and finisher growers) each adding value before the plant reaches the retailer or a single firm can perform multiple stages of production (Fig. 3). On the other hand, a single firm may be vertically integrated and include breeding, producing, and distributing. Thus,

while the horticulture industry has become increasingly efficient at distributing large numbers of plants nationwide, its distribution system has become more complex with multiple layers of firms each with their unique set of functions. These changes make it difficult to identify a single level to focus an intervention to stop or reduce distribution of invasives.

In addition to vertical specialization (Fig. 3), producers may also horizontally specialize in the production of either seed or vegetative propagules (herbaceous annuals/perennials, including grasses; woody perennials). Producers may specialize in specific products such as chrysanthemums, roses, daylilies, trees, or plants for fruit or vegetable producers. Distinctions between different firm's products are not clearly defined, since firms contract with each other for seeds, specialty plants or plant lines to complement or complete their own lines, generate separate lines for different plant markets, or even hold the rights to exclusive product lines at specific levels within the distribution chain. Also, distinctions between a firm's market (w/r) and its role in that market (buyer/seller) may not be clear because nurseries often sell and buy wholesale as well as sell retail. These ambiguities with respect to the role and function of individual agents make it difficult to know how or where to structure invasive interventions.

Breeders

At the top of the distribution chain, public and private sector breeders, plant explorers, and collectors participate in breeding and domestication of new cultivars (Fig. 3). An important source of new cultivars is the domestication of new crops found by plant explorers or from international germplasm collections (Janick 1999, Janick and Simon 1993). Collected genotypes may have plant traits that are common with aggressive or weedy plants as they often require less domestication (Anderson 2006). Domestication efforts include inbreeding, hybridizing, selection, trialing and propagation tests (Anderson 2006, Anderson et al. 2006a, b). Collected specimens may be crossed with related species to supply desirable traits such as drought/heat tolerance and disease/pest resistance (Anderson 2006). Trials are used to test garden performance, but may also be used to test a cultivar's proclivity towards invasiveness (Anderson et al. 2006a). Unless all environmental factors are tested over multiple locations and years—an onerous and costly procedure—these tests cannot be conclusive because, as research has shown, plants not invasive in their native environment can be invasive when moved to another habitat (Anderson 2006). Furthermore, the length of the lag time from a cultivar's introduction to the observation or discovery of its invasive characteristics can be quite long. Purple loosestrife (*Lythrum salicaria*) was introduced in 1814, but its invasiveness was not observed until the 1930s in Canada (Anderson and Ascher 1993). Also, plant collectors, arboreta, botanical gardens, and breeder trials inadvertently create conditions for spontaneous hybridization and the appearance of new species by juxtaposing related plants and species together in gardens (Pauly 2007).

Incentives can be large for horticultural breeders and firms to innovate new, useful plants. Firms offer monetary rewards, such as finder's fees and/or royalty sharing, to workers, smaller firms and the public at large for new plant cultivars for species where breeding can be costly (Buley 2006). Royalties from licensing use agreements for plants with intellectual property (IP) rights gives incentives for breeders and plant explorers to produce new cultivars (Aguirre 2006). The legal framework for these IP incentives in the US are Plant Patents (for vegetatively propagated plants) and Plant Variety Protection Certificates or PVPs (for some seed propagated lines; potatoes) and sometimes utility patents (protecting genes or inbred lines). Being at the head of the distribution chain could make breeders the ideal location for invasive plant prevention measures although the level(s) of domestication and breeding vary for each product. Anderson et al. (2006a, b) proposed that at this phase of product development extensive breeding and testing could be performed to create products with a 'non-invasive ideotype'. Those products requiring no breeding prior to marketing circumvent this phase (Fig. 3). Likewise, any agent can either collect or obtain new plant species from collectors and move them through the distribution channel.

Specialized firms form and rigorously enforce ever more restrictive legal contractual agreements with producers, which greatly control the propagation and use of the cultivar (Aguirre 2006, Hamrick 2004). For example, the licensed network grower program of Anthony Tesselaar, Int'l., Melbourne, Australia (www.tesselaar.com) restricts their products via US

Plant Patents or Plant Breeder's Rights to one grower/sales region (www.greenbeam.com/features/they111901.stm). This assures 100% of the regional sales by removing grower competition. Selective prosecution for infringement gives credibility to the threat of continued enforcement of IP rights, which Proven Winners® exemplified by a recent order for Michigan growers to destroy illegally propagated plants (Anonymous 2008). Such restrictive programs may be ideal places to piggy-back non-invasive products, although the limitations are a small, unproven customer base and fewer products within the distribution channel.

