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Flexible and Adaptable Restoration: An Example from South Korea

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Abstract

Ecological restoration is set to play a key role in mitigating biodiversity loss. While many restorationists worry about what to do about and what to call rapidly changing ecosystems (no-analog, novel, or other terms), ecologists and managers in some parts of the world have avoided these controversies and proceeded with developing and implementing innovative restoration projects. We discuss examples from South Korea, including the Cheonggyecheon river project in Seoul and the new National Institute of Ecology, which combines scientific research, planted reference systems for future restoration, and an Ecorium for outreach and education. South Korea faces a range of restoration challenges, including managing even-aged planted forests, major land use changes (especially urbanization) affecting valuable tidal flats, and fragmented landscapes caused by intensive land use and the fenced Demilitarized Zone (DMZ). The examples from South Korea provide insights that might guide future actions more broadly. These include flexible targets for restoration not based on historical precedents, considering ecosystem functions and functional trait diversity as well as species composition, creating model restoration projects, and managing adaptively.

Key words: biodiversity, novel ecosystems, reference systems, restoration targets.

Introduction

Ecological restoration is set to play a key role in reducing biodiversity loss at a global as well as local scale (Keenleyside et al. 2012; Aronson & Alexander 2013; Mentz et al. 2013). Changes in land use, climate and biogeochemistry, as well as shifting cultural and economic perspectives on nature and invasive species, are altering the global environment, reducing earth's biodiversity and constraining the ability to restore degraded ecosystems and their services, ultimately threatening human well-being (Harris et al. 2006; Parmesan 2006; Klein Goldeweijk et al. 2011). Given the immense pressure of human population growth on the biosphere, restoration of degraded ecosystems will no doubt be an essential part of conservation efforts aimed at mitigation of biodiversity loss. The early idea that restorationists can fully replace lost structural and functional attributes of ecosystems is waning in many circumstances, however. It is becoming clear that, in setting future goals, historical knowledge will become less of a template and more of a guide. While new terms have been proposed for the field, the word "restoration" is pervasive. It might be easier to redefine the concept (keeping the term) and accept the vastly changed face of the biosphere as a result of human activities. We may shift from restoration based on singular trajectories rooted in historical composition and function, to using history as a guide that allows multiple trajectories and a pragmatic emphasis on ecological processes (Choi 2007; Choi et al. 2008).

More recently, the concept of novel ecosystems (Hobbs et al. 2009; Zedler et al. 2012; Hobbs et al. 2013) has been proposed as a means for allowing more flexible goals for biodiversity conservation under conditions of rapid change and significant alteration. Novel ecosystems are defined as "system(s) of abiotic, biotic, and social components (and their interactions) that, by virtue of human influence, differ from those that prevailed historically, having a tendency to self-organize and manifest novel qualities without intensive human management" (Hobbs et al. 2013). For example, many grasslands and shrublands in California have been transformed by nitrogen deposition, which supports exotic annuals and makes these ecosystems very difficult to restore (Fenn et al. 2010). Setting goals of historical composition and function for restoration is becoming more difficult in a growing number of cases, and this difficulty will likely intensify in the years to come. Thus, there will probably be a period of turbulence in sorting out approaches that reflect various

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underlying values along a range of commitment from composition (e.g. strict restoration) to management for specific ecosystem services. Throughout, there are concerns that will arise about how malleable the concept of restoration is, whether novel ecosystems represent a slippery slope toward greater human control of ecosystems, and the importance of historical knowledge in setting goals for conservation and restoration (Standish et al. 2013).

In this article, we consider possible attributes for future-oriented restoration that work toward solutions to these problems. We provide illustrative examples from South Korea, where ecologists and managers appear to have generally stepped around these emerging controversies. Instead restoration projects of impressive scope and scale have been developed and implemented, which already adopt a flexible and pragmatic understanding of restoration.

