Ecological Restoration and Global Climate Change

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Abstract

There is an increasing consensus that global climate change occurs and that potential changes in climate are likely to have important regional consequences for biota and ecosystems. Ecological restoration, including (re)-afforestation and rehabilitation of degraded land, is included in the array of potential human responses to climate change. However, the implications of climate change for the broader practice of ecological restoration must be considered. In particular, the usefulness of historical ecosystem conditions as targets and references must be set against the likelihood that restoring these historic ecosystems is unlikely to be easy, or even possible, in the changed biophysical conditions of the future. We suggest that more consideration and debate needs to be directed at the implications of climate change for restoration practice.

Key words: climate change, ecosystem change, ecosystem function, historical ecosystem, restoration goals.

Introduction

In this paper, we examine the likely implications of global climate change for ecological restoration. Ecological restoration, particularly in terms of (re)afforestation and restoration of degraded agricultural land, is often seen as one of the important responses to climate change because such activities help influence the planet's carbon budget in a positive way (e.g., Watson et al. 2000; Munasinghe & Swart 2005). However, climate change also has the potential to significantly influence the practice and outcomes of ecological restoration carried out for other purposes because of the changed biophysical settings that will be prevalent in the future.

The practice of ecological restoration, and the science of restoration ecology, has developed rapidly over the past few decades to the extent that a cohesive body of theory is beginning to emerge that is linked to increasingly sophisticated restoration practices (e.g., Higgs 2003; van Andel & Aronson 2006; Falk et al. 2006). However, we need to ensure that the theory, and the practice, fit with the realities of our "brave new world," also known as our "planet in peril," where rapidly changing environmental and socioeconomic conditions seem to be spinning entirely out of control, or at least out of all historical ranges of variability.

Set against this is a tendency in much restoration practice, and indeed in much of the theoretical discussion on restoration, to respect historical conditions either as the basis for explicit objectives or to reset ecological processes to defined predisturbance conditions (e.g., White & Walker 1997; Swetnam et al. 1999; Egan & Howell 2001). Here we discuss the potential impacts of climate change on our ability to achieve such a goal and then suggest possible ways forward in framing meaningful and realistic restoration objectives for the future.

Climate Change Impacts

It is increasingly likely that the next century will be characterized by shifts in global weather patterns and climate regimes, according to current climate predictions (Watson et al. 2001; McCarthy et al. 2001; Munasinghe & Swart 2005). The predictions, although containing wide latitudes of potential outcome, are all pointing the same way:

- Changes in weather patterns
- Increases in mean temperatures
- Changes in patterns of precipitation
- Increasing incidence of extreme climatic events
- Increasing sea level

These changes are likely to be sudden (in some cases over periods of <5 years) and unpredictable as to timing and intensity. However, it is clear that even if immediate, concerted, and decisive action is taken, dramatic and significant changes are inevitable in the next 20–30 years. The ecological consequences of such changes are increasingly discussed in the literature (e.g., Hulme 2005; King 2005). There is mounting evidence that the impacts of climate change on plant and animal species and ecosystems can already be detected (Parmesan & Yohe 2003; Root et al. 2003). Can impact on the human species be any less?

Considerable uncertainty remains, however, concerning the direction and extent of change on a regional basis, and this poses significant challenges for restoration and ecosystem management in general. Indeed, such uncertainties can be seen as obstacles that prevent decisions being made (e.g., Lavendel 2003), despite the fact that it seems essential

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to incorporate serious consideration of expected future environments into restoration planning and practice.

Even without the predicted changes in climate over 50 years, the direct impacts of increasing CO_2 concentrations in the atmosphere would themselves have important implications for restoration practices. For instance, detailed studies of African savanna dynamics by Bond & Midgley (2000) and Bond et al. (2003) indicate that the balance between herbaceous and woody components of savannas is strongly linked to atmospheric CO_2 concentrations. This suggests that historical tree–grass proportions are unlikely to be replicated under current or future elevated CO_2 levels; hence, the restoration of savanna ecosystems to a previous state may not be possible in the future with reasonable effort. Concurrently, Bellamy et al. (2005) have demonstrated severe and rapid loss of carbon from soils in the United Kingdom attributed to climate change. This situation is likely to be ubiquitous in extratropical regions globally.