Producers

Firms that propagate horticultural plants encompass a wide variety of companies (large/small, national/regional) and products (seeds, plants, plant propagules). Producer operations range from horizontally specialized production to a full range of products as well as include other functions, such as the assessment of royalties for products with IP. Any size firm can sell products nationwide. Contractual arrangements govern producer's access to or income from popular cultivars with IP rights, as well as control offshore producers. Although some producer firms perform test trials before introducing and marketing their new cultivars (e.g. Baileys Nurseries, Terra Nova Nurseries), competitive pressure provides incentives to prematurely release these cultivars before extensive trials are complete. Also, for new as well as time-tested industry market standard cultivars, producers and agents at all levels of the distribution chain (Fig. 3) have incentive to sell plants with invasive potential when the choices are making profit or losing market share. Furthermore, where markets are nationwide or larger (e.g., catalog, mail order, *e*-commerce), producers are unwilling and confused regarding restricting sales of invasive products (Harrington et al. 2003) because of the inconsistent patchwork of invasive plant regulations among localities (USDA and NRCS 2008). Moreover, producer firms often heavily invest in marketing their new plants throughout the distribution chain. Once a plant has been listed and marketed, a firm would be unwilling to withdraw a new cultivar at this point, because competing firms are already investing in producing "me, too" and "one off" cultivars that look and perform similarly. To the best of our knowledge, complete and voluntary withdrawal of any cultivar from the market due to invasive tendencies is nonexistent in the industry.

Distributors and brokers

Due to the range of plants produced and the types of producer firms with different sizes and forms of the same cultivar, wholesale growers and retailers can have difficulty finding the best sources for the plants that they need for regional production and sales. Brokers and distributors, the mid-wholesale market firms, solve this problem for many wholesale growers reducing the perplexing assortment of available sources of seeds, plants into a smaller set of appropriate products for each market and region. Brokers arrange sales and shipping of plants, seeds and related products (cut flowers/foliage), while distributors sell and ship them. Although a large percentage of seeds and plants that flow through the horticultural distribution channel are controlled by these middle firms, wholesale growers and retailers may purchase directly from producers.

Packet seed companies

Horticultural seed firms such as W. Atlee Burpee & Co., Park Seed Co., and Johnny's Selected Seed, purchase bulk seed from distributor firms for the consumer packet seed industry. Many packet seed companies such as Burpee and Johnny's develop and produce some of their own seed cultivars. Their products, which mostly include seed packets for vegetables, herbs and annual and perennial flowers, are offered directly to consumers through catalogs and *e*-commerce as well as through retailers, landscapers and garden clubs. Increasingly, these firms offer plant products, particularly small propagules and seedlings. Origin of seed products can be difficult to trace once they reach these firms because cultivars may be sold by packet seed companies under different names than those used by the distributor for sale to wholesale growers. For instance, *Abutilon* 'Bella' series (www.panamseed.com) sold (w) to distributors and then growers is the same cultivar as the packet seed product 'Summer Sherbert' (www.burpee.com). Packet seed is often lower quality than that used for wholesale growers. Consumers sowing packet seeds rarely perform germination counts whereas high germination

and yield potential rates are expressly stated on commercial seed lots, as demanded by wholesale growers.

Wholesale growers

Firms that purchase seed, young plantlets and propagules from distributors, producers and other growers choose cultivars based on their own specialization of plant types, size, price, shipping costs, greenhouse operation costs, what is offered through their broker, controlled environment growing attributes, regional or local growing requirements, consumer preferences, novelty, and level of promotion (Fig. 3). At this level, individual plants can flow through several firms—plug growers, prefinishers and finishers—and be sold multiple times. Most growers perform comparative in-house production trials of new products against market standards. In the wholesale grower's competitive markets, restricting sales of unknown and known invasive species could mean losing market share. Likewise, numerous products such as packet seed circumvent the wholesale grower phase (Fig. 3) and would be immune to invasive species restrictions to wholesale growers.

