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Restoration for the Future: Endpoints, Targets, and Indicators of Progress and Success

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Setting endpoints and targets in forest restoration is a complicated task that is best accomplished in cooperative partnerships that account for the ecology of the system, production of desired ecosystem goods and services, economics and well-being of society, and future environments. Clearly described and quantitative endpoints and intermediary targets are needed to manage restoration of ecosystem structure, composition, function, and production. Selecting indicators of key ecosystem attributes that are linked to endpoint and target condition, function, sustainability, health, integrity, resilience, and production is important to monitoring restoration success. Indicators are used to track ecosystem trajectory, assess progress toward achieving endpoints and targets, adapt management, and communicate with external publics. Reference sites can be used to help set endpoints and targets with caution. Other science-based ecosystem models or management tools are available to help quantify intermediate targets and endpoints. Continued work to better understand historic ecosystem conditions is fundamental to assessing change, extent of damage, and restoration potential. A hierarchy of forest plans from regional and landscape to site specific are useful for defining endpoints, targets, and indicators at appropriate ecological scales; and to consider populations, ecosystem function, and socioeconomic factors that operate at a variety of scales.

KEYWORDS *restoration, monitoring, ecosystem function, indicators, targets*

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INTRODUCTION

Restoration of forests naturally implies returning to a previous condition that has been in some way degraded over time. It is a concept in natural resource management that has risen to public prominence with the realization that modern society has degraded the quality of forests or lessened their ability to provide goods and services through the loss of key components and species that impede or disrupt processes important to function, productivity, and sustainability. Even in more intact forests, the accelerated rate of change that commenced with the agricultural and industrial revolution in North America is viewed as a threat to the ability of the forest to adapt to rapidly changing environmental stresses, invasive species, or other perturbations without loss of diversity, function, or productivity. A common future target or endpoint therefore is to go back to the future—i.e., to restore over time the structure, composition, and function of some historic condition that represents a time before significant ecological loss.

Restoration and subsequent sustainable management require planning of activities that result in desired future ecosystem states and functions. Endpoints and intermediate targets need to be well-defined to facilitate achievement of management goals and objectives and to guide selection and timing of needed practices. Unclear, nonspecific endpoints obfuscate design of restoration operations, cloud knowing when the process is complete, add to confusion and dissension among interest groups, and muddle communications with the general public. Lack of intermediate targets allows the development of undesirable conditions to become big and expensive problems before they are discovered. Indicators of desired ecosystem attributes help managers assess restoration progress and signal when the restoration endpoints have been met.

Setting endpoints and targets in ecosystem restoration, and the selection of indicators to measure success are influenced by the underlying view on the role of humans in development of natural systems. Therefore, this article begins with a discussion of the inherent role and influence of humans on natural systems. Many of the natural communities that predate European settlement that are priorities for restoration were strongly human disturbance mediated systems such as woodlands, savannas, and prairies especially in eastern North America. We posit that restoration requires active management to mimic historic human influence on such ecosystems. We recognize that the degree of human influence varied greatly spatially and temporally but was ubiquitous in general in the past. Further, it is not without precedence to include human needs in desired endpoints and targets, or to use measures of productivity, yield, and value as indicators of restoration success. We must understand ecological history for context in restoration, to determine change, to define potential, to set reasonable endpoints and targets, and to prescribe treatments. Some endpoints transcend any difference in viewpoints on the role of humans in restoration such as conserving biodiversity, or managing for resilience in the face of uncertain futures and threats. The article explores setting endpoints and targets, the selection of indicators, the use of reference sites and ecological models to quantify endpoints, targets and identify indicator thresholds, the role of monitoring, and continued active management in sustaining restored systems. Indicators must be scale appropriate and the hierarchy of land planning documents lends itself well to incorporating indicators into an eco-hierarchical framework. Monitoring intermediate targets with an array of indicators provides early feedback and indicates the need for remedial action and modification of practices. We discuss these topics in a logical progression from restoration planning to sustainable management of restored ecosystems. This is not a manual on how to work in partnerships to set endpoints, targets, and indicators. Rather, it is our hope that this discussion will highlight the importance of having clearly described, quantitative endpoints and targets for key stages in the restoration process, and practical indicators for measuring progress and success. We emphasize the need to restore functional ecosystems that are resilient to environmental changes and biological threats; productive contributors to the well-being of society; and sustainable ecologically, economically, and socially. Until now, restoration has been guided primarily by ecological considerations, a desire to return to pre-European conditions in the absence of social interactions or context, and a philosophy of naturalism that excludes humans. Restoration for the future bridges the chasm between the ecological and the social realms.