Although future climate change scenarios vary in intensity of impact (Watson et al. 2001), they share some common features, such as change in mean annual temperatures and changes in patterns of precipitation. In the southern United Kingdom, for example, the lowest impact scenarios have annual changes of +2.5°C and between 10 and 20% less precipitation, characterized by warmer, wetter winters and warmer, drier summers by 2080 (UKCIP 2005). Recent work to map changes in biophysical regime in the U.S.A. found that half of the area would have shifts in moisture, temperature, and soil conditions unable to sustain "historic" ecosystems in those areas, that is, those likely to be present pre-settlement (Saxon et al. 2005). More substantial change is anticipated for high northern latitudes, and evidence of significant change is already being detected (ACIA 2004). Within the next 100 years, and much sooner in some regions, prescribing restorations using purely historical references will prove increasingly challenging at best and at worst lead to failure.

Ecological restoration programs have a timescale of at least this long, particularly when considering wooded ecosystems and reestablishment of complex food chains. For example, there is much focus on conservation of "ancient" woodlands in the United Kingdom, ancient woodland being defined as "land believed to have been continuously wooded since at least 1600 AD" (Spencer and Kirby 1992). This leads to the question "how appropriate are historical ecosystem types when faced with rapidly changing biophysical conditions?" Is it appropriate to consider a temperate woodland restoration endpoint in an area likely to be flooded by rising sea level? Why establish wetland in an area likely to become semiarid?

As much as rapid climate change makes for difficult scientific and technical issues, there are vexing moral questions, too, that make our thinking and action even more complicated. Threatened species and ecosystems will be increasingly hard to predict, and their recovery more difficult, sometimes practically impossible, to achieve. Whatever means develop for restoring rapidly shifting ecosystems, the translocation of species is a likely technique. This bears the burden of breaking our relations with particular places and upsetting long-duration place-specific evolutionary processes. There is the hazard of becoming more comfortable with serving as active agents in ecosystems to the extent where historical fidelity is almost entirely abandoned. It is one matter to watch change happen in ecosystems and wonder how and how much to intervene, and quite another to become a determining agent in that change. How smart can we be, and how much hubris is there in presuming that we can understand and predict ecological change? Finally, and this is by no means an exhaustive list of moral concerns, there are consequences for the vitality of restoration as a practice in a broader public giving up critical support for ecological integrity when ecosystems are changing rapidly. Why, after all, support the finely honed techniques and ambitions of restoration when mere ecological productivity appears adequate?

Static Conservation and Restoration Objectives

The predicted climate change scenarios will thus be particularly challenging in the context of national legislative frameworks designed to protect habitat types and important species. In the United Kingdom, for example, the designation of Sites of Special Scientific Interest for wildlife protection is made on the basis of the presence of particular named species being present on those sites (Department for Environment, Food and Rural Affairs 2003). Similarly, in Canada, recent legislation to protect species at risk focuses primary attention on species instead of ecosystems at risk, which binds recovery and restoration efforts to targets that may become increasingly difficult and expensive to reach. As the biophysical envelope changes geographically, these sites will no longer support many of the species used in the notification and designation process, which must then bring their special status into question. How then are these species to be protected? Active ecological restoration of appropriate sites in new locations would appear to be one answer.

Conservation schemes tying assemblages to one place may actually lead to ossification of those ecosystems—in effect making them more fragile and less resilient by not providing space for the elements of the total gene pool on the fringes of the bell-curve niche space for occasional regeneration, and thereby reducing or eliminating the ability of the species and ecosystem to adapt to changes in biophysical regime. In a constant environment, for example, one forced by "conservative" conservation practices, an "optimum" phenotype is selected for, and extremes selected against. Individuals that vary from this mean are eliminated, reducing the potential for adaptation to a rapidly shifting biophysical regime, as may occur under certain climate change scenarios (Rice & Emery 2003).

