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Where Do We Go From Here? The Challenges of Risk Assessment for Invasive Plants[1]

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Abstract: Exotic species invasions in natural areas are one of the most significant threats to biological diversity globally. Pest plants pose a significant problem because they often go undetected until widespread ecological damage has already occurred. Effective control is both uncertain and expensive. However, not all introduced species become invasive, leading to the hope that we can develop risk assessment criteria for new plant introductions. Two recently proposed assessment programs are reviewed, one based on North American woody plants and the other based on Australian pest species, and the challenges in their application are discussed. Among the significant issues are spatial and temporal variation in plant performance that affect the documentation of invasive behavior and the tendency for horticulturists to value traits that produce invasive behavior (rapid growth, early and consistent flowering, lack of pests and diseases, and vegetative persistence). Two policy alternatives are suggested for botanical gardens as examples of models for plant introduction policies that could be adapted to other institutions: the Conservation Aware Garden and the Strict Conservation Garden. The former is based on risk assessment, whereas the latter prohibits movement of species across barriers to their dispersal. Information needs, the importance of international communication, and adaptive management are discussed as elements of a program to reduce the spread of pest invaders.

Additional index words:—Exotic plant species, new plant introductions, pest invaders, weediness characteristics, AMOAR, BROTE, SCITE, ALAPE, LONJA, PUELO, MLAQU, LYTSA, ELGAN, SENJA, TAAAP, EICCR.

INTRODUCTION

Exotic plant invasions are a major threat to natural areas and populations of native species (U.S. Congress, Office of Technological Assessment 1993). These pest species were introduced to new areas both intentionally and through the inadvertent movement of individuals and propagules. The inadvertent movements are called "accidental," although "careless" was proposed as a better descriptor (Cairns and Bidwell 1996). Intentional introductions are also careless in the sense that they are carried out with little regard to problems they cause (White 1997).

In North America, almost all woody plant invaders of natural areas were originally introduced intentionally for such purposes as ornament, erosion control, wildlife foods, forestry, and agriculture (Reichard and Campbell 1996). Botanical gardens, the nursery industry, government agencies, and private collectors have sought new plants from other parts of the world and have then promoted these in the commercial trade. Botanical gardens also often distribute plants to distant lands. The time has come to assess the environmental consequences of introductions and distribution programs and establish policies and practices that will lower the risk of introducing additional pest species (White 1997).

The worst exotic pest species have been the result of intercontinental introductions, presumably because of release from natural control factors. Herewith, a narrow definition of "exotic" to refer to species from other continental landmasses is employed. Minimizing the exotic plant threat to biological diversity motivates the discussion that follows, but such invasions also cause direct threats to human life and property, as well as direct economic losses measured in the millions of dollars (Reichard and Campbell 1996). Beyond their direct impact, exotic invasive plants can also introduce indirect threats to natural areas through such control practices as herbicide use, habitat manipulation, and the release of yet additional species as biological control agents. The focus is invasive plants themselves rather than related problems, such as the introduction of insect pests and plant diseases, that have sometimes accompanied plant introductions and hybridization with native species. The risks

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Table 1. Variation in exotic plant impact.[a]

Degree of exotic plant impacts on biological diversity
Species that do not persist after cultivation; domesticated species dependent on cultivation
Species that persist after cultivation but do not spread
Species that spread locally after cultivation by vegetative means but not by seed
Species that spread locally after cultivation by seed or seed and vegetative means
Species that spread only in human-created habitats: roadsides, lawns, fields
Species that spread into native habitats but do not reduce native species
Species that spread into native habitats, reduce or eliminate native species
Species that spread into native habitats, change ecosystem function, alter composition, and reduce or eliminate native species

[a] Adapted from White (1998).

of specialized pests and hybridization are predominantly a problem caused by species that are closely related to, usually congeneric with, native species.

