

Horticulture as a Pathway of Invasive Plant Introductions in the United States

SARAH HAYDEN REICHARD AND PETER WHITE

There must have been plenty of them about, growing up quietly and inoffensively, with nobody taking any particular notice of them.... And so the one in our garden continued its growth peacefully, as did thousands like it in neglected spots all over the world.... It was some little time later that the first one picked up its roots and walked.

John Wyndham, *The Day of the Triffids*

The majority of plants used in agriculture, forestry, and horticulture in North America are not native to the continent. Most of the plants that have been introduced are not invasive; they carry out their intended purpose and therefore benefit humans in multiple ways, causing no problems. A small portion of introduced plants, however, escape from cultivation and become pests of natural areas. A recent study found that invasive plants, animals, and fungi are second only to habitat loss and degradation in endangering native plant species (Wilcove et al. 1998). Fifty-seven percent of the imperiled species studied were negatively affected by nonnative invasive species. The impacts on native species include competition for resources (Melgoza et al. 1990, Hester and Hobbs 1992, Mesléard et al. 1993, Huenneke and Thomson 1994), hybridization (Thompson 1991), introduced or increased nitrogen fixation in natural areas (Vitousek et al. 1987), changed hydrologic cycles (Carman and Brotherson 1982), increased sedimentation (Blackburn et al. 1982), and increased frequency or intensity of disturbance cycles (Bock and Bock 1992, D'Antonio and Vitousek 1992). A recent estimate put the economic cost of invasive plants in natural areas, agriculture, and gardens at \$35 billion per year (Pimentel et al. 1999).

The majority of woody invasive plants in the United States were introduced for horticultural purposes—one study found that 82% of 235 woody plant species identified as colonizing outside of cultivation had been used in landscaping (Reichard 1997), and an additional 3% were widely distributed for soil erosion control (virtually all of the latter group were also introduced as ornamentals, however). Herbaceous invasive species are less likely to have been introduced for horticultural purposes; instead, many of these species were introduced through crop seed contaminated with weed seed (Baker 1986, Mack 1991) or through seeds in soil brought over from Europe as ship's ballast and dumped at ports to make room

MOST INVASIVE PLANTS HAVE BEEN INTRODUCED FOR HORTICULTURAL USE BY NURSERIES, BOTANICAL GARDENS, AND INDIVIDUALS

for cargo (Baker 1986). The problem is certainly not limited to the United States: Between 57% (Kloot 1987) and 65% (Groves 1998) of the naturalized flora of Australia, both woody and herbaceous species, were intentionally introduced for horticulture.

We define an invasive plant species as one that has or is likely to spread into native flora and managed plant systems, develop self-sustaining populations, and become dominant or disruptive (or both) to those systems. Invasive species comprise both native and nonnative species, but this article focuses primarily on those invasive plants that are not natives of the areas in which they are invasive. Because these species adversely affect land management, we refer to them as *weeds*, a term with more managerial than biological overtones, and one that is used in many legal contexts.

Given the number of plant species that have been introduced and established outside their native ranges, it may

Sarah Hayden Reichard (e-mail: reichard@u.washington.edu) is a research assistant professor in the Ecosystems Sciences Division of the College of Forest Resources and is affiliated with the Center for Urban Horticulture, University of Washington, Seattle, Washington 98195. Peter White (e-mail: pwhite@unc.edu) is professor of biology at the University of North Carolina at Chapel Hill and is director of the North Carolina Botanical Garden, Chapel Hill, North Carolina 27599-3280.

seem probable that every species is already in the United States. Nonetheless, consider, as Eduardo Rapaport (1991) did, the potential for future introductions: Rapaport estimated that there are about 260,000 vascular plants in the world and, of those, perhaps 10% are colonizing species. Thus, there are 26,000 potential weed species. Of those 26,000, he estimated, 10,000 are seriously invasive species, but only 4,000 have been exchanged among regions of the world. Therefore, 6000 species are considered weeds in their native ranges only and another 16,000 have not become established outside their natural ranges, meaning that 22,000 potential weed species have yet to be moved around the world. Even if these estimates are off by as much as 50%, and even if only 10% of the potential weed species turn out to have serious impacts (Williamson and Brown 1986), the potential exists for the introduction of over 1,000 new invasive pest plant species.

The prevention of new introductions of pest plant species is a worthy goal, given the potential for harmful impacts, and a goal that is at least partially attainable. Scientists can examine primary pathways of species introduction and identify ways to modify those pathways to prevent problematic plant introductions. If substantial numbers of weed species may still be introduced, as Rapaport suggests, and if those species are introduced as horticultural plants, as in the past, many more invasive species might well be introduced into the United States by horticultural pathways in the future. Moreover, new and existing species will continue to be spread within the United States by horticultural pathways. In this article we discuss how introductions of pest plants occurred, with a view toward what might happen in the future and what steps might reduce the likelihood that species with high potential to become invasive will be introduced and distributed.

A historical perspective on Western ornamental horticulture and plant exploration

Plants have been grown and traded since ancient times, perhaps from 8000 BC (Huxley 1978). Initially, the plants that were cultivated were probably those of medicinal or agricultural value. While they may have been arranged in aesthetically pleasing patterns, their purpose was utilitarian. The pure pleasure garden appears only when a culture has excess wealth; such gardens are often restricted to the upper classes (Huxley 1978). The Egyptian, Greek, Roman, and other ancient civilizations were known for cultivating ornamental plants, and the Western tradition of ornamental gardening appears to have taken hold during the Renaissance years of prosperity and overseas exploration (Huxley 1978). The wealth and interest in the natural world that flourished during the Renaissance fueled unprecedented plant exploration. For instance, the limited variety of interesting plants, together with a desire to have the finest gardens for his estate, led an Englishman, Sir Robert Cecil, to send his gardener, John Tradescant, to distant regions of Europe to discover new species in the early 1600s. (Before the 1560s, most plants used by Europeans were native to Europe and the

Mediterranean basin [Hobhouse 1992].) Tradescant was among the first to mount an organized search of new regions for plants of horticultural value (Lyte 1983). Tradescant also established his own garden, which grew nearly every plant species known in northern Europe at the time. Tradescant and his son sold plants from that garden (Hobhouse 1992), and the son continued to introduce new species until 1662.

In the early 19th century, plant exploration became even more popular. Expeditions were led by David Douglas (early 1800s), Joseph Hooker (beginning in 1839), Robert Fortune (beginning in 1843), Frank Kingdon-Ward (early to mid-1900s), and many others to the farthest reaches of the world in search of new and exciting species for the wealthy to grow. These individuals introduced thousands of species to Europe and Great Britain from the 18th century onward.

