chapter fifteen

Improving restoration to control plant invasions under climate change

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Contents

15.1 Introduction

Native forests and grasslands worldwide have been converted to developed lands or invaded by exotic species due to human activities. These pressures are predicted to increase with population growth and climatic stress in coming decades, escalating concerns for the viability of native species and communities that are affected. Ecological restoration is frequently offered as a partial solution to these changes because less stressed ecosystems may be more tolerant of novel changes in the environment (Temperton et al. 2004, Clewell and Aronson 2008). In this sense, restoration could provide a strategy for enhancing ecological resilience, given escalating problems associated with invasives and a changing climate (see Hobbs and Norton 1996).

Traditional restoration efforts have been concerned with matching restored systems to historical or nearby natural habitats, but climate change and biotic invasions can alter the viability of historically based objectives (Figure 15.1). In many places, historically based restoration has become impossible, particularly where development dominates, restoration conflicts with other objectives, or persistent invasive diseases and pathogens have removed dominant or keystone species (Clewell and Aronson 2008). Elsewhere, where restoration has been attempted, restored conditions can only be maintained over the long-term through vigilant monitoring and costly maintenance (Aronson and van Andel 2006). Most restoration efforts are rarely absolute as aggressive invasive species simply cannot be eradicated given current technology. Our management of these latter sites would benefit

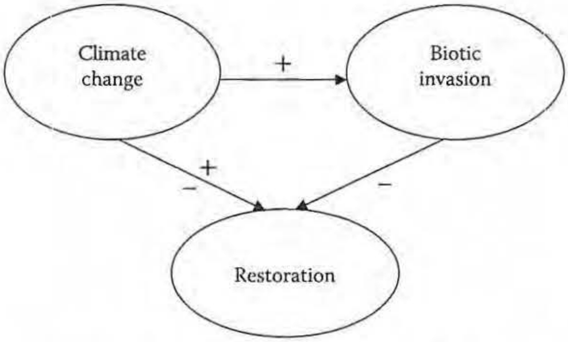

Figure 15.1 A joint framework showing the interactive effects of climate change and biotic invasions on restoration discussed in this chapter. Although climate change may have either positive or negative effects on restoration depending on the species used and climate change as a growing disturbance agent can promote species invasions, both climate change and biotic invasions would make restoration efforts more difficult.

if ecosystems were more self-restoring or self-sustaining—if they were more capable of resisting new invasions or climate-related stress. In recent years, both theoretical and field-based ecological research have provided insights into the means by which stability may be enhanced amid climate change and biotic invasion.

In systems that have been invaded, exotic–native interactions can be complex, and complete removal of exotics may be impossible and, in some rare cases, undesirable, particularly when exotics check the spread of invasives or favorably alter habitat, competition, or food web relationships for natives (D'Antonio and Mack 2001, Ewel and Putz 2004, Vander Zanden et al. 2006). These fundamental biological processes of inhibition and facilitation, broadly conceived to incorporate both natives and exotics, can be manipulated to help meet a broad range of management objectives, some historical and some practical.

Strategies to address climate change and biotic invasions are normally devised and discussed separately rather than in an integrated way (Berger 1993, Perry and Galatowitsch 2003, Price and Weltzin 2003, Bakker and Wilson 2004, Harris et al. 2006, Guo 2007, Holsman et al. 2010). Both factors affect ecological outcomes and can determine restoration success. Therefore, managers and researchers would benefit when these drivers of potential ecological change are considered jointly as integrated strategies in both research and practice. The purpose of this chapter is to review how these joint strategies can improve restoration and promote ecological resilience and stability in a changing environment.

15.2 Setting restoration goalposts

When restoration appears as a management goal, it implies that some measurable change to an ecosystem has occurred and that all or key aspects of the system can be returned toward an earlier condition or dynamic. Today, restoration constitutes an explicit goal of land management to sustain desired attributes or to redirect successional change to a more natural range of variability. For example, the removal of exotics, particularly invasives that aggressively compete with natives, has led to the restoration of species composition to historical assemblages. Similarly, the return of historical fire regimes after decades of exclusion has led to both compositional and structural restoration in forests that developed with fire (Keeley 2006). In both situations, the long-term viability of ecosystems is thought to be enhanced by arresting and reverting the evolutionary or ecological novelty imposed by exotics or the anomalous competitive or demographic dynamics from altered disturbance regimes.