Not all species from other continents become invasive pests of natural areas (e.g., Williamson and Fitter 1996). This leads to the question: What is the risk that a proposed plant introduction will become an invasive pest? The purpose of this essay is to organize and discuss the issues involved in accomplishing this risk assessment. Proposed policy alternatives are presented for botanical gardens as models for policies for any plant introduction and distribution activity. Information needs, the importance of international communication, and the need for adaptive management are discussed.

EXOTIC PLANT IMPACTS AND THE IMPORTANCE OF PREVENTION

Plant species introduced outside their natural range show wide variation in behavior (White 1998) (Table 1). Domesticated species are often wholly dependent on cultivation and pose no threat to native species—indeed, they depend on human watering, weeding, pest control, and seed dispersal. At the other extreme are exotic plants that cause population declines in native species or may even alter key parameters that underlie ecosystem composition, structure, and function, such as hydrology, soil fertility, and fire regime (Table 2). Invasions by species that alter ecosystem processes can have cascading effects, leading to the decline or extinction of many native species.

It is perhaps self-evident that "an ounce of prevention is worth a pound of cure" with regard to exotic invasions. Westbrooks and Eplee (1996) described seven regulatory strategies of the Animal and Plant Health Inspection Service (United States Department of Agriculture) with regard to weeds (in the past, these have been mostly agricultural weeds): prevention, preclearance, exclusion, detection, containment, eradication, and biological control. Because of the uncertainty and expense that accompany the last four of these, strong policies for prevention, preclearance, and exclusion are key elements of policy. In turn, these three strategies require us to carry out a process of screening or risk assessment for new introductions.

TWO RISK ASSESSMENT SYSTEMS FOR EXOTIC INTRODUCTIONS

Risk assessment for exotic introductions leads to three possible decisions (e.g., Pheloung 1995; Reichard 1997; Reichard and Hamilton 1997): rejection (species with a high probability of becoming a pest), acceptance (species with a low probability of becoming a pest), or holding for further evaluation and monitoring (species whose risk is uncertain). Ideally, one wants to minimize the number of species held for evaluation because such research is expensive and time consuming (Reichard 1997; Reichard and Hamilton 1997) and has uncertainties. How long must we hold the species for evaluation? In what environments should we test the species? How do we assess biological factors that affect plant performance, such as plant density (which has been shown to affect pollination efficiency), pollinators, seed dispersers, herbivores, and

Table 2. Examples of invasive exotic plants that alter ecosystem processes.

Invasive exotic plants	Ecosystem effect
Bunch grass, *Bromus tectorum* L. # BROTE; Brazilian pepper, *Schinus terebinthifolius* Raddi # SCITE; melaleuca, *Melaleuca quinquenervia* (Cav.) Blake # MLAQU	Changed fire regime
Beach grass, *Ammophila arenaria* (L.) Link # AMOAR	Altered sand dune dynamics
Melaleuca; tamarisk, *Tamarix aphylla* (L.) Karst # TAAAP	Lowered water table
Water hyacinth, *Eichhornia crassipes* (Mart.) Solms # EICCR	Raised water table
Many floating aquatics	Altered productivity and species composition
Purple loosestrife, *Lythrum salicaria* L. # LYTSA	Waterfowl populations
Russian olive, *Elaeagnus angustifolia* L. # ELGAN	Wildlife populations
Guava, *Psidium guajava* L.	Exotic animal populations
Wax myrtle, *Myrica* spp.	Soil nutrients (N fixation)
Garlic mustard, *Alliaria petiolata* (Bieb.) Cavara & Grande # ALAPE; honeysuckle, *Lonicera japonica* Thunb. # LONJA; kudzu, *Puereria lobata* (Willd.) Ohwi # PUELO	Reduction in cover, establishment of native plants

Table 3. Relative importance of different kinds of errors in risk assessment.[a]

Outcome	Weeds	Nonweeds
Reject	Good!	Less important error
Evaluate	——— Minimize	———
Accept	More important error	Good!