Restoration challenges in South Korea

South Korea is the southern portion (approximately 100,000 km^2) of the Korean peninsula, which extends approximately 1,100 km from mainland Asia in the north to the South Sea (also known as East China Sea) and is flanked by the Yellow Sea in the west and the East Sea (also known as Sea of Japan) with a width of approximately 170 km (Shin 2002). On its northern border is North Korea, which was separated during the Korean War (1950–1953) and has maintained a largely impermeable political and ecological border for more than sixty years (Kim 1997; Korean Forestry Research Institute 2004). South Korea has extensive mountainous terrain, with narrow coastal plains (east and south) and a broader coastal plain on the west, much of which has been "reclaimed" (modified by massive engineering efforts). The climate is influenced by continental systems that produce monsoonal conditions (June to July), and a wide temperature range (hot summer and cold winters). The southern reaches of the peninsula are subtropical (Shin 2002). Extensive defoliation during the Korean War, and subsequent deforestation for development, agriculture, and industrialization, impacted almost all ecosystems. The extent of degradation over such a brief interval created social and political momentum for conservation and restoration and propelled a number of ambitious afforestation and restoration projects in recent years. The conurbation of Seoul (National Capital Area) in the northwest of the country is the second largest in the world with more than 24 million people, and it has promoted extensive urban and peri-urban conservation and restoration projects. South Korea is one of the most densely populated countries in the world (10 times the global average) and one of the most ethnically homogenous (>99% with Korean ethnicity) (OECD 1997). The setting for ambitious and creative restoration projects is distinctive.

Four restoration challenges stand out: reforestation issues, reconnecting fragmented wild-land in the Demilitarized Zone (DMZ), restoring critical areas of the modified west coast, and restoring biodiversity in cities. Most of the montane forests were damaged during the Japanese occupation period and the Korean War, after which around 2 million ha of forests were replanted to control erosion and to provide fuel wood and lumber (Tak et al. 2007). But economic development since then has led rural people to move to cities and allowed South Korea to import its required timber. Many of the plantations, which involve a variety of species, are now valued as much for their ecosystem services, such as wildlife support and clean water, as for their wood products. The issue is how to manage the composition and structure of these largely even-aged pine and oak-dominated forests and to move toward creating self-sustaining and uneven-aged forests (Tak et al. 2007). There are now a number of longer-term efforts to restore from even-aged to uneven aged to self-sustaining forests (Kerr et al. 2010). Dominance of many plantations by non-native trees (e.g. North American pitch pine *Pinus rigida*, Japanese larch *Larix leptolepis*, and black locust *Robinia pseudoacacia*) is a particular concern. Research is needed to determine how to manage these reforested lands so that they can best support native wildlife and provide other ecosystem services. If even-aged forests are unsuitable for wildlife, how should they be improved on the scale needed to make a difference? Rare mammals and birds can and are being bred for translocation, but habitat needs to be restored for these species to achieve sustainable populations. International exchanges of research experiences, including programs with significant public support, could help address the challenge of restoring Korean forests. Recent research in South Korea confirming the transformation of the exotic black locust plantations, suggests promising ways forward. The floristic composition of the new restored forest resembled the native vegetation, and the successional trend was toward the native oak stands (Lee et al. 2004a). In addition, most of the plantations including pitch pine and Japanese larch showed similar trends (Lee et al. 2004b).

The second challenge is reconnecting lands fragmented by the large, fenced DMZ and by intensive land uses. The (approximately) 250 km long DMZ bisects the Korean peninsula, isolating north and south populations of animals. Connectivity is needed to remove impediments to species migration from south to north under a warming climate. At the same time, the entire DMZ area contains relatively intact systems. These could provide a wide array of reference systems for numerous ecosystem and landscape types (Kim 1997; Korea Forestry Research Institute 2004). The Yongnup bog is one example; it is relatively intact, but its hydrological connections are affected by political decisions (Kang & Yoshioka 2006). Additional reference ecosystems are being established at the 2-ha site of the newly established National Institute of Ecology (NIE; see below for more details of the institute). While these will be smaller than needed to assess the full array of natural ecosystem functions, research on relocation and replanting methods will inform larger efforts beyond the NIE site.