In practice, few restoration efforts can be expected to wholly arrest and recover from novel biotic change (see Hobbs 2007). In exotic eradication efforts, it is often only those species that are most invasive and able to be removed that serve as indicators of restoration success. From the reverse perspective, it is usually the density of only the most valuable native species (i.e., threatened or endangered, prominent, commercially important) that measures success. There is no guarantee that such indictors are reliable measures of the recovery or resilience of the ecosystem over the long-term, and so restoration success is often ambiguous.

The success of ecological restoration is also difficult to measure because the attributes of ecosystems are mediated by broader forces (i.e., climate variability and disturbance regimes). For example, restoration may be successful only when climate and disturbance regimes work in its favor, and decades of efforts may be lost during a drought or other disturbance events (Figure 15.1). With such a complex broad-scale and long-term driver at work, restoration success must often be measured by the ephemeral condition of the environment, such as native species abundance.

Given the trend toward more and more invasives and an ecosystem in flux, restoration in practice normally perceives goals as inflexible. Success is measured incrementally as progress toward a predefined goal. A range of strategies are acceptable, and fixed goals clearly demarcate a range of possible acceptable outcomes. Having this combination of clear goals and a range of acceptable future conditions that are informed by historical insight adds flexibility for managers much more than do impractical notions of restoration as mimicry.

The two most tangible aspects of ecosystem restoration—composition and structure—may be less important than a more abstract use of the word. The restoration of ecosystem resilience prioritizes those processes, structures, and compositions that enhance system inertia and elasticity during periods of stress or recovery. For example, returning stem density to historical conditions could reduce moisture stress and increase the vigor of dominants. In other situations, resilience may be engineered above historical levels by modifying historical structure or composition (Ren et al. 2012). Such efforts may be warranted to successfully resist the undesirable effects of invasives and changing climate conditions.

15.3 *Cumulative effects of novel changes*

As mentioned earlier, traditional approaches to restoration rely on species composition and structure from some reference period of the past as a model for management. Yet, under certain climate change and invasive scenarios, these historical species and ecosystems may no longer be viable on site. Under less extreme scenarios, the cumulative effects of climate and biotic stressors are likely to make restoration objectives harder to achieve (Figure 15.2).

Acting individually or together, climate change and biotic novelty due to species invasion could eliminate or reduce habitat for some species while creating more favorable habitat for others. With a warming climate, the most similar habitat to that of the recent past and present is generally at higher latitudes and altitudes. Migration may be difficult for native species. Many invasives are highly aggressive colonizers and so they could slow down or even thwart successful migration of natives to these sites without intensive management. Within landscapes that have been highly fragmented by development, the

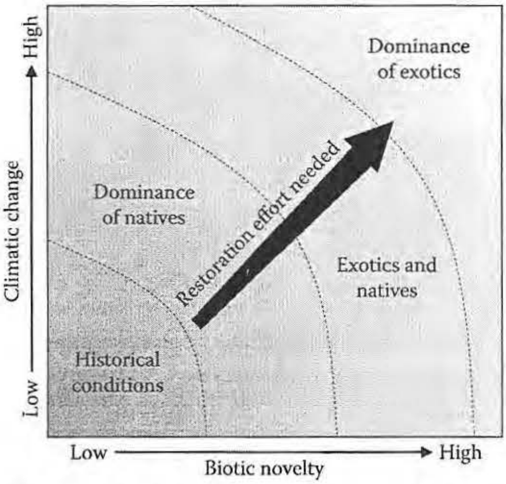

Figure 15.2 The degree of effort needed to restore an ecosystem to historical conditions generally increases with climate change and biotic novelty. Restoration may not be feasible under extreme climate scenarios, but restoration becomes easier where or when climate conditions resemble that of the past.

most mobile species may have a selective advantage. Exotics, particularly invasives, have already been pre-selected for their broad environmental tolerance and dispersal abilities. This may put natives at an even greater disadvantage (Kohli et al. 2008, Ricklefs et al. 2008, Qian and Guo 2010). Given these hurdles that may be faced by native species in the presence of climatic range shifts and aggressive exotic competitors, enhancing the resilience of species and their habitats at or near their current locations may be a worthwhile investment. Stress from moderate climate extremes or disturbances is tolerable for species that have adapted to those conditions. However, the cumulative effects of this stress in the presence of invasives can result in a loss of resilience. Restoration efforts that reduce stress from invasives could make the system more tolerant to climate change, and vice verse.