This could be visualized by considering the two primary physical constraints to vegetation assemblage composition,

stress, and disturbance (Grime 1979). Here the stress, or adversity, of a system is any factor that prevents the community from accumulating more biomass; the limiting factor, which includes those other than nutrients (such as drought or temperature). Disturbance is a sudden event, which changes the nutrient status of an ecosystem; this may be an enrichment disturbance where additional resources remove the limits on the carrying capacity, or a destructive disturbance where part of the existing community is destroyed, releasing nutrients for the remaining community (e.g., gap formation by lightning strikes). The third factor is competition among organisms, but we can plot the first two to envisage a realizable niche space, within which assemblages move about in response to short-term fluctuations in biophysical conditions locally (Fig. 1a). Under rapid climate change scenarios some of these quasi-stable states are no longer viable, but new states are available (Fig. 1b). However, in assemblages that have been locked into place by overly prescriptive conservation management, including exclusion of all non-native species, these systems will not be able to respond—potentially leading to catastrophic failure (Fig. 1c).

In addition to the potential changes in climate, we must also consider the changed species mixes available to colonize disturbed or stressed sites. Deliberate and inadvertent transport of species round the world through increased trade is breaking down biogeographic barriers and leading to increasing numbers of species reaching places they would not normally be able to disperse to (Bright 1998; Mooney & Hobbs 2000). The combination of novel species mixes and altered biophysical settings is resulting in the development of a range of novel or *emerging* ecosystems that have unknown functional characteristics and that may be difficult or impossible to return to a prior condition (Milton 2003; Hobbs et al. 2006). The development of such novel ecosystems may also exacerbate the effects discussed above, resulting in some previously available quasi-stable ecosystem states no longer being viable and being replaced by these new ecosystem assemblages.

Ecosystem Assemblages or Functioning Ecosystems?

The most widely accepted definition of ecological restoration at present is:

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SERI 2004).

The critical question facing us is to elaborate appropriate strategies and tactics for restoration as thus defined in a world of rapidly changing climate regimes, when in many cases relying on historical references makes less