In the United States, plant exploration got a slower start. In fact, horticulture in all phases appears to have lagged behind Europe by about 100 years (Manks 1968). While several crop plants were introduced from Europe as early as 1565 (Huxley 1978), and some ornamentals from Europe in 1631 (Hobhouse 1992), much of the ornamental plant exploration by early North Americans centered on discovering and growing the flora of the continent (Ewan 1969). However, by 1698 there was at least one well-established private ornamental garden in Philadelphia, with plants imported from Europe. John Bartram, the owner of the garden, became the American botanist to King George III and sent native American plants to England in exchange for European species or other species that grew well in Europe (Dozier 1999). The first experimental garden for crop plants was established near Savannah, Georgia, in 1735. The first commercial nursery to conduct intercolonial and international trade was started in 1737 in Flushing, New York, by Robert Prince. For nearly 100 years it featured both food and ornamental species (Manks 1968). The first botanical garden was established in 1747 in Portsmouth, Rhode Island (Ewan 1969). Thomas Jefferson, an avid horticulturist, also introduced several species. He may have been the first person to introduce *Cytisus scoparius* (Scotch broom) as an ornamental species (Wyman 1969); that plant is now an invasive species in many parts of North America. Even though plants were not being actively introduced for horticulture, several nonnative invasive species did make early appearances. Ewan (1969, p. 2) reports a list published in 1672 of 23 "such plants as have sprung up since the English planted and kept cattle in New England."

By the early 1800s global exploration and trade had grown, and industrialization had produced prosperity and more leisure time (Dozier 1999). In 1775, the Continental Congress authorized construction of a network of roads to meet the needs of the Revolutionary War, and these roads opened up the interior of the rapidly expanding young nation to economic trade, including trade in plants (Manks 1968). Plants not native to the continent were finding their way to North America and penetrating inward from the port cities. The chief interest was in agricultural species (Wyman 1968). However, as global exploration and trade grew in the 1800s and

industrialization produced more prosperity and leisure time (Dozier 1999), new nurseries began to carry larger stocks of ornamental plants. Most of these plants came from Europe, where plant explorations and breeding programs continued unabated (Wyman 1968).

Despite their late start—after 1900, in most cases—several prolific plant explorers eventually worked from North America. Ernest Henry Wilson conducted four expeditions to China between 1899 and 1911, first for a British nursery and later for the Arnold Arboretum, which was (and still is) associated with Harvard University (Slate 1968). Beginning in 1920, Joseph Rock worked for the US Department of Agriculture (USDA), bringing in plants suitable for growth in North America and Hawaii. Rock also collected for the Arnold Arboretum. One of the most prolific explorers was David Fairchild, who in 1898 at the age of 22 established the Section of Foreign Seed and Plant Introduction within the US Department of Agriculture. He traveled for 37 years, bringing back new plants, most of them for agricultural use but some for use as ornamentals. He also hired several explorers to work for his program, one of whom was Frank N. Meyer, collector of numerous Asian species.

The Spanish and French also introduced plants into the parts of North America that they colonized. These introductions are not as well documented as those made by British colonists, but we do know that Spanish explorers brought peaches to the southeast United States in the 15th century (Wyman 1968) and that Franciscan missions in California had a number of fruit and other plants as early as 1669 (Hedrick 1950).

The current methods of plant introductions

Little has changed in plant introduction methods over the last 400 years. Plant exploration remains active in the United States and was the focus of a special two-day symposium at the Chicago Botanical Garden in March 1999. International seed exchanges are responsible for the movement of many species. These pathways are legal in the United States as long as they do not introduce insects, pathogens, listed noxious weeds, or species monitored by the Convention on International Trade in Endangered Species.

Botanical gardens and arboreta. A number of botanical gardens and arboreta still actively engage in exploration, including the Morris Arboretum in Pennsylvania, the Arnold Arboretum, and several others. Because of the expense of plant exploration, often many gardens work together on an expedition. Such expeditions are oriented not only toward collecting new species but also toward widening the gene pool of already-cultivated species and species that may be threatened in their native habitats (Meyer 1987).

Sometimes the plants collected by exploration expeditions may be used only in display, but in most cases the plants are distributed either by selling plants to raise funds or by supplying cuttings or seeds to local nurseries. Public service is a

key component of the mission of most botanical gardens and arboreta, and introducing new plants for landscape use may fit their service requirements. If care is taken, exploration by garden expeditions does not have to result in the introduction of invasive species. In particular, because plant sales are not a major part of most gardens' income, the plants need not be released immediately. Unlike most commercial enterprises, botanical gardens are able to hold species for extended periods of time to observe their opportunistic behavior. The delay in release for sale does not entirely remove risk, however, especially for woody plants, which often have a long juvenile period before seed production begins. Invasive plants may not begin to invade for many years (Scott and Panetta 1993, Cousens and Mortimer 1995, Kowarik 1995), a period known as lag time, and thus their ability to invade may not be detected by delaying their release for several years. Delaying introduction may be helpful, though, in preventing some invasive species (especially herbaceous species) from being released to the public. The many gardens and arboreta that are associated with colleges and universities might also work with biology faculty and students in assessing invasive risk and monitoring the species.

Lag time between species introductions and the onset of invasion has not been determined for many species, a fact that is sometimes used to suggest that invasions are capricious and cannot be anticipated or screened. For example, after many years of appearing noninvasive, a species may begin to invade because of changes in the environment, genetic changes in the plant itself, introduction of a pollinator or seed disperser, or a number of other possibilities—or humans may have failed to recognize that an invasion had begun earlier. One study found that the average lag phase between the introduction and initiation of the invasion of woody plants in Brandenburg, Germany, was 147 years (Kowarik 1995). This is clearly not the case in many other places and for many other species. For instance, the Pacific Northwest of the United States was settled by Europeans only in the 1860s, and then only sparsely. Most development occurred after 1900. Therefore, species introductions have been possible only for about 130 years at most. The Pacific Northwest Exotic Pest Plant Council lists 30 woody species that are widely distributed and well established. Much more work, in many more places and for several more years, needs to be done before 147 years can be established as an average lag phase for woody plants invading everywhere. Herbaceous species have a shorter juvenile stage than do woody plants and very likely begin to invade sooner after introduction, in general. Thus they may be especially well suited for screening efforts.

Many botanical gardens participate in formal seed exchanges, with each garden devising an "index seminum," or list of available seeds, and exchanging lists with participating gardens all over the world. Botanical gardens and arboreta request seed from plants they want to include in their collections and the listing garden sends it to them. A few botanical gardens list species that are known to invade somewhere in the world and simply urge caution in grow-

ing the plant. For example, a statement issued by the Washington Park Arboretum, in Seattle, Washington, says, "The Washington Park Arboretum is concerned about the impact of alien plant introductions on local native plant populations. Those species indicated with an asterisk have been reported to naturalize in some regions. It is assumed that institutions or individuals receiving seed will take appropriate steps to evaluate the invasive potential of all plant introductions." A more extreme, but probably more effective, approach is taken by the North Carolina Botanical Garden. Personnel there will not send seed to anyone outside their bioregion, thereby preventing a possible contribution to invasive plant flora. Similarly, the Lyon Arboretum in Honolulu does not issue an index seminum, and it exchanges plants with botanical gardens outside Hawaii only after careful consideration (Charles Lamoureux [Lyon Arboretum, University of Hawaii, Honolulu, HI], personal communication, 1999).