15.4 *Engineering resistance*

Biological invasion can alter the structure and dynamics of entire communities and ecosystems while threatening natives more directly because of their typically high productivity and competitive strength (Berger 1993). In a successional sense, invasives provide classic examples of inhibition. At a community level, existing exotic species can also facilitate or inhibit the arrival of later invaders or they can be absorbed into the species mix with no discernable effects. The same can be said for natives. Understanding these interspecies relationships is critical for identifying if a need for biotic restoration exists or if an increase in species richness might actually enhance resistance to serious invaders. Certain exotic species may be of minor ecological consequence and a few may have management value (Figure 15.3).

One common restoration strategy is to increase resistance to biological invasions through niche occupation and a high rate of biomass accumulation of native species. Habitat resistance to invasives is likely to be affected by the combination of both richness and biomass of existing (native and exotic) species, among other factors (Guo and Symstad 2008). Diverse plantings could help identify the most suitable species that can compete with existing invasive species in local or surrounding habitats. This can help guide future

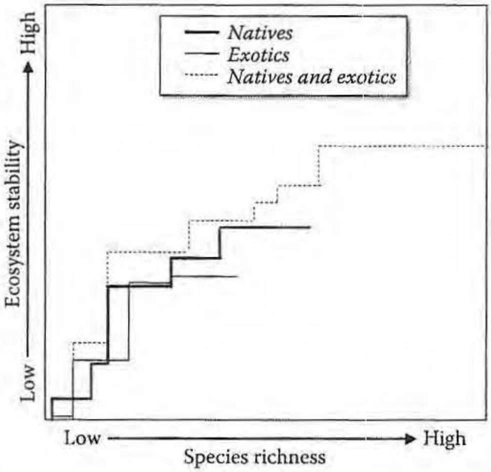

Figure 15.3 Native and exotic species may not vary substantially in their ability to alter the functional stability of ecosystems unless the latter group constitutes highly invasives. In a system where species are not saturated (i.e., niches still available for invading exotics and both natives and exotics can coexist), ecosystem functions may be enhanced due to increased species richness. Identification of natives and exotics as "drivers" of stability or "passengers" that serve complimentary or redundant roles provides powerful tools for restoration. The curve levels off because additional species become complimentary or redundant, whether exotic or native, depending on their individual attributes. The scales for both axes and for natives and exotics may or may not be proportional to each other. (Modified from Peterson, G., C. Allen, and C.S. Holling, *Ecosystems*, 1, 6–18, 1998.)

large-scale restoration efforts, where the habitats may or may not have been invaded. If designed and practiced correctly, the manipulation of species richness and cover could help buffer sites from the effects of highly undesirable invasives.

Restorers need to make sure that native or exotic species used do not facilitate the arrival of new invasives by altering the habitat or through mutualisms. An often neglected yet critical issue in restoration ecology is to make sure the species being utilized for restoration is native but not invasive (i.e., the so-called "home-grown" invasives) (Cox 1999). Further, landscape-level restoration and management are needed to maximize the neighborhood propagule density of natives while minimizing those of invasives (see Larson 2009).

In highly disturbed habitats, we may no longer rely on seed banks and natural seed dispersal processes for revegetation by native species; seed planting or assisted migration of needed species become necessary (Wang et al. 2009). Because of the threats from increasing impacts of climate change and biotic invasions, restoration techniques are often aimed to maximize vegetation growth rate and to inhibit exotic invasion. In a given area, the number and type of species to be planted in order to maximize restoration rates are critical questions that need to be resolved. The importance of germination and survival of the species planted will be used to measure the success of restoration.

