A place for alien species in ecosystem restoration

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Blanket condemnation of alien species in restoration efforts is counterproductive. Where their presence does not unduly threaten surrounding ecosystems, alien species can be tolerated or even used to good advantage, if they provide essential ecological or socioeconomic services. By speeding restoration or making it more effective, non-native species can provide economic and ecological payoffs. Risk is always an issue when alien species are involved, but greater risk taking is warranted where environmental conditions have been severely modified through human activity than where reassembly of a biological community is the sole goal of restoration.

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Most ecologists and engaged environmentalists justifiably regard invasive, non-native species as a leading threat to conservation values. In the US, for example, they are reportedly the second greatest threat to native species, outranked only by habitat loss (Wilcove *et al.* 1998). Increasingly large, though still inadequate, financial resources are being brought to bear in the campaign against alien species. Many conservationists feel that to achieve success resources should be focused on prevention, eradication, control, and containment.

For various reasons, the "kill them all, always, everywhere" perspective is not shared by a very large segment of society. For every ardent opponent of species introductions there are probably several proponents: those who want to move species around the globe, or at least into their subsection of it, because they are valuable or edible or traditional or beautiful, or any of a host of other motivations. A still greater fraction of society seems indifferent about species introductions, being poorly informed or, when informed, not being engaged by the issue one way or another. Those who care are in the minority.

In a nutshell:

- Eradication of alien species in ecosystem restoration efforts is not always cost-effective
- Certain ecological and socioeconomic needs are better met by alien species than by natives
- Assessment of the risks involved in using alien species is likely to be most effective if all stakeholders, not just restoration ecologists, are involved from the start
- Unnecessary collateral damage can be caused by attempts to eradicate innocuous alien species
- Non-native species present at the start of a restoration program can often be tolerated without harm to the outcome

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A side effect of all-out attacks on an alien species, especially when they preempt resources that might be directed at other conservation activities, can be loss of public support. Restoration is not undertaken in cultural or political vacuums; social forces influence chances for success or failure. In some cases, community support is essential because of the funds or labor provided, while in other cases it simply permits the process to occur unimpeded. Use of species endorsed by the local community can muster support for an effort (Panel 1), just as use of species thought to be useless by the community can reduce the likelihood of unwanted harvesting (Panel 2).

Situations where the use of exotic species might be appropriate

Restoration practitioners miss an opportunity when they divert funds to the eradication, containment, or control of aliens that might in fact be benign players or, in some cases, allies in the restoration process. The use of exotics is not appropriate in all restoration landscapes, but their presence should sometimes be tolerated and there are even circumstances in which they can play positive ecological roles. Sometimes an alien species has little impact on the restoration process (and therefore does not merit expenditure of resources for its eradication), and some may play an important role in community maintenance or development.

Nurse plants

By shielding against intense radiation and heat loading, the light shade cast by some plants can facilitate colonization by others (Parrotta and Turnbull 1997; Lugo 2004); dense growth of shrubs can protect palatable species from large herbivores by providing physical barriers to access; plants that are potentially vulnerable to specialist herbivores can benefit from their reduced apparency, when they colonize within stands of one or more other species;

Panel 1. Alien species of value can improve social acceptance

Societal support for restoration efforts often increases when species regarded by the local community as "useful" are included in the mix. One of the authors (JJE) once had a conversation with the then-President of the Republic of Palau, who upon learning of JJE's interests in forest restoration urged him to "... help our people grow our native trees, like mahogany!" In fact, President Nakamura may have been right (even if mahogany is not native to Palau). For example, the valuable mahogany tree (*Swietenia macrophylla*) was used in the 1930s to reforest mountainous farmlands in Puerto Rico (where it is an alien). There it led to recuperation of forest cover that seven decades later is dominated by native species, though the now-huge mahogany trees still form a conspicuous overstory (Lugo 1992). Would those plantations, whether essentially abandoned as wood producers, as is the case in Puerto Rico, where they are now touted as examples of restoration, or managed to produce a high-value product, as in Fiji, where mahogany exports generate more than US$20 million per year (in foreign exchange) have engendered the support of local people if they were composed entirely of native species? Probably not, though one could argue that in both cases willingness to tolerate the planting of a potentially valuable species was supplemented with land-use enforcement (Puerto Rico) or long-term leases (Fiji) by government agencies.

and neighbors can help shape plant architecture (Jennings *et al*. 2003).

