The paradox of invasive species: Do restorationists worry about them too much or too little?

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Introduction

Recently I was bicycling with some friends along a bike trail built on an old railroad bed. As is common in the American Midwest, the railroad right-of-way land along the bike trail was home to remnant prairie and savannah. Very early in the trip, I spotted a huge patch of garlic mustard (*Alliaria petiolata*) that was just starting to flower. Because garlic mustard is considered an aggressive invasive species in the Midwest, I stopped to pull up the plants. Once we got biking again, I saw another large patch of garlic mustard which I also stopped to pull. Upon restarting I soon saw more large patches of garlic mustard all along the trail and it was obvious that I had a choice – I could either continue biking with my friends or spend the day pulling up garlic mustard. One of my friends observed my dilemma about what to do and asked, "Do you ever feel like you're just spitting into the wind?"

Many times, I and other restoration ecologists with whom I have spoken do feel like we are just spitting into a wind of invasive species blowing across our restoration sites. Most of my experience with invasives has arisen due to my role as the director of Knox College's Green Oaks Field Research Station. Garlic mustard is an increasingly large problem in our forest habitats. We also have 40 acres of restored prairie (Allison, 2002) where I have continual problems with both woody invasives (mainly black locust *Robinia pseudoacacia* and autumn olive *Elaeagnus umbellata*) and herbaceous invasives (mostly yellow and white sweet clover, *Melilotus officinalis* and *M. albus* respectively). At times I have been so frustrated by my lack of success in limiting their spread in the prairies that I have become extremely angry with these species, although when I'm being more reflective my anger does not make sense to me. After all those plants that are frustrating me are just doing the job they evolved to do and doing it rather well, although too well from my perspective.

In August of 2008, I attended a workshop hosted by the Grassland Restoration Network in Madison, Wisconsin. The participants at the workshop spent a lot of time discussing problem plants in their restorations. Many of the problem plants were members of invasive species that I have also struggled with. Most were originally native to other regions of the world such as Eurasia (autumn olive, white and yellow sweet clover, and common buckthorn *Rhamnus cathartica*), the southern United States (black locust), but some were native to the Midwestern region and simply had become too abundant in some restorations and thus were deemed problematic. Most of the native group were woody plants considered to be undesirable in prairies such as smooth sumac (*Rhus glabra*), blackberry (several species of *Rubus* but usually *R. allegheniensis*), and gray dogwood (*Cornus racemosa*) but some plants on the problem list surprised me such as Canada goldenrod (*Solidago canadensis*). What was obvious to me was that while problem plants

in prairie restorations generated a lot of passionate discussion, often accompanied by frustration and anger, different restorationists had very different responses to particular species. For example, for some restorationists Canada goldenrod was a huge problem, occupying large areas of prairie and crowding out other species, but for other restorationists it was just a typical part of the prairie ecosystem. Others worried that all the time and effort directed at eliminating or at least limiting the spread of problem plants was time and effort that could be better directed at more important work such as increasing the size and number of restoration projects. After listening to the discussion at the GRN workshop and reflecting on my own experiences and feelings, I was left wondering whether restorationists spend too much or too little time worrying about invasive plants. And how do we decide the best course of action with respect to invasive plants in restorations?

The Scope of the Problem

In order to fully appreciate why invasive species are a problem in ecological restoration, we first need to consider (briefly) what restorationists are trying to do via ecological restoration and also what makes a species invasive. Ecological restoration has been defined in various ways over the years but the most widely accepted definition is as follows:

> "Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." (Society for Ecological Restoration Science and Policy Working Group, 2002)

Humans can damage ecosystems by many different activities such as agriculture, urbanization, logging, mining, road-construction, damming rivers *etc* but in almost all instances human damage to an ecosystem changes the environment in ways that are detrimental to the local, native biota. The damaged ecosystems are frequently colonised by species that are tolerant of human disturbance regimes and often these colonising species include many species that are not native to the local area. Sometimes the mere growth of non-native species such as *Myrica faya* in Hawaii (Vitousek and Walker, 1989) is the major source of damage to the local ecosystem. Thus one of the main goals in any restoration project is to promote the growth of native species and eliminate or limit the growth of non-native species.