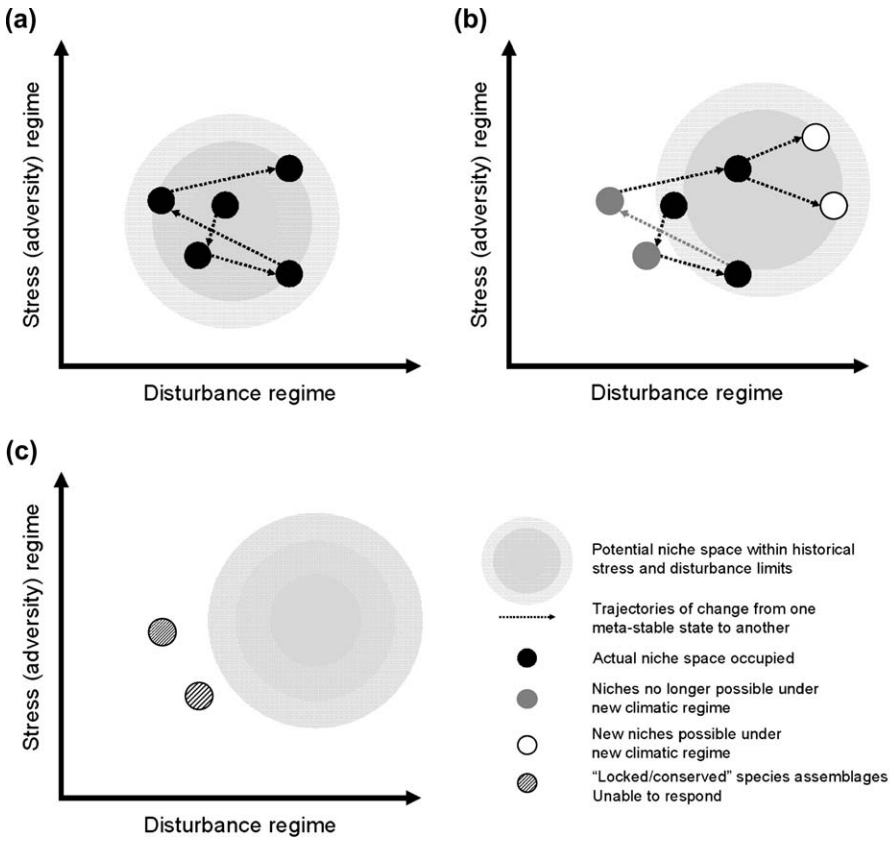

Figure 1. (a) Impact of normal climatic shifts on available niche space; (b) change in available niche space in response to changing climate; (c) "locked" assemblages unable to change in response to changing climate.

sense. Paradoxically, although specific historical references may be less useful as direct objectives, historical information documenting change may rise in importance in developing models for future ecosystem formations. It is our contention that we need to look outside of simple static species or community metrics to wider consideration of ecosystem functions and processes and that we must be realistic and pragmatic.

There is an increasing interest and application of the use of the concept of ecosystem goods and services, which accrue from the natural capital of the world's combined ecosystems (e.g., Costanza et al. 1997; Clewell 2000; Millennium Ecosystem Assessment 2003, 2005; Milton et al. 2003; Eftec 2005; Aronson et al. 2006). In effect, these goods and services are the annual interest arising from the composition and structure (stocks) of natural and mostly unmanaged ecological systems that, through their functioning, yield a flow of goods and services useful to people and all other living creatures. De Groot et al. (2002) outlined a typology of ecosystem service provisions to human society, based on *renewable* resources, the highest level of classification being regulation, habitat, production, and information functions, which were based upon ecosystem processes and characteristics and from which were derived goods and services used by humans. A total of 23 subfunctions were described with 37 goods and services derived from them, some examples of which are given in Table 1.

These resources are, of course, significantly reduced when ecosystems become degraded by intensive agriculture or pollution, severely reduced when surfaces are sealed by urban and infrastructure development, and permanently lost when species become extinct and ecosystem configurations are shifted into new realms of stability. The first two categories are potentially amenable to treatment, but the latter would require "Jurassic Park" type interventions—even if we knew the identities of *all* of the species lost to date.

The desire to reconcile utilitarian economic approaches to valuing ecosystems with biophysical realities presents global society with an intractable problem currently because our notions of wealth are inextricably linked to *potentially realizable* wealth as indicated by monetary instruments, as opposed to *actual* wealth represented by direct management of ecosystem functions, and the indirect and nonuse values of ecosystem services are hard to encompass, or monetize, in economic terms.

There is a way forward, however. The first step is to recognize that without the principal ecosystem functions and processes that characterize natural capital in place, no goods and services will accrue. Second, there are certain goods or services that already have a market value.

So, should we be focusing on past systems as the target for ecological restoration activities—or should we rather be reinstating the space and capacity for ecosystem functions and processes? Presumably in most cases, the matter will not be this stark, but in fact, these two general approaches constitute locations on a continuum from limited human intervention to complete control. Maintaining a commitment to history will remain important in restoration inasmuch that historical change becomes a crucial feature of understanding the range of ecosystems a particular place will support. The extent, pace, and spatial variation of climate-induced change will determine what approach can be taken. Restorationists will almost certainly rely more heavily in the future on the notion of "restoring natural capital" and restoration of delivery of ecosystem goods and services delivered by the ecosystem under consideration and not simply on those metrics based on the numbers and arrangement of the biota.