Retailers and professional gardeners/landscapers

These firms (Fig. 3) choose plant cultivars based on shipping costs, availability through their broker or grower, shelf life, regional or local growing requirements, consumer preferences, novelty, and/or level of promotion. Such firms also purchase packet seed from brokers or distributors, but not from growers. Like other agents in the distribution chain, retail level agents are highly motivated to purchase innovative products without experience or knowledge regarding their potential for invasiveness. Many retailers at big box stores are also inexperienced in the care or knowledge of horticultural products. Landscapers develop a palette of preferred cultivars based on attributes, i.e. landscaping requirements, cost, survival, ease of installation and maintenance that may contribute to the invasiveness of plants repeatedly used.

Consumers

At the end of the distribution chain (Fig. 3), consumers are important agents of dispersal. Consumer preferences, based on plant and product characteristics, plant choices of friends or relatives, novelty, fashion, price, knowledge and experience, and factors pertaining to home ownership (e.g., age of neighborhood, ownership and condition of home and yard), greatly influence which cultivars are produced and marketed. While consumer's preferences are highly variable, most are susceptible to marketing efforts and impulse purchases. Although there is a paucity of studies of consumer preference for ornamental plant attributes, a New Zealand study found that plant price, health, suitability, final height, shape, flower color, bushiness, and leaf color were important traits (Townsley-Brascamp and Marr 1994). Not only do they purchase plants and seed from local retailers, consumers, like other plant buyers in the distribution chain, are able to bypass the usual distribution channels and obtain seeds and plants via *e*-commerce and/or mail-order (Fig. 3; Hall 2000, Reichard and White 2001, Peters et al. 2006, Burt et al. 2007, Maki and Galatowitsch 2004). Enthusiastic gardeners often exchange their favorite, top-performing plants. In addition, life style changes that extend work hours and make leisure a premium increase consumer demand for traits shared with weedy plants, e.g. low maintenance.

Examples of product flow through the distribution chain

Different types of products require divergent types of handling through the distribution chain (Fig. 3). Consider two invasive ornamental crops: *Gaura lindheimeri,* an herbaceous perennial or bedding plant annual and *Euonymus alatus,* a woody shrub. *Gaura* cultivars are predominantly produced as cuttings by a few vegetative annual producer firms; one cultivar 'The Bride' is seed-propagated. Marketing agents (left hand side, Fig. 3) aggressively promote the new cultivars, most of which are patented. Wholesale growers purchase seeds or propagules and produce plugs, pre-finished and/or finished plants to be bought by other wholesale growers and retailers. Consumers can also purchase packet seeds from retailers or via *e*-commerce. *Euonymus alatus* cultivars, produced by woody plant nurseries, are propagated by hardwood cuttings and sold as rooted cuttings, liners, finished field grown stock, and containerized plants to wholesale growers and retailers. Such wholesale growers are

likely to specialize in finishing woody plants for sale to retailers and landscapers. Many producer firms offer differentiated cultivars besides the market standards, which may be protected by IP (Isaacson and Allen 2008). While cultivars of both species may be handled by the same retailers, the route(s) taken may differ significantly, potentially allowing for escape routes around any singular phase wherein invasive species controls are instituted.

Legislated and voluntary regulation

Traditionally the US government has taken a *laissez-faire* attitude towards industry regulation due to a traditional political view that regulation is 'anti-business,' but because of the public attention given to the damage and spread of invasive species, regulations have been increasingly legislated. In the US, there are several layers of regulatory efforts to halt or slow the spread of noxious weeds and invasive species. The US Dept. of Agriculture-Animal Plant Health Inspection Service/Plant Protection & Quarantine Office (USDA-APHIS/PPQ), Invasive Species and Pest Management (ISPM) is responsible for preventing the introduction of organisms that have the potential to do harm to health, the environment or the economy (http://www.aphis.usda.gov/). The Weed Act of 1974 and its amendments provide a list of ~100 agricultural weeds (http://plants.usda.gov/cgi_bin/topics.cgi?earl=noxious.cgi) for which importation and movement are restricted. The US National Invasive Species Council (NISC) coordinates these Federal efforts for invasive species (http://www.invasivespeciesinfo.gov/council/main.shtml). In addition to the federal noxious weed restrictions, states and even counties have their own species lists of noxious weeds and/or invasive species and have regulations that restrict their sales, movement and cultivation. The Federal list excludes more than 700 known invasive species (Anderson 2006). These lists, classification of troublesome weeds and plants, and the associated regulations vary greatly among the states and counties (USDA and NRCS 2008) which can be confusing for industry agents. For example, *Lythrum salicaria* is listed as a noxious weed or invasive by many states ($n = 33$), but only eight of these state listings appear to prohibit the plant (USDA and NRCS 2008).