As many papers in this volume make clear, there are complex issues involved with the naming and defining of non-native or introduced species. It is not my intention to enter into the debates about definitional issues, but I prefer the use of the term "non-native species" when discussing species that have been introduced by human activity to an ecosystem. And even though it is a circular definition, I think of non-native species as being any species not native to the ecosystem being considered (following the definition in President Clinton's Executive Order 13112 on February 3, 1999).

However, not all non-native species attract the same amount of attention from restorationists and site managers. Non-native species can be categorized in various ways

but the most important distinction is between current problems and not problems (Table 1). It is also important to note that some native species may become problems in restorations. The key issue is recognizing problem populations of non-native species. Problem populations are usually considered invasive and the properties that make them invasive are best defined as follows:

> "Biotic invaders are species that establish a new range in which they proliferate, spread and persist to the detriment of the environment." (Mack *et al*., 2000)

Problem populations of invasive species typically change ecosystem properties such as local hydrology, fire regime, nutrient cycles, and energy flow and as a result often lead to a reduction or loss of populations of local native species (Mack *et al*., 2000). Because invasives alter ecosystem properties, their removal is critical at the beginning of any restoration project and is often the first step in restoration. Restoration projects (certainly those I am most familiar with in American Midwestern prairies and savannas) almost always require continued vigilance and removal of invasives in order to maintain the integrity of the restoration for the entire life of the restoration (Norton, 2009).

The goal of ecological restoration is usually to return a damaged ecosystem to its previous condition, although how to choose that previous condition is a challenge (in North America we frequently use the condition of the ecosystem prior to the arrival of Euro-Americans as the desired endpoint for restoration) (Allison, 2007). Recently restorationists have realized that along with trying to match an historical ecosystem, it is critical to plan for restorations that accommodate natural changes due to typical ecosystem processes, dynamics and evolution (Higgs, 2003). If we truly want to match the restoration to historical ecosystems that existed prior to modern human disturbance, then we would almost certainly have to eliminate all non-native species from the restoration and there are purists who argue that non-native species have no place in a restoration. But given that there are so many non-native species in any particular ecosystem today, it may be impossible to eliminate all such populations. New Zealand has the best documented flora of native and non-native species. New Zealand is home to 2,065 native plant species and is also home to 24,774 non-native plant species, of which at least 2,200 have become naturalized (able to survive outside of human cultivation) (Duncan and Williams, 2002; Norton, 2009). Even allowing for the persistence of a few dozen beneficial naturalized species such as some of our food and forage plants, would it be possible to eliminate about 2,200 naturalized species today? If as many as 52% of the species in an ecosystem are non-native species the task of creating completely native restored ecosystems may be extremely difficult to achieve.

Due to limited time and budgets, restorationists have to focus on populations of truly invasive species. Which invasives to focus on will vary from site to site, but will almost certainly be those that cause the most change to environmental properties such as fire regime, hydrology, nutrient cycling, and have the greatest negative affect on native species. Essentially restorationists must practice a form of triage in which they identify invasive populations of greatest concern and work to control them (Hiebert, 2001). Early in the history of prairie restoration, Kentucky bluegrass (*Poa pratensis*) was frequently an

invasive problem but once restorationists began to use prescribed fire on a regular basis they found that Kentucky bluegrass was easily controlled and no longer a problem (Blewett and Cottam, 1984). Today biennial species like yellow and white sweet clovers can be problems at some prairie restorations, at least temporarily, but usually changes to the prescribed fire regime will greatly reduce their abundance (http://www.inhs.uiuc.edu/chf/outreach/VMG/wysclover.html). The greatest problems are woody species that change the fire regime and shade out native herbaceous grass and forb species. Black locust and common buckthorn spread aggressively by vegetative growth. Autumn olive is spread by animals consuming the fruit and passing the seeds, but can also expand via vegetative growth. All three of those species sprout from burned and cut stumps and have very persistent root systems making them difficult to eliminate once they are well established in a prairie. So a site manager would probably attempt to control less problematic populations of Kentucky bluegrass and the sweet clovers simply by prescriptive fire but would have to use more direct and individualized approaches to handle populations of woody invasives.