A third major challenge is restoring west coast ecosystems that were diked to support highways and restrict tidal flows. Impacts include degradation of nearby forests and wetlands following rapid development and urban/industrial sprawl. Recent reclamation has focused on diked rice fields where irrigation caused eutrophication and diversity loss (Khim et al. 1999). Projects for degraded tidal flats include opening floodgates to reintroduce tidal flow, restoring wetlands, and designating large coastal areas as an ecological network. Migratory birds and other species are recovering (Sato & Koh 2004; Lee et al. 2004c; Yoo et al. 2010), although sustaining tidal power and causeways will permanently alter tidal flows and salinities. As these key drivers of estuarine ecosystems shift, unique combinations of marine, brackish, and freshwater species will probably result—and with no natural counterparts to serve as reference ecosystems. Still, research is needed to identify the requirements of native and highly valued species. And landscape-scale plans are needed to guide restoration of remaining wetlands with shifting salinities, recognizing where freshwater will dominate and where achievable goals are needed (National Institute of Environmental Research 2008).

The fourth restoration challenge is addressing biodiversity loss within densely populated urban and peri-urban regions. The recent "daylighting" of Cheonggyecheon River in central Seoul (Morse et al. 2007, Fig. 3) is the most prominent restoration project of recent years and an example of the complex interplay of ecological and cultural values typical of urban projects. A 5.8-km section of the river in the middle of the city had been degraded and polluted early in the twentieth century, then covered with concrete to create a major city street, then augmented with a bi-level freeway on pedestals in the late twentieth century. The idea to remove the concrete and re-create access to the waterway seemed an impossible goal in the core of one of the world's largest cities, but strong stakeholder support, and political leadership made it happen. The Cheonggyecheon River is now a linear urban park with streamside plantings of >200 native plant species and numerous bridges that depict historical, modern, and futuristic designs from the narrow upstream "headwater" to the broad downstream section, where urban gardens and playgrounds serve a wide range of human needs. Among the new amenities are sidewalks, accessible shorelines, and people crosswalks (Lee & Kang 2006; Lee 2010).

The Cheonggyecheon River project gestures to important natural and cultural history, but practical limitations of restoration in such a dense urban site compelled some radical departures from historical reference conditions. During the early development of Seoul (fourteenth–twentieth centuries) the stream was intermittent, carrying water mainly during monsoon months. The "restored" river is not reconnected to former headwaters; instead, water is pumped from a treatment facility to augment natural surface and subsurface flows (Reif 2010). Restoration to a historical condition would have required remodeling central Seoul, replacing the straight channel with meanders, swapping the concrete river bottom with natural materials, and convincing the public to support even more costly actions that would still not "turn back the clock." Instead, the design drew from historical cues, including recognition of the stream as key factor in the original siting of Seoul, and it brought a widely appreciated riverine park to the heart of the city (Lee 2010). While not restoration in a strict ecological sense (Lee 2010; Reif 2010), the Cheonggyecheon project reflects a rich cultural and natural history, returning to memory an important stream that defines Seoul. It is also emblematic of the ambitious, large-scale, and flexible approach taken to revitalize a historic river (Busquets 2011).

The approaches taken to these challenges demonstrate an apparent willingness to try new approaches to seemingly intractable problems and a capacity to implement adaptive ecosystem management in the face of rapid directional change. These approaches are not without controversy, of course, and there are culturally and politically specific reasons why some of what is possible in South Korea might not transfer easily to other jurisdictions.

For example, in recent Korean history strong driving forces of extensive environmental destruction during the Korean War were followed by extremely rapid industrialization, leading to large-scale changes in Korean ecosystems. As a consequence South Korea is a country with strongly human-dominated ecosystems while at the same time having an enormous potential for restoration of degraded landscapes. The pragmatic approach to restoration may not be the most appropriate way forward in historically less human-dominated landscapes, where best options for restoration involve allowing nature to regenerate with little assistance except maintaining extensive management. Nevertheless, the Korean restoration approach in its sheer extent, together with the need to focus more on the future (rather than on the past), provides insights into restoration opportunities in more human-disturbed landscapes. As global change accelerates, more and more of the earth's landscape will fall into this category.