Nurseries. Although the first nursery in the United States was established in 1737, the garden center as Americans know it is part of the post–World War II economic boom (Dozier 1999). Most retail nurseries buy plants from wholesale growing facilities; however, some retail and wholesale nurseries have active plant exploration programs. The expeditions may include both collection of plants from the wild and purchases of local favorites from foreign nurseries (D. Hinckley [Heronwood Nursery, Kingston, Washington], personal communication, 1999). Because they are commercial concerns and need to recoup the expense of the trips, they may be less inclined than botanical gardens to hold species before releasing them to the public. Wholesale nurseries may sell across the country, using their own or commercial trucks to deliver the plants. Most retail nurseries sell only to the local area, meaning that if a species becomes invasive it may not have been too widely distributed for rapid response control efforts to be effective. Some retail nurseries, however, operate primarily or totally by mail order. These nurseries send species all over the country, turning the postal system and commercial shippers into efficient invasive plant dispersers. The use of wholesale shipping or postal mail order increases the probability that an invasive plant will reach an appropriate climate for invasion, and control efforts may be extremely difficult. An invasive species could thus reach and begin spreading from widely separated parts of the continent. At least one popular mail-order nursery, Heronwood Nursery in Washington State, is taking some steps to combat this problem. They have assessed their current catalog and voluntarily withdrawn some known invasive species from sale; other plants have been marked as high-risk species based on their performance elsewhere, and buyers are cautioned to remove the plant if it starts to spread vigorously. Although not ideal, this approach may prevent the spread of some known invaders and the escape and establishment of some new pests; it also helps alert the

plant-buying public of their role in preventing the spread of invasive species.

Garden club and horticultural society seed exchanges. Botanical gardens and arboreta are not the only institutions to exchange seed. Groups such as the North American Rock Garden Society and the International Bulb Society also offer seeds to their members through an exchange. Moreover, a number of more informal seed exchanges managed by individuals have sprung up over the Internet. A quick check of some of the exchange and sale lists on the Internet reveals that a number of recognized invasive species are being offered, including those on state and federal noxious weed lists. It is doubtful that these regulatory lists are routinely consulted before seed is sent in both formal and informal exchanges.

The seed trade industry. The American Seed Trade Association (ASTA) is one of the oldest trade associations in the United States, drawing its membership from seed producers and related industries. Seed producers provide seed for horticultural uses (ornamental growing and revegetation efforts, for example) and agricultural uses (for example, food crops and pasture grasses). Although they do not do much exploration for new seed, seed producers do export seed and ship it all over the country. In October 1999, ASTA issued a position statement on invasive species (see www.amseed.com/documents/invasive102899_1.html). The statement expresses support for protecting the environment but protests the proliferation of invasive species lists, without differentiating between regulatory and advisory lists. ASTA believes that many species considered invasive also have beneficial uses that must be weighed against the harm of invasion. The final paragraph of the document states, "ASTA will oppose and challenge, however, any efforts to list as 'invasive' or otherwise jeopardize the legitimate use and viability of species beneficial to agricultural crops, or when used for turf, conservation, or ornamental purposes" (ASTA 1999).

Other horticultural pathways. Not all horticulture uses are strictly ornamental. Many people grow medicinal and culinary herbs. The upsurge in mainstream interest in herbal remedies is focusing more attention on the growth of some invasive species with medicinal uses. For example, St. John's wort (*Hypericum perforatum*) is a noxious weed with harmful effects on livestock as well as adverse impacts on natural areas, but it is also gaining enormous popularity as an antidepressant. It is now legally grown as an agricultural crop in Washington State, where it is listed as a noxious weed. It was downgraded from the list of species for which control is mandated to a list of species that are considered legally noxious, but control is not required. This change was made to allow it to be grown commercially for the medicinal herb industry.

A number of aquatic weeds have been introduced as a result of their use in personal aquaria, including such notori-

ous invaders as *Myriophyllum spicatum* (Eurasian milfoil), *Salvinia molesta*, and *Egeria densa*. Uninformed people sometimes dump their aquarium water and plants into local water sources, and many of the aquarium plants survive and multiply. *Hydrilla verticillata*, a very aggressive aquatic weed in the South, was probably introduced to provide a domestic source of this plant for the aquarium trade (OTA 1993). Similarly, species such as *Eichhornia crassipes* (water hyacinth) were introduced for aquatic gardening and escaped, with serious consequences (Williams 1980). Aquatic weeds introduced for horticulture are often overlooked by those focusing on the larger terrestrial plant trade, but these weeds are a critical pathway of pest species introductions, especially as water gardening gains popularity (Kay 2000). Because of the interconnected nature of many aquatic systems, species can spread quickly and become very expensive to control. More than \$100 million per year is spent to control mostly nonnative aquatic plants that are invasive (OTA 1993).

A number of species were introduced to combat soil erosion. The US Soil Conservation Service, or SCS (now the Natural Resource Conservation Service), was established in 1933 to reduce soil erosion caused by poor agricultural practices. It aggressively promoted the use of several species, such as *Elaeagnus angustifolia* (Russian olive), *Rosa multiflora* (multiflora rose), and *Pueraria lobata* (kudzu). Although these species originally had ornamental uses and were introduced for that purpose, they were more actively spread by the SCS. For instance, kudzu was available in catalogs of the late 1800s as “porch vine,” but beginning in the 1930s the Soil Conservation Service distributed 85 million cuttings to southern land owners and offered \$8 per acre as an incentive for farmers to plant their fields with kudzu (Everest et al. n.d.).

The US Department of Agriculture estimates that in 1997 the floriculture and horticulture industry had cash receipts of \$11.2 billion (USDA 1999). Gardening is consistently listed as a top hobby in the United States. Obviously, then, horticulture is an industry that is important to consumers, urban environment improvement, and the economy. It is therefore critical that industry and customer needs are understood in efforts to reduce horticulture as a pathway of invasive plant introduction and spread. It is also important that conservationists, botanists, and ecologists work with the horticulture industry to find ways to help them identify invasives and find alternatives for them, rather than blame the industry for the introductions that have happened in the past.