However, even though such questions are being addressed, many practical challenges lie ahead. For example, seeds of many native species are very costly, and therefore, many native plantings are seeded with relatively few species. Although certain practices save money in the short-term, it may lead to inferior results or restoration failure. This could lead to more costly management in the long-term. For this and many other reasons, the number of successful efforts appears to be few, and many restorations are not sustainable.

15.5 Lessons from biodiversity experiments

In most experimental studies, the purpose is to experimentally examine the response of restoration rates and vegetation structure and dynamics to different numbers of planted species. Experimental research to date shows that (1) high-diversity planting did increase the habitat productivity during ecosystem early development (cf. Roy 2001), (2) high-diversity planting could reduce the habitat invasibility by introduced species (e.g., Tracy et al. 2004), and (3) however, there could be "optimal" number of species to be planted in a given area as very high-diversity planting can be wasteful and may cause adverse effects on restoration rates. Results of the experiment will advance our understanding of plant species interactions and their potential role in habitat restoration. The study will also furnish useful information to managers involved in seeding native species.

Diversity, biomass, productivity, and stability are key variables in community and ecosystem ecology, but only diversity and biomass could be directly manipulated in restoration and management and other variables change accordingly (Guo 2007, Larson 2009). High diversity has many other benefits for overall ecosystem health including higher nutrient use and carbon sequestration (CO_2 uptake) efficiency, higher litter decomposition rate, higher community and ecosystem stability, and better habitat and product quality. Diversity indirectly plays the role of resisting invasion through facilitating biomass accumulation. Small-scale planting of more native species could enhance the resistance of community to invasions by exotic species (Figure 15.4). For example, Bakker and Wilson (2004) found that restoration can act as a filter for constraining invasive species and both diversity and species identity can be important.

Experimental studies offer useful insights to improve restoration outcomes (Roy 2001, Guo 2003, Schmid and Hector 2004). However, unlike biodiversity experiments that often seed multiple species on bare soils, restoration in the real world often involves planting native species (1) on preexisting vegetation, (2) across large scales, and (3) with long-term perspectives (see Grace et al. 2007). Thus, applying knowledge from seeding experiments on bare-soil, small-scale, and often short-term requires caution. Experiments show the benefits of high-diversity planting. But what experiments to date have not been able to offer is when, where, and what species to plant first and what species to follow (e.g., different successional stages, multitrophic levels).

In general, productivity increased with the number of planted species but only up to a certain level, and invasibility may therefore decline. The decline could be due to competition, allelopathy, and functional redundancy, among others (Guo et al. 2006). Thus, practical details regarding what species, how many species, how much (number or weight) seeds (or seedlings) for all and each species, and how to arrange the relative abundance among species are all potential issues that need to be resolved before action. Given the costs of seeds and sources of species (which may extend to much larger regions, thus some of the species may not actually be native to the particular habitat or landscape to be restored), planting appropriate number of species and seeds is still the major challenge.

New initiations of restoration efforts, identifying the most successful native species, not only those that can resist invasion by exotic species, but also the ones that can better adapt to future climate changes, become an urgent need in practice (Guo 2007). As mentioned earlier, species selection should also take both inhibition and facilitation effects into account. Inhibition may occur either biochemically, as with allelopathy, or because the invader exhibits faster or denser growth or is in some way more competitive for the available water, light, or nutrients at a site. Inhibition can be successful by lowering the rates of establishment, growth, reproduction, or mortality. For many high-profile invasives, the