[a] Incorrectly accepting weeds in plant introduction is a more important error than incorrectly rejecting nonweeds. Policies should attempt to minimize the species held for evaluation and monitoring (Pheloung 1995; Reichard 1997).

pathogens? As others have noted, the possible errors in risk assessment are not equally important: rejecting a nonpest species in error has much lower consequences than accepting a new pest species in error (Pheloung 1995; Reichard 1997; Reichard and Hamilton 1997) (Table 3).

Two of the best systems that have been developed for risk assessment of plants that invade natural areas are Reichard's scheme for woody plants in North America (Reichard 1997; Reichard and Hamilton 1997) and the Australian Weed Risk Assessment System (Pheloung 1995). These two schemes are reviewed below in order to raise the general issues associated with risk assessment. Both have drawn from earlier work on the biology of weediness (e.g., Baker 1974).

Reichard's Risk Assessment for Woody Plants in North America. Reichard developed her approach by comparing 204 woody plant invaders in North America with 87 noninvaders (Reichard and Hamilton 1997). Species in the latter group were chosen from lists of plants cultivated in North America for at least 100 yr but which had no history of invasion. After completing statistical comparisons of these groups, Reichard described a decision tree that would lead to the three outcomes: acceptance, rejection, and holding for evaluation. Her methods would have successfully rejected 85% of the established pest species of North America had these methods been in place before introduction. Her methods suggested that another 13% of the known invaders would have been held for evaluation and monitoring, whereas only 2% would have been released for cultivation. For noninvaders, the methods were less successful, but, as noted above, this is a less serious error: 46% of noninvaders were accepted for cultivation, 18% were incorrectly rejected, and 36% were held for evaluation.

Reichard's criteria for predicting invasion potential included traits related to vegetative reproduction, juvenile period, growth rate, and germination requirements. Evaluation of such traits must be done carefully because of spatial and temporal variation in the physical environment, variation in the biological environment, and genetic variation (Table 4). History of invasiveness else-

Table 4. Potential role of genetic variation (and subsequent natural selection), spatial variation, climatic variation, and geographically correlated plant traits in using Reichard's criteria to assess invasiveness in plant species.[a]

Criterion	Genetic variation/ natural selection	Problem in evaluation
History of invasion		Depends on the locale and history of cultivation
Vegetative reproduction		
Quick vegetative spread		None; a robust criterion
Juvenile period	Y	These traits vary with environment, soil, year-to-year climate fluctuation, and biological environment
< 5 yr (trees)		
< 3 yr (shrubs, vines)		
Rapid growth in first 2 yr	Y	
No pretreatment for germination	Y	Temperate, boreal species need pretreatment

[a] Criteria abstracted from Reichard (1997) and Reichard and Hamilton (1997). Other considerations in Reichard's scheme include history of invasion elsewhere and taxonomic relationships to known invaders (see text for discussion).

where is also an important variable but obviously cannot be applied for first introductions to cultivation. Taxonomic relationship to known invaders can be important but is difficult to use for genera and families with few species or for species that represent the first introduction of a group.

The Australian Weed Risk Assessment System. The proposed Weed Risk Assessment System (Pheloung 1995) is a three-tiered approach and applies to all plants, not just woody plants. The first tier is consultation with a list of prohibited and allowed species and is a combination of what have been called the dirty (known invaders) and clean (known noninvaders) list approaches. If a species is not on these lists, one moves to the second tier: a decision system that leads to the three alternatives, reject, accept, and hold for evaluation. If a species is not rejected and is a new introduction of a species not already on the allowed species list, one moves to the third tier: postentry evaluation.

Pheloung (1995) reported a retrospective evaluation of the system much like Reichard's approach and with similar results: 84% of weeds were rejected (85% in Reichard's scheme), 16% fell in the hold for evaluation category (13% in Reichard's scheme), and none was accepted outright (2% in Reichard's scheme). For nonweeds, the results were somewhat better than Reichard's: 59% were correctly accepted (vs. her 46%) and only 7% were incorrectly rejected (vs. 18%).