The principal objects of manipulation are the abiotic and biotic components, which we seek to change to overcome abiotic and biotic barriers (Hobbs & Harris 2001). For example, we may need to restore a dynamic water level regime, in terms of both amplitude and frequency, or reinstate heterogeneity to convert arable land to forest; these are both abiotic interventions. We may need to reintroduce species at a variety of trophic levels, from soil symbionts, through primary producers to herbivores and predators—some of which were not recently found on this

Table 1. Ecosystem functions with examples of processes, goods, and services (adapted from de Groot et al. 2002).

Ecosystem Function	*Ecosystem Process and Components*	*Goods and Services*
Regulation functions	Maintenance of essential ecological processes and life support processes	
Gas regulation	Biogeochemical cycling	UVb protection by ozone
Climate regulation	Influence of land-cover vegetation type	Maintenance of a favorable climate
Water supply	Filtering, retention, and storage of water	Provision of water for consumption
Habitat functions	Providing habitat for plant and animal species	
Refugium function	Niche availability	Maintenance of biological and genetic diversity (and hence most other functions)
Production functions	Provision of food and fiber	
Raw materials	Conversion of solar energy into edible plants and animals	Fuel, structural materials
Information functions	Providing opportunities for cognitive development	
	Cultural and artistic information	Use of nature as motive in books, film, and painting

site. Hence, an increasing emphasis will be on proper functioning condition of a site—ecological integrity—and to a lesser extent on nudging a site back to historical conditions based on species. In general, process, not structure, will prevail.

What Are Our Targets

Therefore, if we can now consider targets beyond historical references, intervention in two modes is appropriate:

- **Responsive:** judicious creation (and, where possible, restoration) of habitats of species designed to conserve and protect these assemblages in new areas made appropriate by changing biophysical conditions and to restore natural capital, and therefore ecosystem goods and services.
- **Proactive:** programs designed as active interventions to mitigate and reverse global climate change, that is, intended to sequester carbon and influence local climatic conditions.

This approach allows us to include in our targets considerations beyond those important for the site; for example, the intention to sequester carbon as a key ecosystem outcome may not be critical for the successful establishment of a functional ecosystem but has a positive impact far beyond it in terms of reducing radiative forcing.

A key question is how we go about setting targets using this innovative approach? Clearly, as has been argued in the past, we still need historical information, be it a historic ecosystem, nearby reference system, or time series data (e.g., Aronson et al. 1995; Egan & Howell 2001). However, the impacts of changing climate, especially when mixed with habitat destruction and modification (Travis 2003), mean that historical sources can be a guide but not necessarily a determinate prescription for what needs to be done (Higgs 2003). In that case, how do we incorporate considerations about future climate change into restoration goals and targets?

One way of addressing climate change impacts would be to consider the likely changes in species' ranges, which may occur in response to climate change. We already have in-depth understanding of how some species in some parts of the world have moved in the past in response to changing climates (e.g., Delcourt & Delcourt 1991; Davis 1994), and this is being employed to consider what future changes might occur (e.g., Iverson & Prasad 1998; Iverson et al. 2004). Further, an understanding of the climatic tolerances of species seems attainable by matching current distributions with key climatic variables. The resulting *bioclimatic envelope* gives some idea of species' climatic tolerances. Coupled with climate modeling, which can predict the future spatial extent of the bioclimatic envelope, this provides a method for assessing where the species' range might be under changed climatic conditions. This approach is being used extensively in assessing potential range shifts in response to climate change (e.g., Bakkenes et al. 2002; Berry et al. 2002; Skov & Svenning 2004), although there is ongoing debate as to its validity and limitations (Bakkenes et al. 2002; Berry et al. 2002; Hampe 2004; Pearson & Dawson 2003, 2004). Indeed, there are important considerations relating to whether species and communities are always in equilibrium with the prevailing climate (e.g., Davis 1986) and whether alternative stable states based on land use and disturbance history are likely to be important (e.g., Hobbs 1994).