Legal restrictions on plant introductions to the United States

There is limited spot screening at entry ports for plants smuggled in luggage or in freight and plants that are officially declared imports. Screening may be conducted by x-raying, by hand searching selected luggage, or by using trained dogs to detect plant material. The primary purpose of the screening is to detect fruits and other plant parts that may harbor pests of American agriculture. There are very few restrictions on the deliberate importation of plant species. None of the horti-

cultural pathways of introduction discussed in this article violates any law of the United States, so long as the species is not listed in the Federal Noxious Weed Act, which cites species that are generally already in the country but limited to a small number of states. According to the Federal Seed Act of 1939, imported seeds must also be free of listed weed seeds. The United States, unlike Australia and New Zealand, does not have any regulations requiring screening for invasive capability prior to introduction, although the seeds and plants are subject to inspection for insects or pathogens. The US Department of Agriculture has had the authority to regulate interstate movement of federal noxious weeds only since 29 July 1999, when an interim rule was published (Polly Lehtonen [US Department of Agriculture, Riverdale, MD], personal communication, 1999). Nonetheless, mail-order nurseries do sometimes ship a species to a state that lists the plant as a noxious weed; it is up to those nurseries to research the laws and comply with them.

The US federal government has shown some interest in the issue of invasive plants, as demonstrated by, for example, President Clinton's signing of an executive order on 3 February 1999, instructing federal agencies to develop policies regarding invasive species on federal land and to form an Invasive Species Council. However, it is questionable whether meaningful changes in policy and law will be made in the near future. Numerous trade agreements that the United States has signed (e.g., the Uruguay Round of the General Agreement on Tariffs and Trade and the North American Free Trade Agreement) impose obligations and limitations regarding plant importation laws. So that policies for invasive species prevention do not impede international trade, those policies must be based on scientific principles and justified by risk assessments, provide a level of protection appropriate only to the risk posed, and not be unduly restrictive to trade (Campbell 2001). The United States has agreed that screening and quarantine actions will be based on necessity and will meet standards of harmonization, equivalence, and transparency.

Currently, authority to manage introductions is given to the USDA's Animal and Plant Health Inspection Service (APHIS) under 11 different statutes that date back as far as the Plant Quarantine Act, first passed by Congress in 1912. A more modern and streamlined statutory framework would help protect US resources by providing more effective exclusion of pest species, detection and emergency response, and management, while still allowing international trade, including horticulture, to continue under the terms of international agreements. There is some recognition on the part of the US government that changes need to be made in the regulatory system (National Plant Board 1999). Such changes will take some time in the development and implementation stages, however, and are likely to be at best a compromise between ideal invasive plant exclusion and trade facilitation.

Should we expect change?

Is it realistic to expect change in horticulture's role as a pathway for invasive plants? Although it is difficult to say what form

change will take, it is quite probable that it will happen. Change in procedures and policy occur when a critical mass of people, convinced that a problem or threat exists, demand solutions. The change may come from within the horticulture industry or it may be regulatory, or it may be both.

Reduction in the introduction of new invasive species. Because there is interest in species introductions and because current laws do not restrict introductions, new invasive species will very likely continue to arrive in the United States through horticultural pathways. To minimize the dangers of those introductions, plant importers have begun to assess the risk of invasiveness, mark invasive species in catalogs or lists, or both (e.g., Heronswood Nursery, as mentioned above). At least two relatively easy, quantitatively based methods of risk assessment are available to horticulturists (Rejmánek and Richardson 1996, Reichard and Hamilton 1997), primarily for use with woody species. These methods employ discriminant analysis models of plant traits to evaluate risk; Reichard and Hamilton (1997) also include a nonquantitative model that nonscientists find easy to use. The Australian government has developed an extremely useful risk assessment process (see www.aqis.gov.au/docs/plpolicy/wrmanu.htm). The American Nursery and Landscape Association endorses a statement and a working group supporting risk assessment, although it is unknown how many of the association's members are actually using this approach.

One of the major stumbling blocks in any risk assessment method is gathering the needed information. Several efforts are under way to develop databases that may ultimately deal with such information needs, but in the meantime ecologists, especially those at universities, could work with horticulturists to gather the requisite published or experimental data.

Reduction in the distribution of existing invasive species. It is in the best interests of the horticulture industry to recognize that consumers are becoming opposed to the idea of buying invasive species. One of us, S. H. R., recently surveyed participants of six horticulturally oriented Internet discussion groups that focused on commercial horticulture, woody plants, gardening in the Pacific Northwest, perennials, and organic and general gardening, as well as a small group participating in a tour of nurseries in the Seattle area. There was only one criterion for participation in the survey: Respondents must have purchased plants from a nursery within the last year. One hundred fifty-seven people responded: 137 from the United States (32 states), 15 from Canada, three from New Zealand, and one each from Ireland and Norway. Although those responding may have been predisposed to be interested in or knowledgeable about invasions and thus motivated to respond, the circumstances differ little from those of any other telephone or mail survey in which respondents must agree to participate. Most of the respondents were female (81%). All but 4% were 31 years of age or older, with 83% between 31 and 60 years old, the ages at which most

people generate their highest level of disposable income. In fact, 44% estimated that they had spent over \$400 on plants in the previous year, a fairly considerable amount for an individual gardener. Seventy-five percent described themselves as avid amateur gardeners, while 15% said they were casual gardeners and 10% were horticulture professionals. Ninety-two percent described themselves as "very much" to "quite a bit" concerned about the environment in general, but familiarity with the issue of biological invasions was more limited, with 3% reporting they had no familiarity, 8% reporting a little familiarity, 21% reporting that they were somewhat familiar, 28% quite familiar, and 40% very much familiar with biological invasions.

Five questions relating to invasive plants and nurseries were asked, as well as demographic questions. Questions were scored on a response scale of not at all, a little, somewhat, quite a bit, and very much.

Question 1: Is it important to you to buy plants that will not become invasive?

Despite their apparent overall concern for the environment, many customers still buy invasive species, apparently because they do not know which species should be avoided; 83% of the respondents said that it was "quite a bit" to "very much" important to them that they not buy invasive plants. Ninety-two percent of those who expressed familiarity with the issue of biological invasions also expressed a strong preference to not buy invasive species, while only 52% of those who said they were not at all to somewhat familiar with the issue said they had a strong preference to not buy invasive plants.

The correlation between level of familiarity and buying preference is important, because the public is becoming increasingly aware of biological invasions through the accelerating frequency of articles in the popular press. A search on the Lexis-Nexis® database of popular press articles using the terms *alien species*, *alien plants*, *exotic species*, *exotic plants*, *non-native species*, and *nonnative plants* indicates that the number of articles on the subject has been increasing dramatically since the mid-1980s (Figure 1). This trend is likely to continue. Of those who said they were familiar with the invasives issue, 68% reported that they had become familiar with it by magazine and newspaper stories. This fact is important: Because the preference to buy noninvasive species is correlated with familiarity, as the general plant-buying public becomes more aware of invasions, nurseries and the seed trade industry will have to alter their practices to ensure that invasive species are not sold. To do otherwise would risk their reputation as environmentally friendly concerns.