This extensive patchwork of legislation and regulatory efforts mean national horticultural firms find it difficult to determine appropriate sales and distribution for species that have local restrictions. Even so, these lists may not be extensive enough for optimal control. Furthermore, while enforcement may be stronger at the US ports, it remains porous for horticultural plants and is weak or nonexistent at the state and county levels (Anderson 2006). Also, due to costs, updating the lists of invasive species for all levels of government is often slow. This means species are prohibited only after considerable invasions have already occurred, *e.g. L. salicaria* (Anderson and Ascher 1993). Another problem is that knowledgeable producers find invasive species lists too restrictive because not all cultivars within a species have invasive qualities, e.g. some may be sterile (Anderson et al. 2006b).

Recently, much attention has been given to industry self regulation and other possible means of oversight to prevent the distribution of invasive or potentially invasive plants (Baskin 2002). With a growing willingness to assume responsibility and avoid more intrusive legislative regulation, the industry has made cooperative efforts with other agencies to develop and adopt a set of Voluntary Codes of Conduct for Nursery Professionals ("Codes"; Baskin 2002, Gagliardi and Brand 2007).

Assuming that a scientific determination of potential invasive plants and the regions vulnerable to them can be achieved, there are hindrances to the success of self regulation. Most importantly, given that firms are motivated by profit, self regulation—without imposing sanctions or other formal/informal means of coercion—will fail because it does not address the moral hazard problem where agents tend to act in their self interest when there is a low risk of penalty or loss of reputation. Part of this same problem is adverse selection where a firm feigns compliance to gain reputation and market share without the costs involved with actual compliance (King and Lenox 2000). The moral hazard problem is present in markets where the quality (in this case, the invasive quality) of a product is not well understood or cannot be verified by consumers (Akerlof 1970, Cavaliere 2000, Vetter and Karantininis 2002). This can especially be a problem for higher priced, high demand cultivars where profit rewards will be the motivation for firms to cheat. Reichard et al. (2005)

used a similar argument which she called a "tragedy of the commons" to insightfully point out the problems of self-regulation in the horticultural industries. She identifies the moral hazard problem such that "a few irresponsible industry agents" have the potential to jeopardize the success of the Codes to protect the environmental commons, and proposes a solution to end such uncertainties. Reichard et al. (2005) calls for stronger federal regulations and enforcement in addition to the Codes. The recognition of an additional commons—the horticultural industry reputation—as well as individual firm reputation—can provide a potent and appropriate motivation for firms to comply with the Codes. Cavaliere (2000) shows how very high levels of compliance of self-regulatory codes can be achieved by all firms if motivated by developing a 'green' industry and product. Specifically for a differentiated horticultural product, Landon and Smith (1998) show that the price premiums associated with individual and group firm quality reputation exceeds the premium for the quality improvement.

Presently, there is evidence that the industry is not yet motivated to comply with the Codes. Burt et al. (2007) found that wholesalers and retailers in California gave the lack of information, personnel and time—along with high costs—as the most frequent constraints for fully participating in the Codes. Several years after a coalition of the Florida horticultural industry implemented regulations much like the Codes, a majority of Florida's listed invasive species were openly sold (Burt et al. 2007). There are other documented cases where state invasive plant lists are disregarded (Gagliardi and Brand 2007) and legislated invasive plant prohibitions are violated (Anderson 2006, Maki and Galatowitsch 2004). Years after ratification, many nurseries are not aware of the Codes (Burt et al. 2007). This is not surprising because of the diverse and decentralized nature of the many types of firms in the industry, each with their own sources for information. Deterrents that undermine voluntary efforts that firms cite are: the lack of refinement for invasive species definition, lack of accommodation for regional differences or non invasive forms, minimal scientific documentation of invasive taxa, confusion between invasive and native plants, fear of economic disruption, losing the new potential "big winner" cultivars or losing their high volume and value "bread and butter" crops (Gagliardi and Brand 2007, Hall 2000). These latter reasons give evidence of the moral hazard inherent in voluntary industry self regulation.