The second tier of the Australian Weed Risk Assessment System involves 49 questions in eight categories (Table 5). For each question, a weedy trait is scored one point, a nonweedy trait is scored minus 1 point, and unknown traits are scored 0 points. For acceptance, plants

Table 5. Categories for the 49 assessment questions at the second tier of the Australian Weed Risk Assessment System.[a]

Category	Notes
Domestication/cultivation	Low risk of weediness if domesticated species
Climate/distribution	Environmental match, breadth of tolerance
Undesirable traits	Spiny, burrs, poisons, pollen
Plant type	Free floating aquatics, vines
Weedy elsewhere	Highly predictive of pest species
Reproduction	Correlates with rate of spread
Dispersal mechanisms	Correlates with rate of spread
Persistence attributes	Correlates with survival once established

[a] Adapted from Pheloung (1995).

must have an aggregate score of 0 or less. Plants are rejected if they score 7 or more points and are held for evaluation if they score 1–6 points. Some of the questions are similar to the criteria evaluated by Reichard: persistence attributes (similar to Reichard's finding on vegetative reproduction), reproductive attributes (similar to her finding for short juvenile periods), and weedy behavior elsewhere. The Weed Risk Assessment System involves several other kinds of criteria not used by Reichard: plant type (scrambling and climbing vines and free-floating aquatics are much more apt to be pest species than are other plant types) and plants with undesirable traits (parasites, spines, burs, poisons for people or animals, allergens).

Risk Assessment: A Summary. These two schemes use five kinds of criteria: (1) history of invasive behavior elsewhere, (2) relatedness to species that show invasive behavior, (3) climatic match between original range and proposed introduction area, (4) noxious and undesirable traits, and (5) biological attributes of the plant itself.

The most general and basic form of the assessment problem is represented by the last category. Let us assume that the plant to be evaluated has not been in cultivation before and thus ignore history of invasive behavior. Let us also assume that relatedness to other weeds is a category that results from the absence of knowledge about the plant to be evaluated and is a last resort against mistakes that otherwise would be made. Finally, let us assume that introductions have already cleared the problem of climatic match (if not, they are poor candidates for introduction) and that we can ignore plants whose exclusion is based on human reaction alone (the undesirable species). Thus, we are left with the question: are there any properties that can be observed about the plant species itself that would predict its chance of becoming a pest?

From the two risk assessment schemes described above, along with several other works (Panetta 1993; Rejmanek and Richardson 1996), we define four categories of plant traits that have been correlated with invasiveness and discuss the caveats that must accompany the application of these predictors.

Vegetative growth and reproduction. Pestiness is potentially correlated with the ability to expand quickly through vegetative means (this also spreads the risk of death among more potentially independent "individuals"), the ability to disperse from plant fragments; and the ability to grow quickly once established. Fast inherent growth rates would tend to increase establishment rates when conditions are favorable. For example, vines and clambering plants invest less in the structural material of stems for upright stature but gain in terms of ability to spread quickly in space; they are among the most invasive plant species.

Persistence, tolerance, and recovery. Pestiness is potentially correlated with the ability to sprout or recover vegetatively after injury, the ability to tolerate a wide range of environmental conditions and thus to persist during years that are unfavorable for reproduction until conditions change (this could include climatic conditions as well as the later arrival of pollinators or seed dispersers); the ability to resist herbicides, and the ability to persist as dormant long-lived propagules or underground parts. Ability to tolerate a wide range of conditions increases the chance that dispersal will successfully establish new individuals and those individuals will be able to persist for longer time periods. Ultimately, there is a genetic basis to such tolerance, and selection within the natural range of a species may contribute to this ability. For example, the argument has been made that species from larger native ranges and more species-rich areas should be better invaders than species from narrower ranges or species-poor communities because of higher competitive ability, greater tolerance for variation in environmental conditions, or higher genetic diversity.