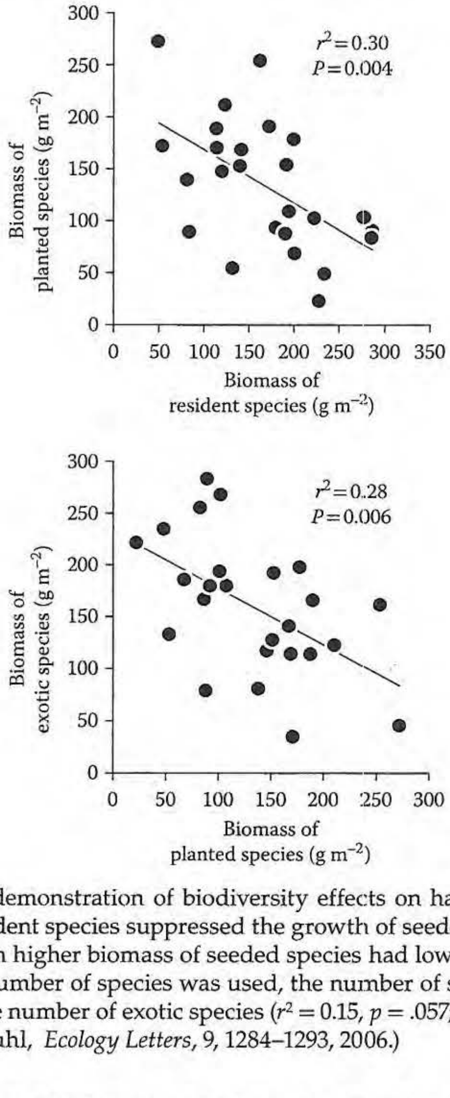

Figure 15.4 Experimental demonstration of biodiversity effects on habitat invasibility. The plots with higher biomass of resident species suppressed the growth of seeded species (as invading species; Top), and the plots with higher biomass of seeded species had lower biomass of exotic species (Bottom). However, when number of species was used, the number of seeded species was marginally negatively related to the number of exotic species ($r^2 = 0.15$, $p = .057$; not shown). (Adapted from Guo, Q., T. Shaffer, and T. Buhl, *Ecology Letters*, 9, 1284–1293, 2006.)

key conservation concern is that invasives become too dominant and inhibit biodiversity. They seemingly fill all or most of the available niches and reduce the number of available niches (cf. Grime 2002). In contrast, less aggressive species may extirpate only a few competitors, simply reduce their population densities, or fill some unoccupied space. In some situations, these latter effects may be managerially useful, as niches filled by relatively benign exotics may reduce the risk of dominance by aggressive invasives. Theoretically, such exotics or transplanted natives could enhance the resilience of ecosystems dominated by native species.

On the other hand, some exotics, especially invasives, can facilitate successional changes that are either compatible or incompatible with site objectives. When invasives reduce site diversity, they may not close niches entirely as much as selectively remove vulnerable species. This can retain opportunities for new species that are more tolerant of the invader. Alternatively, an invader may alter site conditions or disturbance processes in a way that favors native species or invasives that were formerly at a disadvantage. For example, exotic species have proven useful for gradual restoration of native-dominant mangroves (Ren et al. 2008). Also, increased fire frequency from invasive grasses can facilitate the recovery of fire-tolerant natives or the spread of certain invasives (Drewa et al. 2001). As a third example, nonnative trees are often used for reclamation after strip mining with the long-term expectation of a more diverse forest, even when it is not similar to what was historically there (Wikipedia, 2012).

During restorational planting, it is likely that not every species in any multispecies seeding can germinate and establish. Therefore, planting greater numbers of native species may lead to high diversity and restoration rate as measured by biomass accumulation. This is because diverse species planting can ensure that the niches in the habitat could be fully occupied in case of failures among the most productive species, especially in early stages of restoration when the habitat is quite open or the targeted habitat is quite heterogeneous (Tracy et al. 2004). High-diversity planting could increase the chances that rare or endangered species residing in the natural habitats may be included. By planting diverse species, we may identify the most suitable species that are most likely to be successful and persistent and those that are least competitive and might disappear in subsequent years. At the same time, we would not miss other potentially adaptive and productive native species in the restored habitats. Historical vegetation data may be used to identify highly productive species but might not be enough, because disturbance regimes and other factors such as climate might have changed over time. Finally, a high-diversity planting may form persistent seed banks, which would help protect the area from the effects of further disturbances and by ensuring that species important for early succession stages are present in the seed banks.