In October 2012, the central government of South Korea completed the construction of the NIE, near the west coast in Seocheon County, where research, education, and outreach now address how best to meet restoration challenges in a land with highly modified environments and threats from climate change (Figs. 1–3). Below we examine how some of the approaches underway in South Korea can inform future-oriented research aimed at solving the principal restoration challenges being faced in Korea and worldwide.

Possible attributes of future restoration

We present nine attributes or approaches in South Korean ecological restoration that reflect recent trends and debates in restoration:

1. It may be appropriate to consider broader and more flexible restoration targets for the future that are rooted in historical understanding of ecosystems without necessarily viewing historical conditions as a template. The restored ecosystem that is fitted to match historical environments may not thrive or even survive in the uncertain and changed future environment. This kind of flexible thinking was evident in many projects. For example, the Hangang Parks network along the Han River in Seoul comprises 12 parks that mix biodiversity and social values. Extensive restoration efforts in some of the parks have interpreted ecological history in light of intensive urban development. Multiple restoration trajectories and goals are essential to hit the future's "moving targets" (Choi et al. 2008).

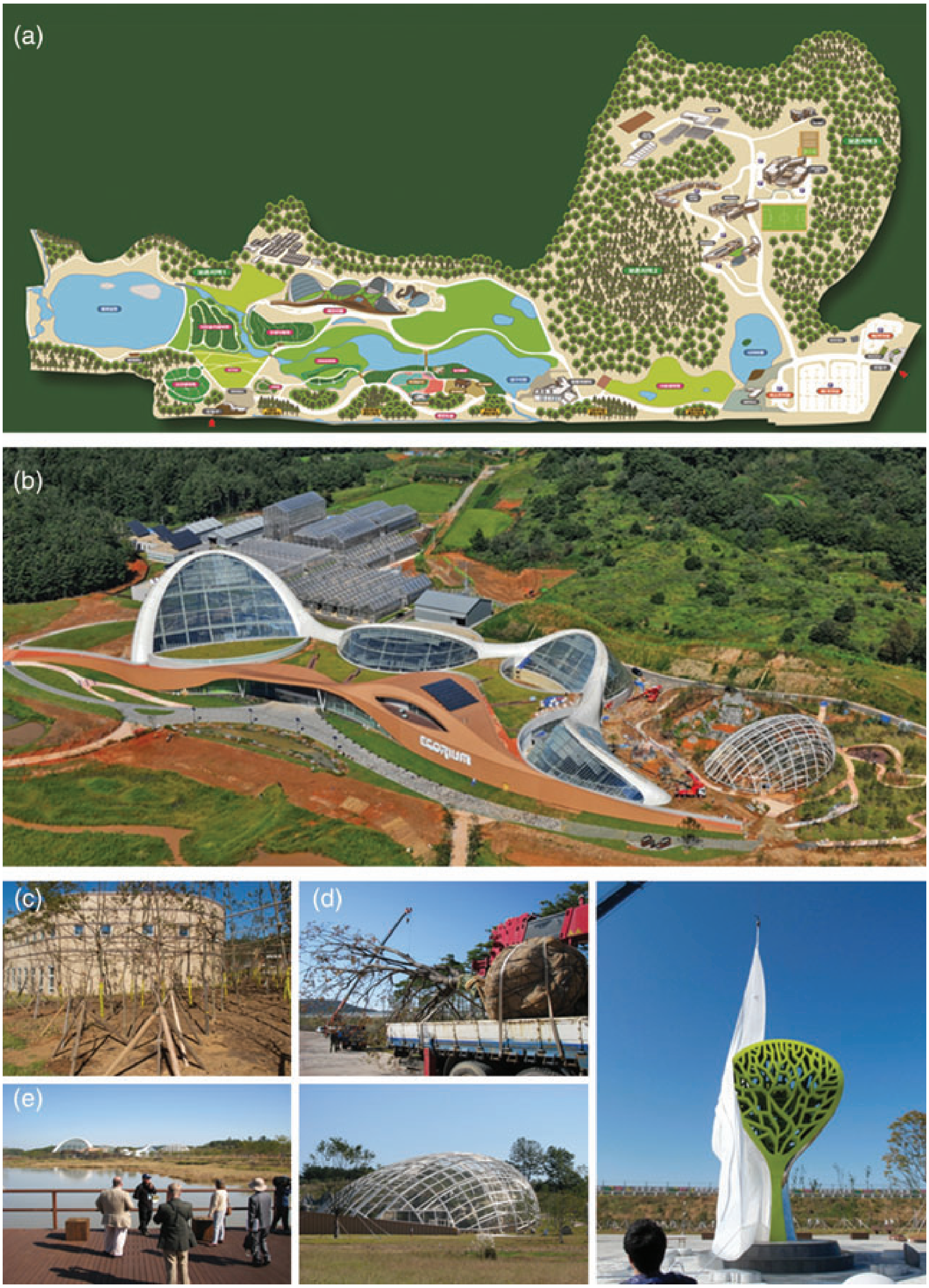