Question 2: If your nursery did not sell a species listed as invasive, would you seek it out from another nursery?

This question addresses a common assertion by nursery owners that they must sell invasive plants to remain competitive; if customers did not find a species in their nursery, they would just go to the next nursery and buy it. However, 92% of the respondents said that they would definitely not seek out

invasive species; the remaining 8% said they would do so sometimes or very often.

A key problem, therefore, is how to inform people about invasive plant issues. Some nonprofit groups such as the Exotic Pest Plant Councils and Native Plant Societies already have lists of nonnative species to avoid; the difficulty lies in making those lists widely available. Of course, distribution to members is helpful, but the information may not reach the general public. Listings on Web sites are accessible only to the technologically advanced and environmentally aware.

In some places (e.g., Florida, Minnesota, Australia) groups are working with the nursery industry to identify species that could be taken off the market voluntarily by the nurseries. The next step is to inform the public. These species could still be offered to the public, but with a tag warning that it is a known invader and the buyer should use caution to prevent escapes. Alternatively, the nurseries could remove the agreed-upon species, using that removal as self-promotion. Finally, an independent group could anonymously inspect nurseries to see whether the agreed-upon species are being sold and, if they are not, issue certificates for posting in the nursery and put out press releases that the nursery could use in advertisements. The purpose of the following three questions was to determine which method of notification consumers prefer.

Question 3: Would you prefer to shop at nurseries that label known invasive species?

This method of informing consumers is analogous to the marking of species on mail-order nursery catalogs and the index seminum of botanical gardens. Consumers would still have the option of buying a species, but they would at least know that the plant could be a problem in the future. Ninety-eight percent reported that they were “not at all” to “somewhat” likely to buy a plant if it were labeled as invasive, leaving only 2% saying that they were very likely to buy the plant.

Question 4: Would you prefer to shop at nurseries that advertise “We sell only approved nonweedy plants?”

Nurseries that remove invasive species from their inventories would be reducing the distribution of invasive species, a public service that could be advertised to attract environmentally aware customers. It would allow customers to buy plants from the nursery without worry. There was no clear consensus in the responses. Overall, 63% said they would “very much” to “quite a bit” like to shop at such nurseries, but the remaining 38% said “not at all” to “somewhat.” Shopping at such nurseries was popular with those who were familiar with the issue (92% of them preferred it, compared with 26% of those who were not familiar with the issue). This option was preferred also by those who described themselves as “casual gardeners” (57%), perhaps indicating that they do not feel they have the experience to decide themselves what they should not buy; only 46% of “professional gardeners” preferred those nurseries.

Question 5: Would you prefer to shop at nurseries that have been certified by an independent group as being “forest friendly” (or something similar) to indicate that they do not sell identified invaders?

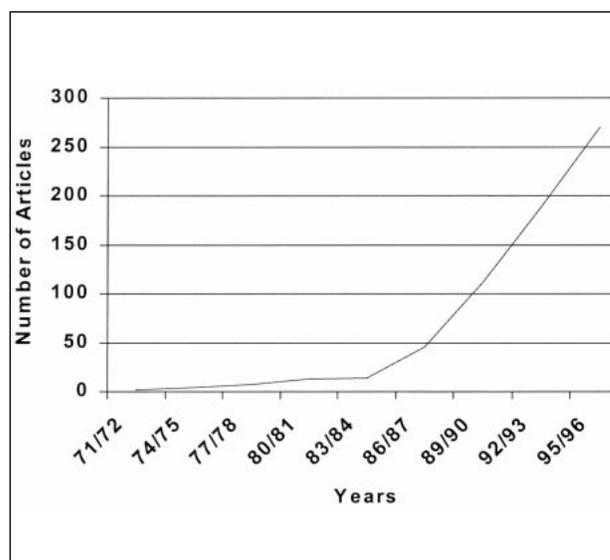


Figure 1. Number of nonscientific articles written about biological invasions.

A pilot project in New Zealand used a group of off-duty government officials and nonprofit groups to inspect nurseries. Nurseries that did not sell species agreed upon by cooperating nurseries and the nonprofit group to be invasive were given certificates identifying the nurseries as “forest friendly.” The advantage of such an approach is that certification, which is granted only when a nursery meets objective standards set by an outside panel, is valuable for advertising purposes. Overall, 68% of the respondents said they would prefer to shop in these nurseries “quite a bit” to “very much,” while 32% said only “somewhat” or “not at all.” Unfortunately, the “forest friendly” certificates are no longer awarded in New Zealand because a majority of retail and wholesale outlets did not agree to join the project. Those who did not join thus had a wider range of plants to sell. This program did, however, begin the dialogue between the government and the nursery industry, which led eventually to a ban on the sale of 130 taxa (Jack Craw [Northland Regional Council, New Zealand], personal communication, 1999).

Two key points stand out from the results of this survey. First, to reduce sales of invasive plants, the buying public has to be educated about the problems that nonnative plants cause in natural areas. Once people are informed about the dangers of invasive plants, they apparently do not want to contribute to the problem. Given the steep rise in the number of popular articles on invasions over the last 15 years (Figure 1) and the likelihood that this trend will continue, consumer demand to reduce sales of invasives will most likely grow. Those who are knowledgeable about invasions could contribute to the effort to reduce sales by writing articles and speaking to community and gardening groups. The second key point is that, although there is support for all methods of informing the public about invasive garden plants, the preferred method is probably to label the species in the nursery as invasive.

Ecologists and horticulturists might work together to establish which species should be labeled and how.

Ecology, conservation, and horticulture: Working together

It is conventional wisdom that most human beings resist change; horticulturists are no different from all other humans in this respect. They have been introducing plants in essentially the same way for 400 years, and the romance of plant exploration is as strong as that of any other type of exploration. Over the last several years, however, with increasing evidence about the impacts of invasive species, nurseries and botanical gardens have been open to change (Morin 1999).

Creating a divisive us-vs.-them mentality will do nothing to resolve the conflicts that seem to regularly spring up between ecologists working on protection of natural areas and horticulturists wanting to bring new plants into the landscape palette. Dialogue between the two groups will lead to solutions; finger pointing will not. It is therefore important for ecologists to understand and to address some of the key objections of horticulturists.

Objection 1: Not growing invasive species means that we can grow native species only, and that is too limiting. Besides, it follows the Nazi dictate that only German native species should be grown (Pollan 1994).

It is important to emphasize that the issue is not natives vs. nonnatives but invasive nonnatives vs. noninvasive species, including most nonnatives. Whether it is beneficial to promote the use of native species in horticulture is a separate issue and a controversial one. By confusing the two, those who support anti-invasive species policies have gotten caught up in the backlash against the native plant movement (Koller 1992, Pollan 1994), an unproductive detour. Invasive nonnatives are a small portion of the total group of nonnative species available to horticulturists. There is no “ethnic cleansing” aspect to the argument that nonnatives that are used in the landscape should be noninvasive. Plenty of nonnative species would still be grown and available.