The current and future structure of the industry and its distribution channel (Fig. 3) thus far has been antithetical to self regulation and other means of oversight because its organization is highly decentralized and complex with many diverse agents. Vertical/horizontal specialization and contractual arrangements that include production, distribution, promotion, and sales mean that distinctions between different firm's plant products are not clearly defined and the pathway each takes through the distribution chain may vary.

Solutions

For the invasive plant issue, partial compliance can mean total failure in preventing a plant invasion. The challenge is to develop an oversight system that will address all the problems that hinder agents in the horticultural industry from participation in regulating invasive species. A viable solution must encompass all agents as well as the complexities and dynamics of the horticultural industry where firms are decentralized and have multifaceted functions in the market. Such conditions lend themselves to a state where any one agent may not see their participation as significant for preserving the environmental commons. Such is the state of the horticultural sector in the US where there are many agents throughout a complex market chain, a patchwork of legislated regulations that are weakly and inconsistently enforced and an industry self-regulation impasse due to the lack of monitoring and sanctions. Thus, there is a moral hazard for all economic agents throughout the distribution chain to sell plants with invasive qualities.

An effective yet reasonable solution to the problem of oversight of invasive species in the horticultural sector is urgently needed. Such a solution must address the economic interests of the horticultural industry to maintain and expand sales and profits from plants. A reasonable solution will effectively slow the flow of potentially invasive crops and stop the sales of known invasive crops while not taking the 'fun' out of gardening for the American public or hurting the horticultural industry.

Important for such a solution is to recognize the economic commons, i.e. firm reputation. Also

important is to view invasiveness as a plant quality with a lower ranking than non-invasive. Since consumers are the final endpoint in the distribution chain (Fig. 3) their demand for non-invasive products would be difficult to circumvent, unlike all other preceding phases of the distribution chain. A solution could involve employing market mechanisms to provide incentives for Codes compliance and cultivating consumer demand for plants with high non-invasive quality.

Self regulation in horticultural industry with all its complexities may not be insurmountable but would require both vertical coordination of efforts along the distribution chain and horizontal organization of efforts across commodity groups with an incentive (or disincentive) of increasing (or decreasing) market share or price with compliance (or non-compliance). For example, a successful self regulation effort began with one product, cut roses where poor quality reduced vase life and market demand for cut roses especially for floral holidays (Valentines Day, Mothers Day). The "Chain of Life", which was instituted by Roses, Inc. (a cut rose grower organization; now the International Cut Flower Growers Association), depended on 100% participation of all agents in the distribution channel to promote post-harvest health and longevity of cut roses (Anderson 2006). Full rose industry participation to eliminate poor quality roses was a leading example for the cut flower industry. This exemplifies what economic theorists have shown that additional value derived from industry reputation can be an effective incentive for regulatory compliance (Gehrig and Jost 1995, Castriota and Delmastro 2009, Cavaliere 2000). Anderson (2006) observed that this example, where one weak link would mean failure, could serve as a model for implementing firm participation in the industry for oversight of invasive species.

Since poor quality of cut roses is soon evident to the consumer after purchase while invasive quality is not, the solution for controlling the spread of invasive plants in the horticultural industry will necessarily involve a public effort that develops consumer awareness of invasive species while promoting interesting, fun alternative plant choices to effectively change demand. In addition, this effort would draw attention to the horticultural industry's role in the introduction of invasive species into the environment. This public attention can provide incentives for the industry to develop positive industry and firm reputation by complying with self regulation (King and Lenox 2000). Gardeners should be receptive to this approach as environmental issues are gaining in importance for consumer choices. The industry should be receptive to this approach because for every decline in the sale of an invasive species there will be the potential for increases in sales for one or more substitute plant cultivars especially if there are premiums associated with plants with noninvasive qualities. New consumer demand may mean the industry could maintain or increase sales by producing and offering new alternative cultivars, including sterile versions of displaced invasive species, and to generate products with less known invasive characteristics (Anderson et al. 2006a, b). Strong demand for specific products will efficiently be transmitted back up through the market chain reaching all plant suppliers. The introduction of "Purple Wave"® petunias exemplified the power of consumer demand to change the product supplied because consumers asked for this specific petunia cultivar by name. A consumer approach will give the ornamental plant industry an opportunity to promote itself as a 'green' green industry. The competitive nature of firms in differentiated plant markets could translate into competition among firms to offer more plants differentiated by non-invasive quality.