Figure 1. Views of the National Institute of Ecology (NIE) in Seocheon, South Korea. (a) Overview map of the NIE created over an area of 100 ha, with the *Ecorium* in the middle and the research complex to the top right. (b) View of the *Ecorium* complex including glass domes with tropical, desert, Mediterranean, warm temperate, and arctic biomes. (c) View of the main institute building with tree transplanting in front, based on natural species combinations and densities found in oak and pine forests. (d) Transport of trees extracted from local forests that are being planted on the campus site; this example with a large tree that required a truck to transport it alone, shows the scale of the restoration activities. (e) View of the *Ecorium* Botanic Gardens behind the restored wetland site, with Prof. Chang-Seok Lee describing activities to the guests. The site includes 8 acres of constructed ecosystems and four greenhouse domes housing many different vegetation types from around the globe. The center also focuses strongly on public outreach and education and has a large visitor center as well as guest apartments for visiting scientists. (f) View of one of the *Ecorium* domes which houses the tropical habitats of the new Botanic Gardens. (g) The unveiling of the tree/seedling symbol of NIE at the opening ceremony in October 2012, attended by Korea's Vice-Minister of the Environment and the Governor of Seocheon County. All photos taken by V. Temperton and Eric Higgs except (a) and (b), which are provided by the NIE.