Regardless of the exact process used to determine restoration targets, the key consideration should be to build resilience to future change into the restoration. This may mean including a wider range of species than would be prescribed based solely on the local ecosystems and cultural landscapes. It might also mean taking a broader landscape perspective and incorporating connectivity as a key characteristic to be maintained or restored, with a view to maintaining or improving the potential for species movement in response to changing climates (Hobbs & Hopkins 1991; Hannah et al. 2002*a*, *b*; Opdam & Wascher 2004; Skov & Svenning 2004).

Future Proofing Systems—Genetic Variability

A key attribute of ecosystems required to ensure resilience and adaptability is that of genetic diversity among and within species. Rice and Emery (2003) have suggested that space for evolutionary development must be incorporated into conservation and restoration programs.

An important aspect of this discussion is the extent to which it is desirable to limit the inclusion of species or populations in restoration projects to local species or provenances. Wherever possible, many restoration practitioners now strive to use plant material derived locally (e.g., Havens 1998; Lesica & Allendorf 1999; Hamilton 2001; Wilkinson 2001; Jones 2003; Krauss & Koch 2004). The assumptions underlying the exclusive use of local material are that it is likely to result in better restoration outcomes because local species/populations are better adapted to the local environment, provide better habitat, maintain the genetic integrity of the site, and prevent any potential pollution of the local gene pool. By insisting on the exclusive use of local material, we may however be consigning restoration projects to a genetic dead end that does not allow for the rapid adaptation to changed circumstances that may be needed if climate change scenarios proceed as predicted. What this means in terms of the design of restoration projects and the use of material of differing genetic origins needs careful thought and is obviously likely to vary from case to case. The use of common garden experiments, for example, in which various regional conditions are tested for flourishing of plant species, is an important step in understanding the practical role of genetic variability in ecological restoration. Such an approach is consistent with an overall attitude that we believe should be central for restorationists: proactive research and action on climate change.

Which Way to the Future?

Ecological restoration is increasingly used as a primary component of humanity's toolbox, which will be required to respond and adapt to the anticipated changes in global and regional climate. In order for ecological restoration to realize its potential as a key tool in managing the challenge of climate change, conventional approaches that rely exclusively on historical references are insufficient. Among our goals should be the continued protection of species and ecosystems at risk, with an understanding that the latter is a more realistic approach than the former, as well as the reinstatement of natural capital with the explicit aim of enhancing ecosystem service provision at local, regional, national, and global scales.

Implications for Practice

We end by listing a series of important but perplexing issues that need more detailed and considered discussion within restoration theory and practice:

- The ecosystems we manage and restore are complex systems that often have nonlinear and unpredictable behavior. Our understanding of how systems work under current conditions is often rudimentary, and we often have to learn as we go.
- To this complexity and lack of understanding, we now have to add the fact that environments are changing, and the rate of change is unprecedented. The past is no longer a prescriptive guide for what might happen in the future. There is a large component of ecological restoration that still places considerable value on past ecosystems and seeks to restore the system's characteristics to its past state. Valuing the past when the past is not an accurate indicator for the future may fulfill a nostalgic need but may ultimately be counterproductive in terms of achieving realistic and lasting restoration outcomes. The past should serve as a guide—not a straightjacket—and also should temper our ambitions toward unfettered design and development (Higgs 2003).
- Hence, a key question for everyone involved in restoration is the proper balance between rebuilding past systems and attempting to build resilient systems for the future. Perhaps in some cases, both goals are achievable, but the prognosis seems to be that this may not always be the case.
- We must tread very carefully. A consequence of rapid climate change may be the loss of public interest in conservation and restoration goals. Inured to the change, the idea of supporting painstaking restoration goals will give way to functional, emergent, and designer ecosystems. Clear discussion and debate is required on the question of when traditional restoration goals are appropriate and when more functional and design-driven goals are necessary.

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