Seed recruitment

Trees and shrubs growing in open areas provide perches for birds and bats that disperse seeds needed to accomplish restoration (Holl 1998; Carrière *et al*. 2002). Alien species can provide the physical structure that makes them acceptable as perches, and the time required to eliminate alien trees or shrubs and replace them with native species of equal stature may be a costly setback.

Provision of fuel

Fine fuels are needed for the frequent, low-intensity fires needed to restore native savanna. Removal of exotic pasture grasses and invasive shrubs is expensive and can result in proliferation of broad-leaved herbs that do not burn well. Using the aliens as fuel while gradually converting the vegetation to native species composition saves money and time (Figure 1).

Secure the site

Alien species that form dense colonies can help reduce invasions by other aliens (D'Antonio and Mack 2001; Kolb *et al*. 2002) or by native species that would slow restoration by preempting resources, by burning too hot or only with difficulty, or by having spines and toxins that make management difficult. Some species of ryegrass (*Lolium* spp), for example, are good candidates to hold sites for short periods (Clewell 1996). Their seeds germinate quickly; they are allelopathic (ie they suppress the growth of other plant species by releasing toxins), a property that can impede colonization by more problematic species; and they are short-lived and non-reproductive in many climates. To hold sites against colonization for multiple years, species such as the deep-rooted, mat-forming perennial peanut (*Arachis glabrata*), which is not sexually reproductive in many locations outside of its home range, are called for.

Trophic relationships

An alien predator that consumes another alien, plant or animal, and controls its population can prevent larger impacts in the food chain. Most biological control involves the use of aliens to consume other aliens; with increased attention being paid to ecological risks, it may now become more widely accepted as a restoration tool (Hoddle 2004; Louda and Stilling 2004). Sometimes biological control is un-planned; in Hawaii, for example, it was found that the most common and widespread alien bird-controlled populations of an alien spider, which in turn was a consumer of native insects (Gruner in press).

Courtesy of V Thaxton

*Figure 1. Fire in an alien shrub, Chinese privet (*Ligustrum sinense*), growing on a fire-maintained pine savanna in the southeastern US.*

*Figure 2. A native Hawaiian honeycreeper, `Apapane (*Himatione sanguinea*) using an alien vine, banana poka (*Passiflora tarminiana*).*

Guide composition

Selective consumption of an alien plant by an alien herbivore can direct succession towards vegetation of a desired life form. In Colombia, for example, light grazing by cattle led to increased shrub dominance, which in turn created a suitable habitat for establishment of native tree species (Posada *et al.* 2000).

Provision of surrogate resources

True restoration of the original ecosystem is sometimes impossible due to extinctions, but can be approximated by using non-native species. In Hawaii, for example, flowers on alien *Passiflora* vines fuel native forest birds (Figure 2), and alien *Psidium* fruits feed the endangered Ala`la (Hawaiian crow). In New Zealand, use of relatives of extinct mammalian predators was advocated as a means of restoring former selection regimes (Atkinson 2001). The need to replenish the full suite of goods and services sometimes arises short of extinction, and not uncommonly this need is met by aliens (Lugo 1988; Westman 1990; Thacker 2004).

Phytoremediation

Plants can sometimes be used to restore soils and waters subjected to abusive uses such as disposal of toxic wastes or nutrient enrichment. The brake fern (*Pteris vittata*), for example, hyperaccumulates arsenic (Ma *et al.* 2001). Other plants are similarly adept at accumulating nickel, zinc, selenium, and other metals, while the alien plants that blanket eutrophic lakes and marshes consume large quantities of phosphorus. Such plants sequester the target substance and can then be harvested and removed for safe disposal elsewhere.