A recent industry survey showed that awareness of invasive horticultural crops and the ability to recognize them varies between agents within the distribution chain (Peters et al. 2006). Some landscape architects and contractors preferentially use native, presumably non-invasive, cultivars in environmentally challenging sites (Brzuszek et al. 2007) but whether these agents would choose non-invasive over invasive species is unknown. A minority of consumers (41.3%) felt that legislation should be used to prevent the sale of non-native, exotic plants and even less (27.8%) were in favor of laws to permit the sale of only native plants (Kelley et al. 2005). Consumers vary in their willingness to pay for invasive/non-invasive crops, particularly across socio-demographics and attitudes (age, income, gender, concern about environment, interest in plant quality, ease of care, price sensitivity) as well as whether or not the crops being purchased are native species (Yue et al. 2009). Several successful programs have been piloted which encapsulate consumer willingness to purchase

environmentally friendly products. Most programs are joint efforts between the horticulture industry, regulatory agencies and/or academics: the Garden Smart program in Oregon (http://oan.org/associations/4440/files/pdf/gardensmartguide.pdf) and Colorado, the PlantRight program of California (http://www.plantright.org/) for non-invasive plants in each region of the state, or GardenWise publication for Washington state (http://www.nwcb.wa.gov/education/Western_Garden_Wise_Web.pdf). More research is needed to test and evaluate the potential for the consumer approach because King and Lenox (2000) found that, without explicit sanctions, there is the danger of adverse selection where firms mimic the outward appearance of conforming to the Codes while failing to change the effective behavior. Even with explicit sanctions, because consumer information about the environmental impacts of the industry's plant products is both incomplete and asymmetric, there is a potential for over-compliance of self-regulation by firms (Cavaliere 2000).

Conclusion

Devising an effective organization of oversight for the horticultural industry without consumer involvement has been a conundrum. The horticultural industry is integral to the changing American landscape. To what degree this change involves the introduction and continued spread of invasive species depends on actions taken now. However, research is needed to ascertain that the affects of proposed actions have the desired effects. Significant additional research efforts are needed (e.g., breeding, exploration and trialing) that are already underfunded in the horticultural industry (Alston and Pardey 2008). Certainly, any solution also entails assembling and disseminating knowledge regarding which species are invasive and under what conditions they are invasive to all agents in the horticultural distribution chain—especially consumers.

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References

Aguirre P (2006) Protection: Plant patents, utility patents, plant breeders' rights, trademarks, branding, royalties. In: Anderson NO (ed) Flower Breeding & Genetics: Issues challenges, and opportunities for the 21st century. Springer, Dordrecht, pp 75–106

Akerlof GA (1970) The Market for "Lemons": quality uncertainty and the market mechanism. Q J Econ 84:488–500

Alston JM, Pardey P (2008) Public funding for research into specialty crops. Hort Science 43:1461–1470

Anderson NO (2006) Prevention of invasiveness in floricultural crops. In: Anderson NO (ed) Flower Breeding & Genetics: Issues challenges, and opportunities for the 21st century. Springer, Dordrecht, pp 177–214

Anderson NO, Ascher PD (1993) Male and female fertility of loosestrife (Lythrum) cultivars. J Am Soc Hortic Sci 118:851–858

Anderson NO, Galatowitsch et al (2006a) Selection strategies to reduce invasive potential in introduced plants. Euphytica 148:203–206

Anderson NO, Gomez N et al (2006b) A non-invasive crop ideotype to reduce invasive potential. Euphytica 148: 185–202

Anonymous (2008) Nurseries ordered to destroy illegal plants. Am Nurseryman 207:10

Baskin Y (2002) The greening of horticulture: new codes of conduct aim to curb plant invasions. Bioscience 52: 464–471

Brennan MF, Pray CE et al (1999) Impact of industry concentration on innovation in the U.S. plant biotech industry. In: Transitions in agbiotech: economics of strategy and policy. Food Marketing Policy Center. University of Connecticut and Department of Resource Economics, University of Massachusetts, Amherst, pp 153–174