Sexual and asexual propagule production and dispersal. Pestiness is potentially correlated with a short juvenile period, consistent and prolific yearly seed production, and good dispersal. Reichard included early age at first flowering in her decision tree (< 5 yr for trees and < 3 yr for shrubs and vines). Self-fertile species (whether monoecious or with perfect flowers) and species that produce seeds without the need for fertilization can be expected to have higher rates of spread because the first individual to establish is sufficient for further seed output and there may be no effect of population density on the efficiency of pollination and seed production. Rejmanek and Richardson (1996) showed that invasive pines tend-

Table 6. Traits that produce successful invasion are often traits that are deemed attractive in horticultural plants.

Traits of successful invaders	Desirable traits for horticultural trade?
Environmentally fit	Yes!
Rapid growth	Yes, both for client and for holding in nursery
Early maturity (flowering)	Yes, both for client and for display
Prolific seed production	Some species (seasonal color, wildlife populations)
Highly successful	
Dispersal	No, except perhaps species for wildlife populations
Germination	Yes, easier to propagate
Establishment	Yes, easier to propagate and hold
Rampant vegetative spread	No, except for soil erosion control species
No major pests	Yes!

ed to have shorter juvenile periods, more frequent seed crops, and smaller seeds than noninvasive pines.

Easy germination and establishment. Pestiness is potentially correlated with the absence of specialized requirements for germination and establishment of new individuals. Lack of pretreatment requirements for germination was one of the predictors in Reichard's scheme. Baker (1974) found that lack of dormancy and unspecialized germination requirements were a general feature of weedy plants.

Traits of Successful Invaders Vs. Desirable Horticultural Traits. Many of the traits that are potentially correlated with invasiveness also make the plants more attractive in horticulture (Table 6). Horticulturists often want plants that are environmentally fit, have no major pests, establish rapidly, flower early, abundantly, and often, and are easy to germinate or propagate vegetatively. Such plants perform well when planted and are easy to grow and attractive when on display for sale in nursery settings (Reichard and Campbell 1996). Perhaps the only invasive traits that horticulturists do not select for are vegetative spread (an exception here is plants grown for erosion control) and seed dispersal. This fact alone should give us pause to consider that exotic species problems will continue if risk assessment is not further developed.

Horticultural selection may also lead to spurious association of invasiveness with certain traits. If horticulturists select for traits of fast growth, early and abundant flowering, and easy germination, there will always be more of these species in the landscape than species with less desirable traits. However, this should not be taken as evidence that species with other traits are noninvasive under the right conditions.

Table 7. Spatial and temporal variation, potential evolutionary response, and likely time lags in the traits used to predict invasiveness.

Predictors of invasions
Innate biological traits
Vegetative growth and reproduction[a]
Persistence, tolerance, and recovery[a]
Sexual and asexual propagule production and dispersal[a,b]
Easy germination and establishment[a]
Biological environment
Plant density[a,c]
Pollination[a,b,c]
Seed dispersal[a,c]
Herbivory[a]
Competition[a]
Invasibility of the community and disturbance
Disturbance[a,c]
Habitat fragmentation[a,c]
Genetic variation and evolutionary change[c]

[a] Spatial and temporal variation expected.
[b] Evolutionary response possible.
[c] Time lags likely

CHALLENGES IN PREDICTING INVASIVE BEHAVIOR

Risk assessment criteria based on traits of the species to be introduced pose several challenges to researchers and practitioners. These challenges (summarized in Table 7) suggest areas for future work.