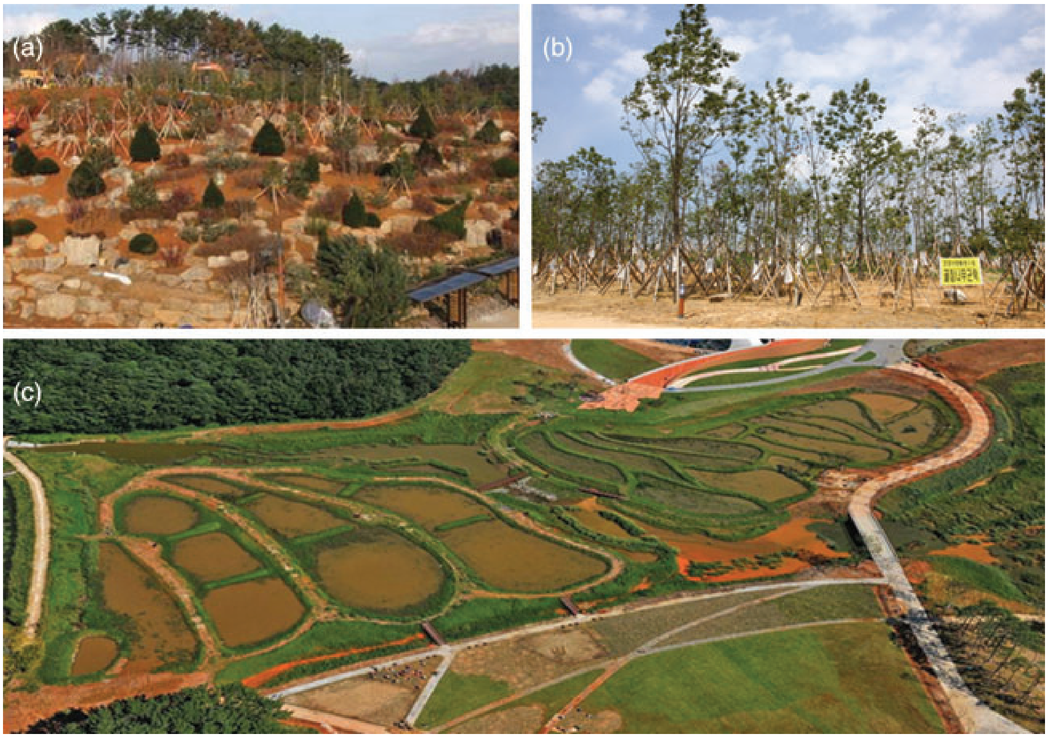

Figure 2. Examples of some of the reference systems being created at NIE as part of the goal to inform future restoration projects. (a) Alpine garden created based on ecological design including cooling of area to simulate alpine environments. (b) *Quercus variabilis*-dominated forest created using the composition and spatial distribution of natural forests as a reference for future restoration projects. (c) Wetland garden created based on the same principles as those applied in examples provided in B.

2. The setting of appropriate goals for restoration, and the determination of a social license to proceed, will require extensive and ongoing deliberation at all levels from neighborhoods to nations (Hobbs 2007). Humanity has entered an era in which social deliberation accompanies ecological understanding to determine appropriate and forward-thinking interventions. This is especially the case in urban regions, where historical references may be largely erased, and extensive effort is required to recover lost knowledge and incorporate myriad perspectives about urban ecosystems (Gobster 2000). Rapid environmental, ecological, and cultural changes will be disorienting, and deliberation will help in identifying and addressing concerns about novel ecosystems.
3. The NIE in South Korea, with priority given to restoration research and education, provides significant capacity for restoration and sends a strong signal about the importance of restoration at a national level. This is a compelling model for concentrating restoration research in other countries, and eventually for linking these together in a global network, as discussed by Menz et al. (2013). Within the Institute (Figs. 1 & 2) are experiments that provide guiding principles for future restoration in Korea, including restoration of remnant forested ecosystems, field testing of new methods, adaptive decision-making, social science studies, and controlled assembly experiments. Research is coupled to education, and there are overnight facilities for field- and workshop-based courses. Significant also is the attention given to broader public education. The Ecorium, a series of large artificial biome exhibits, is served by high speed rail so that public visitors can become more aware of biodiversity conservation and restoration. The concentration of effort at the Institute encourages the exploration of critical unknowns in restoration. A few priority examples are the soil biota and the conditions they require, how and why diversity and ecosystem services can be optimized for both temperate grasslands and wetlands (which often have quite different diversity–function relationships; Marquard et al. 2009; Zedler et al. 2012), how even- versus multi-age forests provide wildlife habitat and other ecosystem services, how plants and animals will establish and persist under changing environments, and how ecosystems will respond to extreme events that differ in frequency, intensity, and sequence. Long-term ecological research will be needed in new reference sites to study and assess a broad suite of biogeochemical processes.
4. Future restoration targets will need to achieve a balance between ecosystem services and the re-assembly of historical communities. A dynamic, negotiated balance will differ from ecosystem to ecosystem, and more significant levels of change will entail a focus on services over composition. The compositions in the future may not match ones that occur now or in the past. Certain species may fill desirable functional roles that become vacated by contemporary species.

Figure 3. Various views of the rehabilitation of the Cheonggyecheon River in central Seoul. (a) A birds-eye view taken in October 2012 of the rehabilitated river running through the center of Seoul where there used to be a major highway. (b) View of the few remaining highway supports left standing after the "daylighting" of the ancient water course that had been covered by a road and topped by a highway. (c) Created island sandbar habitats in the river, further upstream from central Seoul, one of a whole range of restoration measures undertaken to improve habitat structure for plants and birds and invertebrates. (d) A view of the river downstream (around 6 km from the center of Seoul) which is starting to resemble a more natural river, and already harbors a high diversity of birds.