Biogeochemical services

The conversion of atmospheric nitrogen to forms available to plants is a biological process facilitated by microbes, some of which live in plant roots. By introducing plants capable of supplying their own nitrogen and thereby enriching the local supply, nitrogen replenishment can be hastened substantially. A number of species effective at colonizing harsh sites and restoring nitrogen stocks have been identified by agronomists, foresters, and forage specialists (MacDicken 1994: Englert *et al.* 2002); these should not be discounted by restoration biologists solely on the basis of their non-native status.

Judging appropriateness

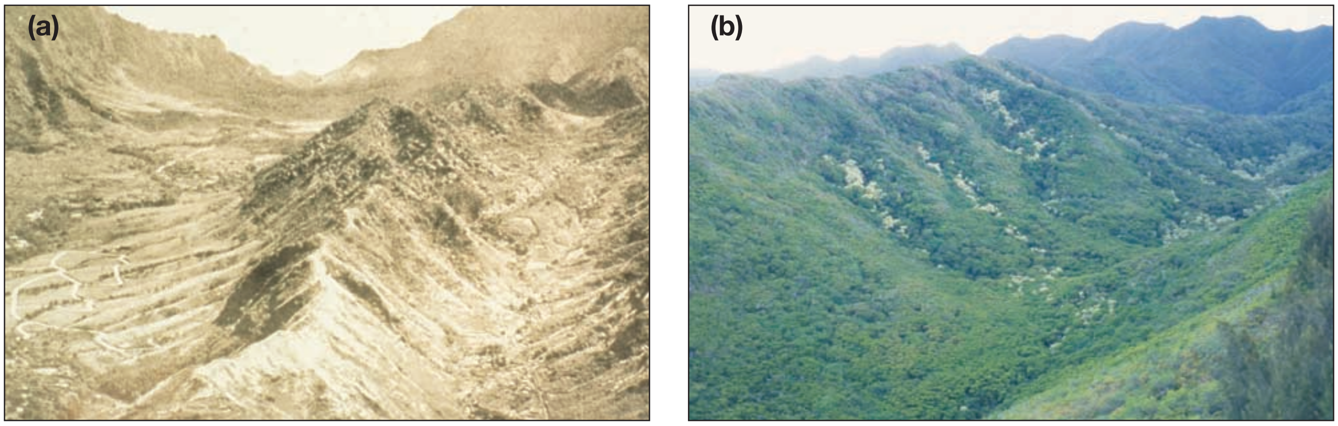
How does a manager decide when the use of one or more alien species might be tolerated and/or used appropriately? That determination must involve an assessment of the costs entailed, the benefits derived, and the risks involved. Risk acceptability depends upon the degree of restoration required and the ecological condition of the surrounding landscape.

Costs, benefits, and risks

Costs and benefits are measurable, tangible variables whose values are assessed using metrics such as money, land area, degree of soil protection, carbon sequestered, social acceptability, water quality, and so forth. The costs

Panel 2. Dr Lyon's figs

Local communities may support the planting of species of value to them, but they do not invariably refrain from destructively reaping the economic benefits. Nearly a century ago, the sugar barons of Hawaii realized that the water supplies they depended upon for irrigation on the coastal plain were jeopardized by deforestation of the uplands. When they attempted to reforest those watersheds, they found that local inhabitants were quick to harvest the planted trees for firewood. Enforcement was out of the question (due to politics and terrain), so they turned to ecological trickery. A young botanist, Harold L Lyon, was hired to restore forests on the watersheds that had been denuded by wood harvesting and grazing. He introduced a number of tree species that were exceedingly poor sources of cooking fuel, usually because they were slender or had low-density wood. Dr Lyon's most devious and ecologically intricate choices were figs (*Ficus* spp), together with the host-specific wasps that pollinate them (Lyon 1929), which produce crooked stems with low-density wood and exude copious quantities of sticky latex. Today, such an action would be judged ecologically irresponsible because it led to the introduction of non-native species capable of naturalization. It would also be regarded as socially irresponsible, unless accompanied by an alternative mechanism to provide cooking fuel for the rural poor.