Brzuszek RF, Harkess RL et al (2007) Landscape architects' use of native plants in the Southeastern United States. HortTechnology 17(1):78–81

Buley N (ed) (2006) J. Frank Schmidt & Son Co. bare root catalog 2006–2007. J. Frank Schmidt & Son Co., Boring Oregon

Burt JW, Muir AA et al (2007) Preventing horticultural introductions of invasive plants-potential efficacy of voluntary initiatives. Biol Invasions 9:909–923

Butterfield B (Director) (1981, 1987, 1992, 1996, 2002, and 2008). National gardening survey. Harris Interactive for the National Gardening Association, South Burlington

Castriota S, Delmastro M (2009) The economics of collective reputation: minimum quality standards, vertical differentiation and optimal group size, AAWE working paper, American Association of Wine Economists

Cavaliere A (2000) Overcompliance and voluntary agreements. Environ and Resour Econ 17:195–202

Craig R (2003) Creating a more beautiful world: a century of progress in the breeding of floral and nursery plants. HortScience 38:928–936

Dehnen-Schmutz K, Touza J et al (2007a) The horticultural trade and ornamental plant invasions in Britain. Conserv Biol 21:224–231

Dehnen-Schmutz K, Touza J et al (2007b) A century of the ornamental plant trade and its impact on invasion success. Divers and Distribu 13:527–534

Dunne N (2004/2005) Sudden oak death-what gardeners need to know about a deadly pathogen on the move. Plants & Gardens News 19 Available at: http://www.bbg.org/gar2/topics/essays/2004fa_suddenoak.html. Accessed Sep 2008

Duvick DN (1996) Plant breeding, an evolutionary concept. Crop Sci 36:539–548

Fernandez-Cornejo J (2004) The seed industry in U.S. agriculture: an exploration of data and information on crop seed markets, regulation, industry structure and research and development. Economic Research Service/USDA, Washington, DC

Gagliardi JA, Brand MH (2007) Connecticut nursery and landscape industry preferences for solutions to the sale and use of invasive plants. HorTechnology 17:39–45

Galatowitsch SM, Anderson NO et al (1999) Invasiveness in wetland plants in temperate North America. Wetl 19(4): 733–755

Gehrig T, Jost P-J (1995) Quacks, lemons, and self regulation: a welfare analysis. J Regul Econ 7:309–325

Groves RH (1996) Recent incursions of weeds to Australia 1971–1995. CRC Weed Management Systems, Technical Series 3

Hall M (2000) Invasive plants and the nursery industry. Environmental studies, Brown University, Providence Available at: http://www.brown.edu/Research/EnvStudies_Theses/full9900/mhall/IPlants/IPlants_Frames.html. Accessed Sep 2008

Hall CR, Hodges AW et al (2005) Economic Impacts of the Green Industry in the United States: Final Report to the National Urban and Community Forestry Advisory Committee. University of Florida IFAS Extension, FL, Gainesville

Hamrick D (2004) The state of breeder's rights. FloraCulture Int 14(2):1–3

Hanan J (1998) Greenhouses: Advanced technology for protected horticulture. CRC Press, Boca Raton, p 7

Harrington RA, Kujawski R et al (2003) Invasive plants and the green industry. J Arboric 29:42–47

Higginbotham JS (1990) Four centuries of planting and progress: a history of the US nursery industry. Am Nurseryman 171(12):36–59

Isaacson RT, (ed) (1987, 1989, 1993, 1996, 2000 & 2004) Andersen horticultural library's source list of plants and seeds, 1st–6th eds. Andersen Horticultural Library, University of Minnesota, Minneapolis

Isaacson RT, Allen K (eds) (2008) Plant Information Online. Andersen Horticultural Library, University of Minnesota Available at: http://plantinfo.umn.edu/. Accessed 19 Oct. 2008

Janick J (ed) (1999) Perspectives on new crops and new uses. Proceedings of the Fourth National Symposium New Crops and New Uses: Biodiversity and agricultural sustainability. American Society for Horticultural Science Press, Alexandria, VA

Janick J, Goldman IL (2003) Horticulture, horticultural science, and 100 years of ASHS. HortScience 38:883–900