Objection 2: Invasive plants invade only disturbed areas, such as those around roads and shopping malls.

Many invasive plants do exploit the reduction in competition following disturbance, but this is not always true. Several species, such as *Alliaria odorata* (garlic mustard), *Hedera helix* (English ivy), and *Geranium robertianum* (herb robert), appear to invade and affect areas with no apparent disturbance. And, although some speculate that areas of low species richness are more easily invaded (Darwin 1859, Elton 1958), Stohlgren and colleagues (1999) found that in many locations, areas of high species richness are invulnerable. They report that invasion may be more closely related to available resources in the community (which may be great in areas of high biodiversity) than to species richness.

It should also be understood that disturbance is a natural part of many ecosystems (White 1979, Pickett 1980, Hobbs

and Huenneke 1992). Fire, hurricanes, landslides, floods, earthquakes, and many other events are disturbances that are crucial to the maintenance of the systems in which they periodically occur. Introduced invasive species capable of exploiting disturbance may be able to recolonize more rapidly than native early-successional species; moreover, because the invaders often reach reproductive age quickly and reproduce vegetatively (Reichard 1997), they can increase the population rapidly, to the point of excluding native species.

Objection 3: Invasive plants can also be native species.

Indeed, some native plants can certainly be considered invasive. When they are considered invasive they must be managed, just like nonnative invasive species. However, native weeds do not reduce global plant diversity by replacing healthy native plant communities with aggressive nonnative species. The worst invaders, with the highest impact, are intercontinental.

Objection 4: Invasions are natural occurrences. Plants have always migrated into new areas. (Related objection: Humans are natural animals, so why are we considered to be unnatural plant dispersers? And aren't we the most invasive organism of all?)

Fires, treefall, and floods are all natural occurrences too, but they are managed so that harmful effects are limited. As with so many other “natural” environmental processes, humans change the scale of species introductions. Take, for example, Hawaii, the most isolated island chain in the world. Estimates put the natural rate of successful introductions resulting in “wild” populations at one species every 100,000 years (Fosberg 1948); the 1,094 native flowering plants now in Hawaii originated from approximately 270 to 280 successful colonization events (Wagner et al. 1990). When the Polynesians colonized the islands about 1500 years ago, they brought several species with them, and the rate quickened to one introduction every 50 years. In contrast, approximately 4988 species (both angiosperm and gymnosperm) have been introduced to the islands since European colonization, a rate of about 22 taxa per year (St. John 1973). At least 869 of the introduced species have been established in the last 200 years (Wagner et al. 1990). At this recent rate of introduction, native communities are overwhelmed with new species that are often very aggressive. Hawaii, because of its isolation and island ecology, may be an extreme case, but the rate of introductions carried out by humans over the past few centuries around the world is clearly far higher than the natural rate of dispersal.

The related objection may also be answered with a similar explanation. The rate at which humans disperse plants is not natural. For most of human history, humans moved relatively few plants by migration by foot, pack animals, or small boats, and they moved them across relatively small distances, without the aid of hundreds of jumbo jets and container ships that transport people and cargo around the world daily. And yes, humans are invasive organisms. But a harmful in-

vasive plant transported by an invasive animal does not change the potential impact of that invasive plant.

Finally, it should be pointed out that natural migrations of plants usually are from one area to a contiguous area, both of which are within natural barriers in the “coevolutionary envelope”—that is, such migrations are usually accompanied by the simultaneous movement of natural enemies, including specialized pathogens and herbivores that attack or feed on one or a few plant species. Most harmful invasions are across broad, discontinuous landscapes.

Objection 5: Anti-invasive policies are bad for the nursery industry.

This statement is not accurate for several reasons. First, as shown above, consumers increasingly wish to be informed of invasive ability so that they can avoid purchasing invaders. If the nursery industry wants to continue to be perceived as a “green” industry, it will have to recognize this trend and respond appropriately to it. Second, invasive plants are a small part of the sales of most nurseries, so removing them from sale is unlikely to have a significant effect on the business’s bottom line. Third, removing invasive plants from sale could actually stimulate sales, if handled correctly, because replacement plants would be promoted and sold. How many landscapes use *Hedera helix* (English ivy), an invasive species along the west coast and parts of the east coast, as a groundcover? What if consumers were encouraged to remove that species and plant with a noninvasive species? Finally, advertising that a nursery sells only noninvasive species could attract customers, as the survey discussed above revealed.

Objection 6: I can grow invasive species because I can prevent them from setting seed or growing vegetatively outside my property.

This perhaps well-intentioned thought is naive. Perhaps some smaller plants can be controlled for a time by removing seed heads and confining rhizomes, but control is impossible for larger plants over a long period of time. Larger plants may grow to a size beyond the reach and capabilities of the grower. And over time, circumstances change—people become ill, move away, sell their land to less vigilant property owners, among other things—and thus even the most conscientious of gardeners may prove unable to maintain control. A destructive invasive species should not be grown.

Objection 7: Restrictions against invasive plants may be needed, but they should be imposed only on a regional or state level.

The answer to this objection is yes—and no. It is true that most species do tend to invade only certain areas of the country. It may be possible to restrict the sale of existing invaders in only those regions where they can escape and establish outside of cultivation. Each bioregion could have a coalition of ecologists and horticulturists to determine which species could reasonably be removed and establish a time frame in which to do it. However, for species not yet introduced or established

in the country but judged likely to escape and become a pest in some region, the restrictions should be enacted at the national level. North America includes just about every type of climate and soil imaginable. Once a species has entered the United States, it may spread very quickly through the horticultural channels described above. Thus, the probability that it would arrive in the region to which it is best suited to invade is high. Screening of new introductions must be done with that likelihood in mind.