(a) Courtesy of Hawaiian State Archive

Figure 3. *By the early 1900s, mountainous watersheds on Ohau, above Honolulu, Hawaii, had been severely degraded by uncontrolled grazing, wood cutting, and fire. (a) Situation in 1920, prior to reduction of threats and tree planting. (b) Eighty years later, the watersheds are blanketed with alien plants, doing a good job of protecting water supplies, but not supporting large populations of native plants or animals.*

incurred globally as a result of human-mediated invasions of species have attracted a vast amount of well-deserved attention in recent years. Those costs include direct financial impacts as well as harmful repercussions for native species, human health, agricultural productivity, ecosystem functioning, and more (Pimentel 2002). Despite those well-documented costs, the movement of alien species around the face of the Earth is typically motivated by the prospect of personal short-term economic gain, and the true cost to society is usually ignored. As a result, translocations are seldom accompanied by a thorough analysis of costs and benefits (McNeely 1999; Naylor 2000). Furthermore, the true costs associated with aliens are often slow to manifest themselves. The lag time between introduction and impact can be decades or more, making prediction of long-term impacts a pressing research need (Ewel *et al.* 1999).

In some circumstances, use of aliens reduces operational costs. True restoration of an original ecosystem is an economic luxury, available only to a small subset of the world's political entities. More often than not, restoration is a rehabilitation effort designed to re-establish some, but not all, functional attributes of the original system – watershed protection (Figure 3), habitat provision, or economic return. Costs of ecological restoration are not trivial (eg US $75 000 or more per hectare in the case of wetlands; Mitsch and Gosselink 2000), and anything that reduces the cost of a project is likely to augment its social acceptance. It is not uncommon for non-native species to be the least expensive alternative (D'Antonio and Meyerson 2002).

Stern and Fineberg (1996) define risk as a "...concept used to give meaning to things, forces, or circumstances that pose danger to people or to what they value". Risk has two components: a probabilistic element (the likelihood of a given consequence) and a magnitude component (the measure of what is at stake should things go wrong). Therefore, risk is more difficult to define and quantify than are costs and benefits. How much risk from alien species in restoration projects should be tolerated? Certainly, zero is the appropriate answer in many situations, but it should not be the universal response. Concern about alien species has reached such a fever pitch among conservation biologists in wealthy nations, however, that consideration of their potential utility is often disregarded out of hand, and zero risk is assumed to be the only possible position. We do not take this extreme stance when we choose a mode of transport, when we select among health-care options, or when we invest our retirement nest egg; nor should we take it when considering the use of non-native species in restoration.

Deviation from target: a guide to risk taking

Given the opportunity to augment the speed, cost-effectiveness, or social acceptance of a restoration effort, the resource manager must decide whether to tolerate or even to use exotic species. On a local scale, this decision depends in part on the degree to which conditions deviate from the restoration target. In general, the further the starting conditions are from the desired end conditions, the greater the risk warranted.

Deviation from initial conditions has both biotic and abiotic components, the former dependent upon species composition, and the latter dependent upon the extent of environmental change (typically soil and hydrological modifications). An ecological community whose composition is nearly identical to the restoration target would be far less appropriate for the use of alien species than would a site whose biota has been dramatically altered. Furthermore, change that is solely biotic is often easier to rectify than is abiotic change, such as loss of soil structure or nutrient enrichment. Desired species can be attracted, planted, tended, or protected, while the dominance of undesirable species can be reduced by manipulating competition and fire, and through judicious employment of chemical and mechanical controls.