The Way Forward

Ecological restoration is likely to be one of the most important, if not the most important, land management practices in the twenty-first century as we attempt to repair human-caused damage to the Earth's ecosystems (Hobbs and Harris, 2001). Indeed, some groups have identified ecosystem restoration as the primary strategy for addressing global climate change (http://www.econeutral.com/era.html). Yet just as ecological restoration is becoming a more widespread and accepted practice, the continued spread of invasive species in almost all global ecosystems (Chornesky and Randall, 2003) raises questions about how successful ecological restoration will be in meeting the goals of both restoration to a previous condition and repairing human caused damage to ecosystems. Habitat destruction is the greatest threat to locally rare native species, but populations of invasive species and their impact on local biota are the second leading cause of reductions in populations of endangered species, leading to declines in 57% of endangered plant species in the US (Wilcove *et al*., 1998). Moreover human habitat modifications and spread of non-native species are leading to the world becoming increasingly domesticated (Kareiva *et al*., 2007) and homogenized (McKinney and Lockwood, 1999). I once heard Daniel Janzen give a lecture in which he said he feared that the entire planet would come to resemble Iowa – a comment meant to generate mental images of extensive rural areas dominated by domesticated corn (*Zea mays*), soybeans (*Glycine max*), cattle and pigs, and urban areas consisting of expanses of Kentucky bluegrass, Norway maples (*Acer platanoides*), house sparrows and starlings. This was not meant to disparage the good people of Iowa. Given the reality of global climate change and spread of non-native species, ecological restoration is likely to be an increasingly important tool, more so than habitat preservation, as we attempt to maintain high levels of species and ecosystem diversity (Hobbs and Harris, 2001). Predictions that ecosystems will become dominated by just a few species that tolerate human disturbance regimes and climate change, while most species decline due to sensitivities to both human disturbance and climate change are particularly disheartening (McKinney and Lockwood, 1999). Ecological restoration may be our most effective tool for preventing

the development of an ecologically boring world dominated by a few hardy cosmopolitan species.

But some authors question the recent focus on non-native and invasive species and don't think those species cause many problems. In fact they claim that with plants in particular the arrival of non-native species has resulted in an increase of local species diversity with no or extremely few instances of non-native plants driving native plant species extinct (Brown and Sax, 2004, 2005; Sax and Gaines, 2008). However there is ample evidence that non-native and invasive species do have a large, negative impact on populations of native species (Wilcove *et al*., 1998; Mack *et al*., 2000; Chornesky and Randall, 2003; Ricciardi, 2003; Cassey *et al*., 2005). Of particular concern is the question of when do naturalised non-native species become invasive? Most invasive non-native species go through a latent period that may last for decades during which they are non-problematic naturalised species before becoming invasive problems (Mack *et al*., 2000). At the current time it is very difficult to predict which non-native species will eventually become invasive problems and which will remain minor additions to the local biota. A focus on species richness as the prime measure of ecosystem quality (as in Brown and Sax, 2004, 2005; Sax and Gaines, 2008) misses the point that a native species may continue to exist despite losses of many local populations (Ricciardi, 2003) and the fact the invasive populations may greatly alter ecosystem properties such as nutrient cycling, energy flow, fire regime and hydrology so that the ecosystem no longer resembles or functions like the previous ecosystem even though local native species persist (Mack *et al*., 2000). In my experience, a prairie invaded by black locust and autumn olive may still have a majority of native prairie species but it is no longer a prairie, instead it has been converted to shrubby woodland that does not resemble or function like a prairie.