First, growth rates and juvenile period vary with spatial and temporal variation in the physical environment, including climatic conditions and soil variation. For example, a species that grows poorly in one part of North America, or even within one microclimatic situation or on one soil within a landscape, may grow well in another. A species that grows poorly and fails to reproduce in 1 yr may do well in a year with a different temperature regime or rainfall. Spatial and temporal variation in the environment means that we have to be careful when we assess biological traits. Further, the traits of potential invaders must be judged in a relative sense. Reichard's criterion of fast initial growth rates, for example, can be interpreted only in a relative sense. A fast growth rate in Boston is a slow growth rate in Florida. Thus, our criteria, such as relative growth rate, must be evaluated and adjusted regionally or, for example, within plant hardiness zones.

Second, plant performance varies with the biological environment. Like the physical environment, the biological environment is apt to be both spatially and temporally variable. Some plants have low pollination rates when grown at low density, whereas seed set increases dramatically as density increases. Reproductive output and establishment will also vary with the presence of pollinators and seed dispersers. Growth rates and age at sexual maturity may vary with herbivory (D'Antonio 1993). All of these factors mean that a plant that appears to be noninvasive at some places and times may be invasive at others.

Third, establishment varies with the invasibility of natural communities (e.g., Lodge 1993). In particular, establishment is often fostered by disturbances that remove dominant plants and allow for new establishment (e.g., McEvoy and Rudd 1993). Hobbs and Huenneke (1992) cited both natural and human disturbances that play a role in exotic spread: fire, grazing, soil disturbance, trampling, and habitat fragmentation. Bergelson et al. (1993) showed that disturbance patches increased the rate of spread of the exotic pest common groundsel (*Senecio vulgaris* L. #[3] SENVU).

Fourth and last, traits for predicting invasiveness exhibit genetic variation and are capable of evolutionary change. For example, self fertility may increase in a population grown at low density. Seed output and invasiveness may therefore increase over time. Some genotypes of one species may be well behaved, whereas others act as aggressive weeds.

Variation in the physical environment, variation in the biological environment, infrequent but inevitable disturbance to intact vegetation, and genetic variation all make assessment more challenging. These factors may also contribute to a time lag between the time of introduction and the time that a species is perceived as a widely distributed invasive. This time lag cautions against superficial application of screening criteria. Further, this problem leads to two questions. Over what time frame should we judge invasiveness? After what period of time would time lags be overcome?

Release From Natural Controls and Biological Control. There is one final caveat in using innate plant traits for risk assessment. One frequent explanation of invasive behavior is that invasive plants lack natural control agents: they have been transported without their natural enemy load. Indeed, Schierenbeck et al. (1994) showed that an introduced *Lonicera* had less than one-half the herbivory as a native *Lonicera* in the same habitats. Similarly, Imura and Carstensen (1993) found that herbivory was twice as high on kudzu [*Puereria lobata* (Willd.) Ohwi # PUELD] within its home range in Japan compared with introduced sites in Georgia. That natural enemies can control populations is also supported by the introduction of successful natural control agents, the practice of crop rotation to avoid the build-up of specific pests and diseases, and the fact that many crop plants produce better in other areas of the world than in the native area of their wild relatives.

If release from natural enemies explains invasive behavior, then prediction from the innate biology of the plant introduction will always be problematic. Essentially, the explanation of invasiveness lies, at least in part, in the biological environment of the introduced plant rather than in its own attributes. Even species that spread slowly may saturate their available habitat. We should remember that once an exotic introduction experiment has begun, time is not limiting. On the other hand, innate biological traits may be correlated with the rate of invasion, if not the final outcome. For example, species with slow growth rates, late maturation, small seed crop sizes, specialized germination requirements, and dependence on infrequent natural disturbances may, if released from natural enemies, ultimately reach a saturation of available habitat—but such a species will presumably do so slowly. An important consequence of this reasoning is that slowly spreading species may be more easily controlled.

TWO ALTERNATIVES FOR LIMITING THE RISK THAT PLANT INTRODUCTIONS WILL PRODUCE INVASIVE PEST SPECIES

Risk assessment for plant introductions should be pursued further as a critical research topic. In order to most clearly contrast the consequences of our ability to predict invasiveness, two alternative policies for gardens are outlined (adapted from White 1997): the Conservation Aware Garden, based on risk assessment of plant introduction, and the Strict Conservation Garden, based on a native plant policy (Table 8). Future work and practice will help resolve whether risk assessment adequately protects natural areas from additional pest species.