Physical modification of site conditions, in contrast, warrants the use of exotics to a greater extent than does biotic modification (ie the slope of "risk acceptance" as a function of degree of modification is greater for abiotic than for biotic deviation from the target conditions). This is due in large part to the relative difficulty of restoring physical and chemical conditions. Consider, for example, the legacies of nitrogen (Richter *et al.* 2000; Dalton and Brand-Hardy 2003) or phosphorus (McCollum 1991; Comerford *et al.* 2002) from past agricultural and plantation forestry on soils that originally were nutrient-poor. Nutrient additions such as these are known to facilitate alien plant invasions (Huenneke *et al.*1990; Vinton and Burke 1995), so the resource manager's first reaction might be to consider reversing the eutrophication process. In addition to the dozens of possible manipulations for dealing with nutrient enrichment discussed in the review by Marrs (1993), addition of carbon (as sugar, starch, or sawdust) has been suggested as a way to reduce nitrogen availability through microbial immobilization (Morgan 1994). Nevertheless, large scale applications of carbon would probably be expensive, and success would not be assured; results of experimental additions have been mixed (cf Török *et al.* 2000; Blumenthal *et al.* 2003; Corbin and D'Antonio 2004). Depletion of phosphorus is an even more daunting task, sometimes requiring actions as extreme as substrate removal (Dalrymple *et al.* 2003).

Faced with a site that has been nutrient-enriched, the risks involved in tolerating the presence of aliens may be worth taking if the alternative is a futile expenditure of resources to modify species composition without modifying the substrate. The resource manager may have few options other than to work with what grows successfully, alien or native, until soil nutrient supplies gradually return to their pre-agricultural levels. Thus, the choice may not be "alien or native" but "high-risk alien or less risky alien". As in the case of biotic deviation from target, the tolerance or use of aliens might be more warranted on a site that has undergone severe physical modification (eg soil erosion, unimpeded leaching, modified hydrology) than one where the physical environment is virtually identical to the original condition.

Combining the three axes – risk warranted as a function of both biotic and abiotic deviation – yields a schematic response surface (Figure 4), one that tilts toward the origin and does so more steeply in the case of physical change than biotic change. Is it possible to quantify such relationships? Not precisely, but perhaps in terms of the relative benefits and costs associated with varying degrees of risk.

The assessment of risk is dependent upon the local objectives and the impediments to restoration. Managers must consider the circumstances: Is the intention to conserve biological diversity? Is it to protect a watershed? For augmentation of economic value? Is the local community supportive? Is the action reversible? Are funds and labor available to accomplish the job at the desired scale? Where restoration of ecosystem services is the goal, exotics might work perfectly well or better than natives (for example, eucalypt plantations for biomass planted in degraded pastures in South America, or albizzia plantations for carbon sequestration in anthropogenic grasslands in Southeast Asia). What about choosing species for reducing erosion? There is no reason, physical or biological, to think that biogeographical origin (native or exotic) should be correlated with a species' appropriateness for soil protection.

Landscape context

Risk is not solely an attribute of a species, but also of the context of the larger landscape. For example, the likelihood of adverse results from using a non-native species in a restoration effort undertaken on a patch within a landscape of intact, native communities is greater than using that same species on a site surrounded by communities that already contain the species of concern. Current weed-risk-assessment schemes (Pheloung *et al.* 1999; Daehler *et al.* 2004), for example, do a good job of evaluating traits of species, but they only indirectly consider the nature of the landscape in which newly introduced plants might be deployed.

The likely magnitude of a species' impact should it move off site must be considered. Some alien species seem to be relatively innocuous components of the communities they invade, whereas others have dramatic impacts on ecosystem composition and functioning. Again, it is essential to consider the ecosystems that may be invaded, in addition to the traits of the prospective invader. Grasses, for example, often have strong impacts on ecosystem functioning: they sometimes form dense root and litter mats (changing water infiltration and seed germination) and modify fire regimes (eg fueling fires in non-fire ecosystems; Budowski 1956; D'Antonio and Vitousek 1992; Mack and D'Antonio 1998). Yet, invasion by an alien grass into a savanna or grass-dominated prairie may be a far less serious ecological issue than grass invasion into a formerly grass-free tropical forest (Kauffman and Uhl 1990; Hughes and Vitousek 1993).