Perhaps most surprising to me is that Brown and Sax (2005) suggest questions of whether a decline in biodiversity or the effects of invasive species are good or bad are not questions to be answered by scientists. In many ways their position is an abdication of public trust. Most scientists have been educated and supported throughout their careers by funds supplied by the government, which ultimately means from taxpayers. Such education and support is provided with the expectation that scientists will function as experts able to make recommendations to the public about what are the best choices to make given a particular situation. The original ecologists in the U.S. certainly felt a duty to make recommendations about how humans should interact with ecosystems (Worster, 1990). Restoration ecologists must be willing to provide expertise and make judgments about how to restore ecosystems, how to set reasonable goals for restoration projects, and whether proposed management plans are good or bad, although they must be careful to separate their statements about data from their opinion and be willing to accept that the general public may disagree with their opinions and recommendations.

Given our legitimate concerns about the development of a world of domesticated, homogenized ecosystems, the question of whether to restore ecosystems so they contain species previously found there or simply to focus on ecosystem function is a false dichotomy. We could almost certainly maintain basic ecosystem functions of hydrology, nutrient cycling and energy flow with a few well chosen hardy species but such

ecosystems would be lacking in both native species diversity and the dynamics of continued evolutionary change, at least evolutionary change in species rich assemblages of locally native populations. In order for ecological restoration to be truly successful all stakeholders involved in the restoration have to be informed about the restoration and must value both the process and final or on-going (given that restoration projects never really end) product of restoration (Higgs, 2003; Jordan, 2003; Allison, 2007).

Restorationists highly value restorations that return and maintain local native species, and allow for the continuation of natural processes within those restorations (Higgs, 2003; Jordan, 2003). For most restorationists an ecosystem that lacks many native species would not be particularly valuable even if it maintains desired ecosystem function because one of the most valuable aspects of ecological restoration is the maintenance of native species diversity (Higgs, 2003; Jordan, 2003). In today's world a focus on native species is not usually a form of prejudice against non-native species (Simberloff, 2003), rather it reflects a love and respect for the species that evolved in that place and which have meaning to the local human population (Olwig, 1995; Jordan, 2003).

Because global climate change, human habitat modification, and spread of non-native species will almost certainly continue for the foreseeable future, probably at increasing rates, managing ecological restoration projects so sites continue to maintain populations of native species will be an increasing challenge. We can assume that in a restoration project we can limit any further direct human habitat modification. However, the effects of global climate change are likely to become greater and may result in changes to the local ecology that are so great that many local species will no longer be able to reproduce and survive on site. Naturalised non-native species usually disperse either on their own or with assistance of other species, so that it is difficult to keep them from arriving at a restoration site. Thus there is likely to be continued and increasing spread of non-native species in the future. As mentioned previously restorationists must focus on the most serious problems due to time and budget limitations that prevent working on all real and potential problems for a site. The focus on pressing problem species may allow species initially seen as non-problematic to increase until that species becomes a large problem. Restorationists must work with proven methods and be sceptical of unproven methods until experimental trials have demonstrated their effectiveness. For example, Donlan has suggested that because American prairies lack large native herbivores, it might be worth introducing large African herbivores to those grasslands to both preserve populations of those herbivores and to allow them to fill the niche once occupied by American native large herbivores. As much as I like the mental image of zebra in the prairies, I would not advocate pursuing Donlan's idea without extensive testing. There is good data which indicates that non-native herbivores have a negative effect on populations of native plants but only limited or even positive effect on populations of non-native plants (Parker *et al*., 2006). Zebra in Illinois may only make the situation worse for native prairie plants.

There may be ecosystems that are so damaged or changed from their original condition that restoration to the original ecosystem or even something similar to the original will be prohibitively expensive in terms of time, labour and money (Jackson and Hobbs, 2009). In such cases, the most that can be accomplished via restoration may simply be managing

or directing the development of new ecosystems that combine native and non-native species so that ecosystem functions are preserved (Jackson and Hobbs, 2009).