What has gained less attention in traditional restoration is that logical plantation and management regimes should follow the evolutionary forces that favored the initial success, for example, best adaptation to climate change and disturbances such as fire. If phylogenetically close relatives could better resist invasions by closely related species because of using the similar resources (Cadotte et al. 2009), planting congeners would be an effective way to resist invasions of closely related exotic species. On the other hand, recent studies suggest that some hybrids between native and introduced species often show greater invasiveness (Gaskin et al. 2009). Thus, avoiding planting the native species or preventing possible introductions of close relative or sister exotic species that may form hybrid invasive species have become increasingly important.

15.6 Bottom-up, top-down, and multitrophic (or food-web) restoration

Most previous and ongoing restorations are focusing on a single trophic level, mostly in plant communities (or primary producer). However, many plant species are relying on animals that serve as agents of dispersal, pollination, or reproduction that may require a broad view of restoration. Other critical elements to be restored include fungi and soil microbes that some plants need. Therefore, the more effective ways for restoration could be to restore multiple trophic levels as they depend on each other for long-term survival. If herbivores' existence relies on their native predators, the latter will need to be introduced as well ("the trophic cascade hypothesis" or the food web theory) (see Hastings 1988). In this regard, the effective way could only be the "bottom-up" approach.

The most common approach of restoration in the past and at present is the bottom-up producer. In contrast, an alternative and new approach proposed would be, First, the much needed elements for producers (plants) such as below-ground communities (e.g., arbuscular mycorrhizal fungi—as a symbiotic supporting system) (Perry and Amaranthus 1990, van der Heijden 2004) may need to be restored with producers and other elements such as pollinators should follow immediately. Second, the top-down approach (restoration of consumers) should also follow when producers have established. For example, often top predators are needed to regulate lower-level predators and primary producers to maintain the established systems.

15.7 *Suggested restoration pathways*

Sites that have different levels of destruction or degradation may benefit from different restoration pathways. For example, in highly destructed grassland or forests, restoration often involves direct seeding of native species after pretreatment of soils to eliminate the seed banks of exotic species. Yet, in highly degraded habitats invaded by exotics, restorationists usually seed or plant native species on preexisting vegetation. Often, exotics are also useful for creating temporal favorable conditions, for example, for soil erosion control in early stages of succession (e.g., California chaparral and grassland after fires) or for creating initial habitats suitable for natives in forests (Williams 1997, Guo 2003, Ren et al. 2008). Although actual restoration processes may be complex and may need flexible justification from time to time, here we propose a simplified pathways or scenarios for consideration. First, in barren areas or highly degraded (destroyed) habitats where natives might not survive and establish, planting facilitating exotics would be necessary to ensure later colonization of native species (Figure 15.5). In such cases, natives are not suitable to be used, and suitable but noninvasive exotics are used at the initial stages because they can fix soil erosion or create benign conditions for natives (Path I in Figure 15.5) (Ren et al. 2008). Second, in most cases where exotic species already exist, restorationists are likely to plant native species directly onto preexisting vegetation and, therefore, forming a mix of both natives and exotics. In such conditions, however, exotics may be dominant, especially in early stages (Path II) (Guo et al. 2006). Third, in other cases where bare soils exist or can be fully treated to remove the seed banks of exotics, native species are planted directly to form native communities without exotics (e.g., many controlled seeding experiments in grasslands), although certain exotics might invade subsequently in the future (Path III). However, in all scenarios, given the ongoing (and even accelerating) species invasions and the fact that completely eradicating exotics is virtually impossible, an eventual habitat condition with both native and exotic coexistence may be acceptable. This is especially the case because restoration sites are most likely at places with great human disturbances and have been already invaded by exotic species. Intense management of exotics at such sites is needed to ensure the dominance of natives (Figures 15.5 and 15.6).

15.8 *Biomass manipulation and tradeoffs of enhancing biodiversity*

While most physical factors are almost completely beyond human control, careful manipulation of other factors such as fire, grazing, nutrient addition, and continued seeding is important for restoration and ecosystem performance (Bradshaw 1987). One needs to realize that restoration is a continuing process, rather than one-time event. Because much needed species, especially those that fail to establish after initial planting, will need to be planted until viable populations are established.