Risk assessment should also include consideration of the ability to contain a species beyond the bounds of the specific restoration project should it prove invasive and harmful. Some species are relatively easy to eradicate, control, or contain, whereas others are extremely tenacious, and the time to make this determination is before using them in restoration, not after. What makes a species easy to control? In the case of plants, vulnerability to herbicides and fire are important, as is propensity to spread vegetatively or to sprout following cutting. Plants that are dispersed by wind or gravity tend to spread along a single front of invasion, whereas those dispersed by birds or mammals commonly leapfrog great

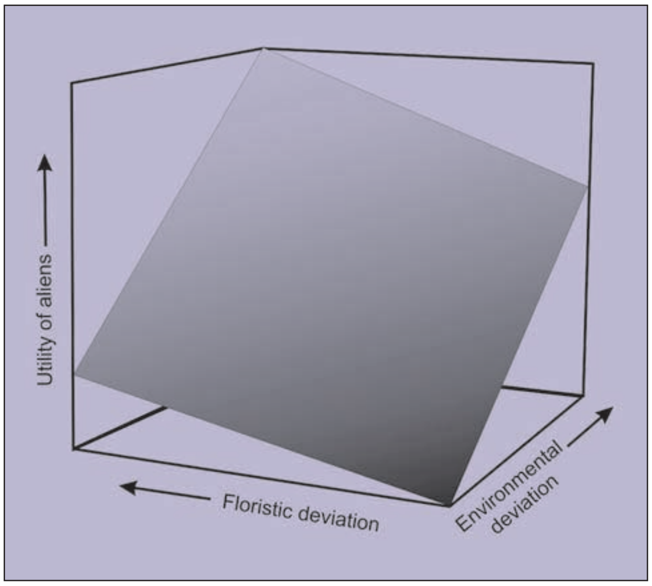


Figure 4. The potential usefulness of aliens in restoration increases with degree of deviation of the site to be restored from its initial conditions. Sites degraded only by changes in species composition are less appropriate for use of aliens than sites where soil and water have been modified.

distances across the landscape, creating multiple loci of invasion (Pielou 1979). Also, the ranges of plants that have specific habitat requirements are more constrained than are those of generalists. More focus on the use of aliens that have narrow site requirements, rather than the kinds of grow-anywhere plants that have been so commonly used in reclamation efforts, could lead to substantial risk reduction.

The landscape in which ecological restoration is to occur also involves a human community. To ignore that voice in decision-making entails a substantial risk of its own. For a number of years, dealing with risk (primarily human health issues in the US) was conceived of as a sequential process, whereby scientific information concerning a particular risk was assembled, the risk was assessed using those research findings, a characterization of the risk was developed based on that assessment, and a risk management plan was developed (National Research Council 1983). That process failed repeatedly, often because it excluded the full range of stakeholders affected. This led to a reevaluation by the US National Research Council and recommendations for a different scheme, one that involves all affected parties every step of the way (Stern and Fineberg 1996). Although it can be argued that attempting to accommodate all parties can lead to "paralysis by analysis" or to even more dangerous lose–lose compromises, it is also true that failure to allow everyone a voice can lead to policy impasse. The appropriate choice may be specific to the sociopolitical setting. Ecologists might do well to enlist greater involvement of colleagues from the social sciences in seeking guidance on appropriate communication with stakeholders.

Conclusions

Native species are often unavailable for use in restoration because of lack of planting stock or the absence of information on their ecological and horticultural requirements. Under some conditions alien species can provide ecological services that are needed for restoration, filling a role because native species are locally unavailable, absent, or extinct, or because the alien does the job more quickly or effectively. Guidelines for use or prohibition of aliens need to be case-specific, but resource managers should ask the following:

- To what extent do the biological and abiotic conditions of the site deviate from those of the target ecosystem?
- Is there an ecological or economic restoration need that can best be facilitated by the use of alien species?
- Have the views of the full range of stakeholders been considered?
- What are the potential landscape-scale consequences of tolerating or encouraging an exotic?
- Does the presence of the exotic warrant attempted eradication on ecological and economic grounds?
- Is the use of an alien species reversible?

Careful consideration of tolerating or using non-native species, as opposed to categorical rejection of all alien species always and everywhere, will enable us to accomplish more restoration in more places at a faster pace and with less money.

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