Restorationists will have to be flexible in their management of restored sites in the future. Management plans will have to be modified as we see first hand how global climate change and the arrival of new non-native species affect restoration projects. The combination of global climate and invasive species is creating groups of organisms that have never occurred together in the past and which form ecosystems that some ecologists refer to as 'novel ecosystems' (Hobbs et al. 2006). The development of novel ecosystems greatly complicates our understanding of ecological restoration because at least some novel ecosystems appear to be especially robust and potentially stable. We are unlikely to be able to restore ecosystems to an absolutely pristine pre-damage condition. Given all the environmental changes likely to occur in the next century pristine is probably an impossible goal. It may be time to ask how long a species has to be naturalized in an area before it can be considered native. There is no obvious way to make that determination (Coates, 2007) but many non-native species have evolved local differences once *in situ* in new habitat (such as adaptation to micro-habitat differences in disturbance in non-native dandelion *Taraxacum officinale* (Solbrig and Simpson, 1976)). Is there a point at which we consider evolution and adaptation to local conditions sufficient to make a population native to a site? Surely there must be because we do not consider species that moved to a new area on their to be invasive (whether it be opossums moving from South America to North America millions of years ago or more recently cattle egrets spreading worldwide from Africa). Allowing for such changes in classification will be a challenge for restorationists given our usual focus on local native species and the value we place on ecosystems dominated by those species.

At this point my own energies are directed at eliminating or limiting the spread of invasive populations that are especially detrimental to prairies (black locust, autumn olive) because they thoroughly change the character and function of prairies. I cannot imagine a time when either of those species would be considered native or not problematic in prairies, especially considering that some woody natives like gray dogwood and smooth sumac are problematic. Flexibility in light of the changing environment cannot be used as an excuse for letting restored sites that were restored for a particular reason become something completely other than was originally intended. If climate change researchers are correct that by 2095 Illinois will have a climate that resembles the climate of East Texas today (Kling *et al*., 2003), then the restored prairies I manage may become more similar to prairies or savannas currently found in Texas, but I think there should be a commitment to maintaining them as prairies rather than allowing them to become forest or shrubland.

Conclusions

Do restorationists worry about invasive species too much or too little? Well that depends upon the individual restorationist, but invasive species do merit serious consideration and concern. Because populations of invasive species change ecosystem properties and have a negative effect on native species in sites of ecological restoration, they are a problem that

needs to be controlled as much as possible. Global climate change, the continued spread of non-native species, and the potential for increased homogenization of the world's biota indicate that the problem of invasive species will most likely get worse in the future. Restorationists will have to focus on limiting the influence of invasive species that cause the greatest changes to their projects. Even as they maintain such focus, they must be on the lookout for the arrival of new problem species and changes to local ecology as climate change progresses. They will have to be in constant communication with all stakeholders in a restoration to ensure that the restoration continues to fulfil both the ecological and cultural goals for the restoration. Our restoration sites may undergo considerable shifts due to climate change but the restoration itself must be maintained in a way that reflects the original plans and possibilities of that site. Restorationists must also use ecological restoration to maintain ecosystems of ecological and cultural value. We must also work to promote restorations that allow for ecological and evolutionary functions and processes that occur outside the realm of human influence. Ideally we will use ecological restoration to prevent the development of a completely domesticated, ecologically boring world that exists only to satisfy basic human needs. If we can do those things, restorationists will play a key role in preserving an ecologically diverse and interesting planet.

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Table 1. *Characteristics of problem and non-problem species in the context of ecological restoration.*

Problem invasive species	Not native to ecosystem. Increase and spread in ecosystem, offspring easily dispersed. Lead to decline in native species via negative interactions such as competition, predation or parasitism. Cause changes in ecosystem properties such as hydrology, nutrient cycles, energy flow, fire regime. Tolerant of human disturbance regimes.
Problem native species	Native to ecosystem. Effects are ecologically similar to problem invasive species. Frequently they are edge species tolerant of human disturbance.
Non-problem native species	Native to ecosystem. Populations exhibit minor fluctuations in size and distribution. Presence enhances other native species. Maintain ecosystem properties. Frequently sensitive to human disturbance regimes.
Non-problem non-native species	Not native to ecosystem. Reproduce and survive in ecosystem. Populations exhibit minor fluctuations in size and distribution. Presence at least is not leading to decline in native species abundance or distribution. Do not lead to changes in ecosystem properties. Have potential to become problematic as climate changes.