Working together

Although the horticultural industry is responsible in part for the introduction of invasive species, the burden of finding a solution to the problems posed by invasive plants does not necessarily fall on the shoulders of that industry. It is in various groups and disciplines working together and adding their strengths that some solutions may be found. In the summer of 1997 the American Nursery and Landscape Association and the Weed Science Society of America brought together ecologists from the Nature Conservancy, the University of Washington, and the University of Florida with representatives from a number of horticulture service and trade organizations to discuss possible areas of agreement and collaboration. The grounds for collaboration of these diverse groups have been laid and some state and regional dialogues begun. The dialogue needs to continue, with several positive goals in sight. Among these goals are the following:

- The collected and analyzed data about the impacts and biology of invasive plant species needs to be shared with horticulturists, who need solid facts upon which to base informed decisions. And in many cases horticultural enterprises are ideal for transmitting that information to consumers. There also needs to be more effort to involve and educate garden writers, the “tastemakers” (Dozier 1999), so that their writings do not support problem plants but do address the issue of invasions.
- Botanical gardens should take a leadership role in efforts to prevent more damage by invasive plant species. The American Association of Botanical Gardens and Arboreta has sponsored symposia on invasive plant species at its annual meetings for the last several years. At the 1999 meeting in Vancouver, British Columbia, the North Carolina Botanical Garden (NCBG) issued the “Chapel Hill Challenge” (see the box on the next page), a code of conduct for botanical gardens. NCBG has a primarily native plant focus, but its code can easily be adapted to gardens or nurseries with a less restrictive policy. It can also be adapted to gardens that lack the resources for some undertakings mentioned in the code, such as risk assessment, but can participate in other beneficial efforts. In other words, a garden could adopt the entire code of conduct or only those parts most relevant to its mission and activities. Like a Hippocratic oath for botanical gardens, the code asks that gardens first do no harm to plant diversity and natural areas. Most botanical gardens and many nurseries already have education programs and publi-

cations and could easily supplement these with classes and articles on new invaders in the region, information on how to avoid buying invasive species, and so on.

- More generally, the botanical garden and nursery communities should adopt a code of “conservation ethics” to which their members would subscribe. That code might encompass several conservation issues. Specific to the issue of invasions, a code might prohibit smuggling material, encourage monitoring to assure that imported material is free of disease and contaminants, and ask that recipients of seeds in exchanges be informed that certain species have demonstrated invasive ability and urged to exercise caution. This work is under way for botanical gardens.
- Horticultural businesses that plant existing invasive species, even though they do not introduce new plants, should be informed of the dangers of the invasion potential of new introductions. This includes landscape architects and landscape gardeners. Most effort has been placed on getting the message to nurseries and botanical gardens, but those specifying and planting invasive species should be a priority for inclusion in finding solutions.
- Invasive plants should be removed from sale. Such an approach may be pursued regionally, with groups of ecologists and horticulturists working together. The exotic pest plant councils forming in many parts of the country may be the appropriate organizations to take the lead, working with state nursery associations, as has been accomplished in Florida.
- Horticulturists should be encouraged to prescreen new introductions and given assistance in that endeavor. Prescreening may be beyond the resources of nurseries or botanical gardens. If this is true, ecologists should attempt to work with the nurseries to use best-practice methods of risk assessment.
- A national plan should be developed to deal with invasive species in the horticulture industry. Australia released a draft plan in February 1999 that has several useful components, including development of regulations, education programs, plant lists, logos and slogans, and plant labeling. The United States should develop and implement such a plan, using input from weed scientists, ecologists, government officials, and horticulturists.
- The public should be involved in eradication efforts in natural areas. Land managers should encourage public participation in weed control, especially in high-profile areas. The survey previously noted found that 53% of the respondents who reported familiarity with invasions knew of them from direct observation and experience. A survey in the Southeast found that 62% of those who could name a plant invader knew of it through personal observation (Dozier 1999). Participation in control efforts will also impress people with the difficulty of eradicating a garden plant “turned bad.”

The “Chapel Hill Challenge,” a proposed code of ethics for botanical gardens and arboreta:

Do no harm to plant diversity and natural areas.

Perform risk assessment for introductions.

Remove invasives from plant collections.

Control invasives in natural areas.

Develop noninvasive and native alternative plant material.

Do not distribute plants and seeds that will be invasive elsewhere.

Educate the public.

Become partners with conservation organizations.

- Finally, the gardening public must be educated—perhaps the most critical need in the future. Gardeners are often unable to understand that the consequences of buying a plant for their backyard may contribute to biological invasions (Colton and Alpert 1998). As we have previously indicated, however, 92% of the survey respondents familiar with invasive species do not want to purchase them. Better communication from ecologists to the public about which species are causing problems will discourage people from buying them. This means ecologists should offer to write articles for the popular press, give talks to garden clubs, and work with the horticulture community to disseminate information. It is important that efforts continue to integrate ecological and horticultural perspectives.

Acknowledgments

We thank Amy Rossman and Mark Lonsdale for inviting us to participate in the American Institute of Biological Sciences symposium at the International Botanical Congress. Thanks go also to Hallie Dozier for sharing unpublished information from her PhD dissertation. We gratefully acknowledge the valuable comments of Charlie Lamoureux, Scott Medbury, John Randall, Rebecca Chasen, and four anonymous reviewers. Part of the work was done under a grant from the Horticultural Research Institute to S. H. R. We dedicate this article to the memory of Charlie Lamoureux, horticulturist and conservationist.

References cited

- [ASTA] American Seed Trade Association. 1999. Position statement on invasive species. (28 October 1999; www.amseed.com/documents/invasive102899_1.html)
- Baker HG. 1986. Patterns of plant invasion in North America. Pages 44–57 in Mooney HA, Drake JA, eds. Ecology of Biological Invasions in North America and Hawaii. New York: Springer-Verlag.