In this sense, incoming species can be evaluated for functional equivalency with species in severe decline for inclusion in novel guilds (Hobbs et al. 2009). Adaptive management will include assessments of the extent of both negative and positive impacts of species that are new to the community (Shackelford et al. 2013). This difficult and contentious proposition is increasingly important to consider, as ecosystems are being homogenized on a global level by interchange of species. Early acknowledgment and action on this and related issues seem preferable to neglect. The Korean examples provide three potential strategies. First, sustain biodiversity at regional scales, rather than attempting to match future distributions with their exact historical pattern. Second, restoring species might best be developed within biogeographic regions, permitting introductions to specific sites even where there were no known historical occurrences. Such introductions may be different from assisted colonization in the past, in that the key focus may be as much on adaptation to a changing climate as to the reintroduction of an endangered species. Third, restoration sites can be used to learn which targets are most achievable through experimentation over time and space, then those targets can be selected for broader testing, in an adaptive restoration framework (Zedler et al. 2012).

5. Where human impacts are massive and persistent, restoration is not expected to turn back the clock. For instance, where invasive clonal plants form productive monotypes in wetlands enriched by urban and agricultural watersheds flows, it will be necessary to acknowledge the ability of productive species to persist under future climates with increased flows, more extreme storm water pulses, and greater nutrient influxes. Where nitrogen (N) deposition from urban and agricultural sources causes eutrophication of terrestrial and aquatic ecosystems, productivity will change, plant species will shift in abundance, and species richness will decline. Invasive species that take up N at high rates will likely dominate (Fenn et al. 2010; Pardo et al. 2011). Even in the absence of invasive species, some native species, such as certain grasses, may dominate and decrease richness (Stevens et al. 2004).
6. Adaptive management provides advantages for restoration under conditions or rapid environmental change and shifting socioeconomic patterns. For example, working out ways to convert abundant even-aged forests planted after the Korean War to uneven-aged and more diverse forests (Angelstam 1998; Kerr et al. 2010) will require application of best available scientific and management knowledge and adaptive management. As methods are improved, efforts can be expanded to incrementally increase forest diversity and structural complexity. When social and economic circumstances change and opportunities arise in places where restoration was not previously possible, a flexible approach allows the both modification of existing ecosystems and reassembly on new sites.
7. Ecosystem resilience in the face of rapid change is a priority attribute of effective restoration (Walker & Salt 2006; Lamb

2011). The flexible interpretation of restoration observed in South Korea may provide pathways toward greater resilience. This involves acknowledging significant constraints (urbanization, biogeochemical changes), while having the audacity to work on behalf of biodiversity conservation, maintaining some historical continuity, however, attenuated it may become.

8. Including human interests in restoration designs gives greater emphasis to the social and economic context in which restoration is done. This is increasingly important due to uncertainties imposed by climate change and the conflict between economic progress and environmental preservation, including challenges of poverty alleviation (Hobbs 2007). South Korean restoration projects emphasized human engagement through direct involvement in planning and planting, for example, and recreational amenities incorporated within various projects (e.g. walkways, picnic sites, athletic facilities, contemplative gardens).
9. Innovative approaches to restoration will also entail developing and adapting enabling policies, regulations, practices, and engagement (Bridgewater & Yung 2013). This helps ensure that ecosystem priorities remain relevant in the face of rapid development and environmental change. This is evident in Seoul, where restoration is encouraged in spite of the odds against it in one of the world's largest and most densely populated cities. Development of progressive policy helps avoid perverse outcomes, such as the forfeit of major ecological connectivity in favor of recovering individual populations of threatened species. There are no simple one-size-fits-all policy solutions, and approaches will vary among jurisdictions, as discussed at the 2012 IUCN World Conservation Congress in Jeju, South Korea. At this meeting the World Commission on Protected Areas released the first international compendium of principles, guidelines, and best practices for ecological restoration (Aronson & Alexander 2013). The approach of adopting principles and guidelines allows flexible implementation and still preserves essential elements of "effective, efficient, and engaging" restoration (Keenleyside et al. 2012).

Implications for Practice

- South Korea's social, historical, political, and ecological circumstances have created a distinctive approach to ecological restoration that holds relevance for restoration science and practice elsewhere.
- There is an increasing need for more flexible targets, adaptive restoration approaches, concentrated research nodes, innovative policies, and emphasis on human engagement.
- Models from densely populated regions and countries can offer important innovations for both the science and practice of restoration.

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