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

PETER S. WHITE and ALLISON E. SCHWARZ

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 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 promote 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, FUELI, PUEL, MLAQU, YLTS, ELMAN, 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 pro-
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 Pitzer 1996). This leads to the question: What is the potential 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 processes. This variety in behavior varies from aquatic species that dominate standing areas to those that are controlled by variances in soil salinity and water availability. Invasive exotic plants that affect ecosystem processes.

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<thead>
<tr>
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</tr>
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Adapted from White (1998).

Table 2. Strategies of invasive exotic plants that affect ecosystem processes.

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Table 4. Possible uses of genetic variation (and subsequent natural selection) in using Reichard's criteria to assess invasiveness in plant species.

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>Genetic variation/natural selection</th>
<th>Problems in evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestication</td>
<td>History of invasion</td>
<td>Depends on the plant and history of cultivation</td>
<td>Noise, a robust variable. These traits vary with environment and year-to-year climate fluctuations, and biological environment. Then, the genetic variation in adaptation.</td>
</tr>
<tr>
<td>Dispersal</td>
<td>Vegetative reproduction</td>
<td>Quick vegetative spread</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Juvenile period</td>
<td>( &lt;3) yr (3m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rapid growth in first 2 yr</td>
<td>( &gt;0) mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dominance of sexuales</td>
<td>Unclear, because species needs pollination.</td>
<td></td>
</tr>
</tbody>
</table>

where there 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 has been called the dary (known invaders) and clear (known noninvasives) lists. The second tier is establishment of whether the species moves to the third tier: postentry evaluation.

Pheloung (1995) proposed a retrospective evaluation of the system much like Reichard's approach with similar results: 84% of weeds were rejected (85% in Reichard's scheme), 6% fell in the hold for evaluation category (13% in Reichard's scheme), and none was accepted outright (2% in Reichard's scheme). For non-alleles, the results were somewhat better than Reichard's: 59% were correctly accepted (vs. 64% 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 3). For each question, a yes/no test is scored one point, a noweed is scored minus one point, and unknown traits are scored 0 points. For acceptance, plus,


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Vegetative growth and reproduction. Pestness is poten-
tially correlated with the ability to expand quickly
through vegetative means (this also spreads the risk of
dehth among more potentially independent "individu-
als"), the ability to disperse from plant fragments; and
the ability to grow quickly once established. Fast inher-
ent growth rates would tend to increase establishment
rates when conditions are favorable. For example, vines
and clambering plants invest less in the structural ma-
terial 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. Pestness is poten-
tially correlated with the ability to sprout or recover veg-
atively after injury, the ability to tolerate a wide range
of environmental conditions and thus to persist during
years that are unfavorable for reproduction until condi-
tions 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 propagate production and dispersal.
Pestness 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 (less than 5 yr for trees and
less than 3 yr for shrubs and vines). Self-fertile species
(whether monocious 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. Rejmánek
and Richards (1996) showed that invasive pines tend-
ed to have shorter juvenile periods, more frequent seed crops, and smaller seeds than noninvasive plants.

Easy germination and establishment: Pestiness is potentially correlated with the absence of specialized requirements for germination and establishment of new individuals. Lack of pregermination requirements for germination was one of the predictors in Rehfeldt’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). Herbivores 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 (Rehfeldt 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 associations 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.

### 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. 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. Rehfeldt’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...
and 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 1997). In particular, establishment is often fostered by disturbances that remove dominant plants and allow for new establishment (e.g., McDermott and Rudd 1993). Hobbs and Huennekens (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 vulgatus L. # SENVY).

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 causes variance in the use of new variables to screen species. Further, this problem leads to two questions. Over what time frame should we judge invasiveness? After what period of time would the lags be overcome?

Releases From Natural Controls and Biological Control. There is one final caveat in using natural 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 the native Lonicera in the same habitats. Similarly, Imura and Casentinesi (1993) found that herbivory was twice as high on kudzu (Pueraria lobata (Wild.) Ohwi # PUEL) 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 infranatural 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.
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 natures-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 exotic lists. 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 (Beichard 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.

**LITERATURE CITED**


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

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**Table 8: Two sets of policies for plant introduction**

<table>
<thead>
<tr>
<th>Garden</th>
<th>Standard/observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Conservation Aware Garden</td>
<td>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 genetic flow to those populations. Do impact and risk analysis; predict the danger of exotic species impacts from current plantings and introductions; use exotic species only if it is safe 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.</td>
</tr>
<tr>
<td>The Swiss Conservation Garden</td>
<td>Do not transport species and genera across natural barriers to disperse; do transport species and genus beyond natural range (unless, at some time in the future, climate change causes a matching of the geographic range of species, and then transport species only within one continent in times of appropriate climate change, however, 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. Selects for native species and genotypes for specific horticultural situations and promotes these in horticulture. Remove exotic plantings. Assume responsibility for impacts in areas; form management partnerships with natural areas.</td>
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