- Blackburn W, Knight RW, Schuster JL. 1982. Saltcedar influence of sedimentation in the Brazos River. *Journal of Soil and Water Conservation* 37: 298–330.
- Bock JH, Bock CE. 1992. Vegetation responses to wildfire in native versus exotic Arizona grassland. *Journal of Vegetation Science* 3: 439–446.
- Campbell FT. 2001. The science of risk assessment for phytosanitary regulation and the impact of changing trade regulations. *BioScience* 51: 148–153.
- Carmen JG, Brotherson JD. 1982. Comparison of sites infested and not infested with saltcedar (*Tamarix pentandra*) and Russian olive (*Elaeagnus angustifolia*). *Weed Science* 30: 360–364.
- Colton TF, Alpert P. 1998. Lack of public awareness of biological invasions by plants. *Natural Areas Journal* 18: 262–266.
- Cousens R, Mortimer M. 1995. The dynamics of geographic range expansion. Pages 21–54 of *Dynamics of Weed Populations*. Cambridge (UK): Cambridge University Press.
- D'Antonio CM, Vitousek PM. 1992. Biological invasions by invasive grasses, the grass/fire cycle and global change. *Annual Review of Ecology and Systematics* 23: 63–87.
- Darwin C. 1859. *The origin of species*. Reprint. New York: Penguin Books.
- Dozier H. 1999. Plant introductions and invasion: History, public awareness, and the case of *Ardisia crenata*. PhD dissertation. University of Florida, Gainesville, FL.
- Elton CS. 1958. *The Ecology of Invasions by Animals and Plants*. London: Methuen.
- Everest JW, Miller JH, Ball DM, Patterson MG. n.d. Kudzu in Alabama: History, uses, and control. Alabama Cooperative Extension Service. Circular no. ANR–65.
- Ewan J. 1969. *A Short History of Botany in the United States*. New York: Hafner Publishing.
- Fosberg FR. 1948. Derivation of the flora of the Hawaiian Islands. Pages 107–119 in Zimmerman EC, ed. *Insects of Hawaii*, Vol. 1. Honolulu: University of Hawaii Press.
- Groves RH. 1998. Recent Incursions of Weeds to Australia 1971–1995. Australia: Cooperative Research Centre for Weed Management Systems. Technical Series no. 3.
- Hedrick UP. 1950. *A History of Horticulture in America to 1860*. Portland (OR): Timber Press.
- Hester AJ, Hobbs RJ. 1992. Influence on fire and soil nutrients on native and non-native annuals at remnant vegetation edges in the Western Australian wheatbelt. *Journal of Vegetation Science* 3: 101–108.
- Hobbs RJ, Huenneke LF. 1992. Disturbance, diversity, and invasion: Implications for conservation. *Conservation Biology* 6: 324–337.
- Hobhouse P. 1992. *Gardening through the Ages*. New York: Simon and Schuster.
- Huenneke LF, Thomson JK. 1994. Potential interference between a threatened endemic thistle and an invasive nonnative plant. *Conservation Biology* 9: 415–425.
- Huxley A. 1978. *An Illustrated History of Gardening*. New York: Paddington Press.
- Kay SH. 2000. Water Gardens, Aquascaping, Lake Restoration, and Aquatic Weeds. (10 April 2000; www.cropsci.ncsu.edu/aquaticweeds/comturf/turf.htm)
- Kloot PM. 1987. The naturalized flora of South Australia, 3: Its origin, introduction, distribution, growth forms and significance. *Journal of Adelaide Botanic Gardens* 10: 99–111
- Koller G. 1992. Native dictates. *Arnoldia* 52: 23–32.
- Kowarik I. 1995. Time lags in biological invasions with regard to the success and failure of alien species. Pages 15–38 in Pysek P, Prach K, Rejmánek M, Wade M, eds. *Plant Invasion—General Aspects and Special Problems*. Amsterdam: Academic Publishing.
- Lyte C. 1983. *The Plant Hunters*. London: Orbis Publishing.
- Mack RN. 1991. The commercial seed trade: An early disperser of weeds in the United States. *Economic Botany* 45: 257–273.
- Manks DD. 1968. How the American nursery trade began. Pages 4–11 in Manks DS, ed. *Origins of American Horticulture: A Handbook*. New York: Brooklyn Botanic Garden.
- Meyer PW. 1987. A case for plant exploration. *Public Garden* 2: 6–8.
- Melgoza G, Nowak RS, Tausch RJ. 1990. Soil water exploitation after fire: Competition between *Bromus tectorum* (cheatgrass) and two native species. *Oecologia* 83: 7–13.
- Mesléard F, Ham LT, Boy V, van Wijk C, Grillas P. 1993. Competition between an introduced and an indigenous species: The case of *Paspalum paspaloides* (Michx) Scribn. and *Aeluropus litoralis* (Gouan) in the Camargue (southern France). *Oecologia* 94: 204–209.
- Morin N. 1999. Solving the invasive plant problem. *Public Garden* 14: 16–17.
- National Plant Board. 1999. Safeguarding American plant resources: A stakeholder review of the APHIS-PPQ safeguarding system. National Plant Board.
- [OTA] Office of Technology Assessment. 1993. *Harmful Non-Indigenous Species in the United States*. Washington (DC): Office of Technology Assessment, US Congress.
- Pickett STA. 1980. Non-equilibrium coexistence of plants. *Bulletin of the Torrey Botanical Club* 110: 107–119.
- Pimentel D, Lach L, Zuniga R, Morrison D. 1999. Environmental and economic costs associated with non-indigenous species in the United States. (12 June 1999; www.news.cornell.edu/releases/Jan99/species_costs.html)
- Pollan M. 1994. Against nativism. *New York Times Magazine*, 15 May 1994.
- Rapaport E. 1991. Tropical vs. temperate weeds: A glance into the present and future. Pages 215–227 in Ramakrishnan PS, ed. *Ecology of Biological Invasions in the Tropics*. New Delhi (India): International Scientific Publications.
- Reichard SH. 1997. Prevention of invasive plant introductions on national and local levels. Pages 215–227 in Luken JA, Thieret JA, eds. *Assessment and Management of Plant Invasions*. New York: Springer.
- Reichard SH, Hamilton CW. 1997. Predicting invasions of woody plants introduced into North America. *Conservation Biology* 11: 193–203.
- Rejmánek M, Richardson DM. (1996). What attributes make some plant species more invasive? *Ecology* 77: 655–661.
- Scott JK, FD Panetta. 1993. Predicting Australian weed status of southern African plants. *Journal of Biogeography* 20: 87–93.
- Slate GL. 1968. The plant discoveries of Ernest H. Wilson. Pages 72–74 in Manks DS, ed. *Origins of American Horticulture: A Handbook*. New York: Brooklyn Botanic Garden.
- St. John H. 1973. List and summary of the flowering plants in the Hawaiian islands. *Pacific Tropical Botanical Garden Memoir no. 1*. Lawai (HI): Pacific Tropical Botanical Garden.
- Stohlgren TJ, Binkely D, Chong GW, Kalkhan MA, Schell LD, Bull KA, Otsuki Y, Newman G, Bashkin M, Son Y. 1999. Exotic plant species invade hot spots of native plant diversity. *Ecological Monographs* 69: 25–46.
- Thompson JD. 1991. The biology of an invasive plant: What makes *Spartina anglica* so successful? *BioScience* 41: 393–401.
- [USDA] US Department of Agriculture. 1999. *Agriculture Income and Finance Situation and Outlook*. Washington (DC): USDA.
- Vitousek PM, Walker LR, Whiteaker LD, Mueller-Dombois D, Matson P. 1987. Biological invasion by *Myrica faya* alters ecosystem development in Hawaii. *Science* 238: 802–804.
- Wagner WL, Herbst DR, Sohmer SH. 1990. *Manual of the flowering plants of Hawai'i*, Vol. 1. Honolulu: Bishop Museum.
- White PS. 1979. Pattern, process, and natural disturbance in vegetation. *Botanical Review* 45: 229–299.
- Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E. 1998. Quantifying threats to imperiled species in the United States. *BioScience* 48: 607–615.
- Williams MC. 1980. Purposefully introduced plants that have become noxious or poisonous weeds. *Weed Science* 28: 300–305.
- Williamson MH, Brown KC. 1986. The analysis and modeling of British invasions. *Philosophical Transactions of the Royal Society, London, Series B* 314: 505–521.
- Wyman D. 1968. The introduction of plants from Europe to America. Pages 12–16 in Manks DS, ed. *Origins of American Horticulture: A Handbook*. New York: Brooklyn Botanic Garden.
- . 1969. *Shrubs and Vines for American Gardens*. London: Macmillan.
- Wyndham J. 1951. *The Day of the Triffids*. New York: Ballantine Books.