The two strategies outlined in Table 8 differ on whether risk assessment is possible. The Strict Conservation Garden policy simply circumvents the problem by prohibiting transportation of species across natural barriers. Because the worst exotic problems have resulted from transportation among continents separated by long distance and oceans, and because more subtle natural barriers will be hard to precisely define, the simplest form of this policy would prohibit intercontinental introductions. The policy also carries a clause that would permit movement of species to contiguous areas as an adjustment to climate change and the shifting of hardiness zones.

[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*. Revised 1989. Available from WSSA, 810 East 10th Street, Lawrence, KS 66049-8897.

Table 8. Two sets of policies for plant introduction.[a]

Garden	Standard/explanation
The Conservation Aware Garden	Follow all applicable laws on the prohibitions on the introduction of soils and plants, and follow quarantine procedures; establish stricter policies, if legislation is deemed inadequate to prevent new exotic species problems
	Avoid introducing close relatives that will hybridize with native species and create substantial gene flow to those populations
	Do impact and risk analysis; predict the danger of exotic species impacts from current plantings and introductions; use exotics only if the risk is low and remove known invaders from collections; if prediction is uncertain, develop sound and peer-reviewed monitoring protocols
	Do impact and risk analysis for the distribution of gene pools beyond the region in which they were collected; export plants only to institutions with a compatible exotic species policy
	Develop sterile exotic plant material
	Assume responsibility for impacts in natural areas; form management partnerships with natural areas
The Strict Conservation Garden	Do not transport species and genes across natural barriers to dispersal; do not transport species and genes beyond natural range (unless, at some time in the future, climate change causes a resetting of the geographic range of species, and then transport species only within one continent to sites of appropriate climate); hence, perform no exotic species introductions and do not distribute plants or seeds outside native range
	Grow and promote native plants of a region or physiographic province
	Select for native species and genotypes for specific landscape situations and promote these in horticulture
	Remove exotic plantings
	Assume responsibility for impacts in natural areas; form management partnerships with natural areas

[a] The Conservation Aware Garden policy is based on risk assessment. The Strict Conservation Garden policy is based on avoiding all exotic introductions because of lack of adequate risk assessment (developed from White 1997).

By contrast, the Conservation Aware Garden policy relies on a risk assessment for introduced species and, for species that are allowed under this policy, requires strict adherence to quarantine and inspection policies aimed at excluding insects, diseases, and other pest species that might accompany the introduced plant. That policy also promotes the use of sterile clones of exotic species, a project already undertaken by the Harold L. Lyon Arboretum in Hawaii because of the severe threat posed by exotic invasives in that state. The Conservation Aware Garden policy draws its inspiration from the simple observation that many exotic species are noninvasive and are quite useful to people. For example, crop plants are often dependent on cultivation and are incapable of maintaining wild populations. Many other horticulturally grown species are nonpersistent without human intervention or are persistent but not invasive. Gardeners and horticulturists are less likely to adopt a natives-only policy in the face of this experience.

Risk assessment will require the development of databases and international communication so that species proposed for introduction can be assessed quickly for invasiveness elsewhere in the world, the biological attributes discussed above, and the history, geography, and outcome of past introductions. Successful risk assessment will allow the establishment of a certification program so that gardens and nurseries can make available only certified noninvasive exotics. Lists of both noninvasive (the clean list) and invasive (the dirty list) species can then be formulated and continuously updated. Such a program will allow us to learn from past mistakes (Reichard 1997) and to accumulate the knowledge we need through time. This kind of iterative improvement in policy and practice has been termed adaptive management in the ecological literature. Managing the exotic species problem will require this sort of flexible approach.

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