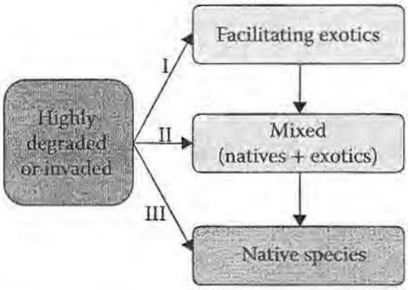

Figure 15.5 A sample of possible pathways in terms of species selection in restoration process. Highly degraded or invaded area includes all habitats that need to be restored (e.g., newly created bare grounds such as landslides and chemically treated areas for removing exotic seed banks). Path I: in barren areas or highly degraded (destroyed) habitats where natives might not survive and establish, planting facilitating exotics would be necessary to ensure later colonization of native species. In such cases, natives are not suitable to use, noninvasive exotics may be used at the initial stages because they can fix soil erosion or create suitable conditions for natives. Path II: in most cases where exotic species already exist, restorationists are likely to plant native species directly onto preexisting vegetation, therefore, forming a mix of both natives and exotics. Path III: in some cases where bare soils exist or can be fully treated to remove the seed banks of exotics, native species are planted directly to form native communities without exotics. However, in all scenarios, given the ongoing (and even accelerating) species invasions and the fact that completely eradicating exotics is impossible, an eventual acceptable habitat with both native and exotic coexistence may result. Proper control of exotics is needed to ensure the dominance of natives.

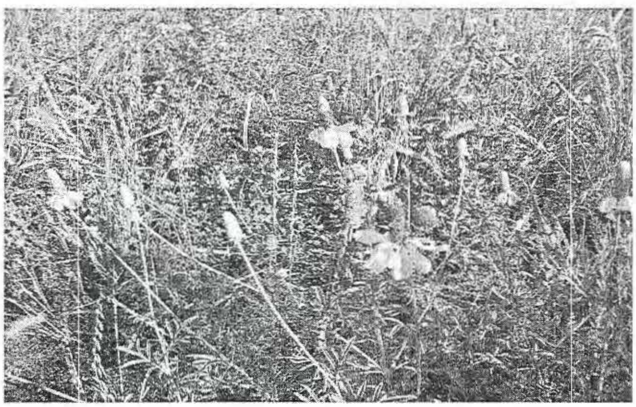

Figure 15.6 An example of restoration by seeding native species onto preexisting prairie grassland that had been heavily invaded by several exotics such as Canada thistle (*Cirsium arvense*), alfalfa (*Medicago sativa*), and smooth brome (*Bromus inermis*) near Jamestown, North Dakota, U.S.A. (photo by J. Schatz). During the first few years after seeding, natives and exotics appeared to coexist. (Adapted from Guo, Q., T. Shaffer, and T. Buhl, *Ecology Letters*, 9, 1284–1293, 2006.)

In management practices, biomass is the most easily and frequently manipulated variable (Huston 2004, Guo 2007). It is likely that after the community biomass reaches a certain level, some of the planted species will likely disappear because of increased competition or other environmental changes. Periodic removal of above-ground biomass through varying frequency, intensity, and timing of burning and grazing can often increase species diversity and habitat productivity. However, the optimal frequency and intensity of some of these activities in various habitats are often debated.

In habitats invaded by nonnative species, when total elimination of invasive species is not feasible, techniques that can effectively remove their biomass should be developed. However, although invasive species management usually adopts burning, grazing, physical or chemical treatment, and biocontrol agents, these practices are also disturbances and their effects on native species need to be evaluated. In addition, below-ground biomass, a frequently neglected factor, could also be considered in future restoration and management plans.

Management tradeoffs may develop from strategies designed to control invasives and the need for native species to migrate in response to climate change. Although enhanced species diversity at a site may slow the spread of problematic invasives in the near term, this change may close niches that are necessary for native species to effectively respond to environmental changes at the landscape scale. In other words, while increasing diversity may enhance resistance to invasives, it may *reduce* the ability of species to migrate or alter population densities at the landscape scale. Such factors need to be considered in restoration planning.