Janick J, Simon JE (eds) (1993) New crops. Wiley, NY

Kartesz JT, Meacham CA (1999) Synthesis of the North American flora. North Carolina Botanical Garden, University of North Carolina, Chapel Hill

Kelley KM, Stumpf JR et al (2005) Invasive plant species: consumer awareness, knowledge, and expectations. HortScience 40(4):1136

King AA, Lenox MJ (2000) Industry self-regulation without sanctions: the chemical industry's responsible care program. Acad of Manag J 43:698–716

Landon S, Smith CE (1998) Quality expectations, reputation, and price. South Econ J 64:628–647

Mack RN (1990) Catalog of woes. Nat Hist 99:44–53

Mack RN (1991) The commercial seed trade: an early disperser of weeds in the United States. Econ Bot 45:257–273

Mack RN (2000) Cultivation fosters plant naturalization by reducing environmental stochasticity. Biol Invasions 2:111–122

Mack RN (2003) Global plant dispersal, naturalization, and invasion pathways, modes and circumstances. In: Ruiz GM, Carlton JT (eds) Invasive species: vectors and management strategies. Island Press, Washington, DC, pp 3–30

Mack RN (2005) Predicting the identity of plant invaders: future contributions from horticulture. HortScience 40:1168–1174

Mack RN, Erneberg M (2002) The United States naturalized flora: largely the product of deliberate introductions. Ann Mo Bot Gard 89:176–189

Maki K, Galatowitsch SM (2004) Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. Biol Conserv 118:389–396

Miller MN (2001) Floriculture industry overview: production, sales and marketing in North America. Acta Hortic 543: 23–29

Pauly PJ (2007) Fruits and Plains: The horticultural transformation of America. Harvard University Press, Cambridge, Massachusetts

Peters WL, Meyer MH et al (2006) Minnesota horticultural industry survey on invasive plants. Euphytica 148:75–86

Pimentel D, Zuniga R et al (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol Econ 52:273–288

Pyšek P, Jarošík V et al (2009a) The global invasion success of Central European plants is related to distribution characteristics in their native range and species traits. Diversity and Distrib 15:891–903

Pyšek P, Křivánek M et al (2009b) Planting intensity, residence time, and species traits determine invasion success of alien woody species. Ecology 90:2734–2744

Randall JM, Marinelli J (eds) (1996) Weeds of the global garden. Brooklyn Botanic Garden, Brooklyn

Reichard SH, Hamilton CW (1997) Predicting invasions of woody plants introduced into North America. Conserv Biol 11:193–203

Reichard SH, White P (2001) Horticulture as a pathway of invasive plant introductions in the United States. Bioscience 51:103–113

Reichard SH, Schmitz DC et al (2005) The tragedy of the commons revisited: invasive species. Front in Ecol and the Environ 3:103–109

Ruiz GM, Carlton JT (2003) Invasion vectors: a conceptual framework for management. In: Ruiz GM, Carlton JT (eds) Invasive species: vectors and management strategies. Island Press, Washington DC, pp 459–504

Strickland R (ed) (2004) Farm income: Cash Receipts, 1924–2004 In: Farm income data files, USDA ERS Available at: http://www.ers.usda.gov/Data/FarmIncome/Zip_files.htm. Accessed 23 Aug. 2005

Townsley-Brascamp W, Marr NE (1994) Evaluation and analysis of consumer preferences for outdoor ornamental plants. Acta Hort 391:199–206

USDA (2005) Addressing the risks associated with the importation of plants for planting, US Department of agriculture, animal and plant health inspection service, Available at: http://www.aphis.usda.gov/import_export/plants/plant_imports/downloads/q37_whitepaper.pdf

USDA and NRCS (2008) The plants database. National Plant Data Center, Baton Rouge Available at: http://plants.usda.gov/index.html. Accessed Oct. 2008

Vetter H, Karantininis K (2002) Moral hazard, vertical integration, and the public monitoring of credence goods. Eur Rev of Agric Econ 29:271–279

Yue C, Hurley T et al. (2009) Do native and invasive labels affect consumer willingness to pay for plants? Evidence from experimental auctions. Selected Paper of Agric and Appl Economics Assoc 2009 Annual Meeting, Milwaukee, WI. Available at: http://purl.umn.edu/49212. Accessed Dec 2009