15.9 Perspectives

The effects of biomass on biodiversity and the effects of diversity on productivity are two closely linked foci in both basic and applied research. Most related studies have dealt with these two issues separately and their practical implications have not been given enough attention (Guo 2007). Experiments show the benefits of initial high-diversity planting. But what experiments to date have not been able to offer is when and where to plant what species first and what species (e.g., multitrophic) and where to follow. Such questions are at least equally important, if not more. Future restoration should focus on these issues in planning and actual efforts.

Human-driven changes are reflected in vastly disturbed habitats worldwide. This suggests that the high-end of the classic disturbance–diversity curve may be soon reached in these places, thereby threatening diversity (i.e., the intermediate disturbance hypothesis). How to reduce the effects from human activities amid ongoing efforts of economic growth and development is the major challenge in maintaining global or regional biodiversity and ecosystem health.

Many restored ecosystems seem unsustainable, especially those without continued management and subsequently invaded by highly invasive species (SER 2004). This is in part due to our lack of understanding of basic ecology needed in restoration and in part due to the lack of timely and efficient communication and proper application (Palmer et al. 1997). To effectively control biotic invasions, management and restoration must go hand in hand. In addition to the practical requirements for restoration, continuing and sometimes intensive management is necessary to effectively constrain biotic invasions and adapt climate change. For example, to preserve biodiversity, periodic thinning, burning, and grazing are needed to reduce biomass and competitive exclusion by invasive species.

Aside from biomass manipulation, restoration is also about how diversity manipulation (e.g., seeding, planting) affects biomass and productivity. For invasive species management, restoration is to build up enough abundance (biomass or cover) to constrain invasion. In most cases, optimal management often involves regulating biomass so that high diversity and productivity or other preferred habitat characteristics can be achieved and maintained, while restoration usually involves planting or seeding a certain number or combination of native species so that the native structure and function of the habitat can be restored and degraded ecosystems can recover faster.

15.10 Conclusions

In the past, the concept of restoration was useful to highlight the degree to which ecosystems had changed and how past conditions or dynamics often provided a better means for sustaining a wide assortment of ecosystem values. These have not changed. What has and will change is the degree to which conditions have been altered due to forest loss and fragmentation, invasive species, and climate change (Kohli et al. 2008). While historical conditions may have been useful in the past, trends toward increased novelty may require creative management strategies that are less and less guided by the past.

To retain its usefulness, the restoration concept must evolve past its historical usage. Restoration will always invoke the past, but less so as a goal and more as a justification for maintaining and enhancing site resilience of species and ecosystems. The word is also useful in a more general sense, as in restoring habitat structures that may include novel components that are engineered using exotic species. Our best options for achieving species conservation given the cumulative threats from invasives and climate change may be incompatible with restoration, even if it were possible.

Although many physical factors are clearly beyond our control, diversity and biomass can be manipulated through management. There is evidence that the optimal management that maintains higher biodiversity may to some degree buffer the adverse physical effects, especially those from catastrophic events. However, no matter how well designed, the newly restored ecosystems are most likely to be novel or different from the conditions if the habitats had not been altered by human activities. Thus, not only do we need historical information and past experience to help guide us in restoration and management efforts, but we also need to be creative to counter the new challenges that may emerge in the future (Falk et al. 2006).

In restoration, planting or encouraging the right species and an optimal level of native species richness would help achieve and maintain habitat productivity and stability. Such niche occupation and a high biomass or cover of native species would increase the resistance to biological invasion by nonnative species. In some cases, even using certain exotics with certain genetic or life history traits could help stabilize the systems and initially create more suitable habitats for natives. Future insights from the basic research on the relationships among diversity, biomass, and productivity and those between diversity and stability or resilience can offer better guidelines for efficient restoration and for reducing the effects of invasive species.

In short, while there is still no quick fix in restoration amid biotic invasions, continuing effective and proper management especially through biomass manipulation is crucial. We should keep in mind that restoration is a continuing, long-term effort and often involves intense follow-up management. A carefully designed and restored ecosystem may not be the ideal system a habitat might support, but it could become the best system that is practically achievable. In future efforts, projected changes in climate and from exotic invasions must be considered in restoration guidelines to ensure the desired outcomes and to avoid unintended consequences.

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