SETTING ENDPOINTS AND TARGETS

The Historic Role of Humans in Developing Ecosystems

Often the endpoint of restoration is set by what we believe was here before European settlement. This is a common historic period or signature event in the transformation of North American ecosystems. Proponents of this viewpoint may rationalize that North American Indians lived in harmony with nature or were so few in number before European settlement that they had little influence on vegetation and ecosystem function on a large scale. This viewpoint presumes that natural disturbances (i.e., not human in origin) and processes prevailed as ecosystem drivers and that the resultant diversity, structure, composition and function were, therefore, ideal derivatives of nature. This perspective overlooks the fact that humans have inhabited North America for at least 13,000–15,000 yr BP (Dixon, 2001; Goebel, Waters, & O'Rourke, 2008), and that they may have had profound impacts on vegetation structure and composition, and animal populations across the continent (Williams, 1989; Denevan, 1992a; Krech, 1999). Through history, human disturbance on ecosystems varied spatially and temporally with changes in climate, land use, and population density across North America. Fire was historically the way North American Indians directly influenced vegetation composition and structure, and in drought years or in plains regions, fires could spread across broader landscapes. In some regions such as northern New England, climate minimized the influence, or even the use of fire by Indians, while in portions of the Southern United States they could burn in practically any season of the year (Guyette, Stambaugh, Dey, & Muzika, 2012). North American Indians also indirectly influenced vegetation through their subsistence pressure on ungulate and other herbivore populations. Fluctuations in human population density were dynamic resulting from intertribal warfare, migration, or later, the introduction of European diseases that decimated local populations. Estimates of pre-Columbian populations in North America range from 2 million (Ubelaker, 1988, 1992) to 18 million (Dobyns, 1983) with a number of experts estimating populations in the 4 to 12 million range (Dobyns 1966; Thornton, 1987; Denevan, 1992b). Wherever humans settled, they cultured the landscape to produce the goods and services that their societies desired.

The period some select as a benchmark defining the desired future condition—i.e., pre-European settlement—may represent an anomaly as ecosytems were responding to changes in disturbance regimes, with a lessening of human influence in regions that were depopulated by diseases, conflict, and warfare. Thus, a fundamental understanding of these interrelationships and how they changed the influence of humans on ecosystems over time is critical in how we consider historic conditions in setting restoration endpoints.

Humans have had an ever increasing influence on ecosystem character and function from the beginning in North America. Long ago, overhunting by Paleoindians has been identified as a contributing factor to the mass extinction of mega fauna—wooly mammoth (*Mammuthus primigenius*), mastodon (*Mammut americanum*), dire wolves (*Canis dirus*), giant beavers (*Castoroides ohioensis*), etc.—during the latter portion of the Pleistocene (Martin, 1967, 1973; Krech, 1999). This was followed by the dawn of agriculture in the continental United States some 7,000 yr ago (Hurt, 1987). Sophisticated agricultural societies (e.g., Cahokia in the central Mississippi River region, and Hohokam and Anasazi in the Southwest) developed circa 1,000 BP based on large field production of corn, beans, and squash culture. Elaborate irrigation systems supported agriculture production in the Southwest. An agriculture economy changed North American Indian land use and settlement patterns. However, the large agricultural complex societies suddenly collapsed by the 15th century. Their decline was exacerbated by the negative consequences of deforestation, resource overuse and degradation, and, in the Southwest, salinization of the soil from irrigation. Poor crop production and failure resulted in food shortages during a period of cold and droughty climates. Hunger, combined with a scarcity of fuel and building materials, led to social upheaval, population emigration, and abandonment of the city-state (Krech, 1999). The cyclical nature of human populations and the subsequent impacts on the landscape cannot be discounted when considering restoration targets.

Elsewhere, the distribution of forests and grasslands was shaped by North American Indian fire for thousands of years (Transeau, 1935; Denevan, 1992a; Anderson, 2006). Forest structure and composition were determined by North American Indian fire regimes (Black, Ruffner, & Abrams, 2006), as was the distribution of woodlands, savannas, glades, and other fire mediated barrens and oak openings (Nelson, 2010). North American Indians had a long tradition of using fire to shape the landscape and promote habitats for animals important to their subsistence such as bison (*Bison bison*), elk (*Cervus canadensis*), deer (*Odocoileus* spp.), and wild turkey (*Meleagris gallopavo*; Pyne, 1982). They frequently burned the landscape (Guyette et al., 2012) to promote production of nuts, berries, and fruits; to drive animals being hunted; to facilitate travel; and as an act of warfare on their enemies. Then, in the 1600s, Spaniards introduced the horse to North America, and this forever changed the way native Americans hunted, managed grazing herds, and traversed the landscape.

When European settlers were documenting life in the New World, the terrain was in a state of transition from North American Indian inhabitation and use. European diseases had decimated many North American Indian tribes since about 1500 AD, reducing local populations by 80% or more (Snow & Lanphear, 1988; Thornton, Miller, & Warren, 1991; Thornton, 1997). The vegetation in more productive areas and climates quickly changed following this disruption in the cultural disturbance regimes. What Europeans encountered and recorded may have been substantially different from what existed at the halcyon of North American Indian culture. A further complication in using historic reference conditions is that the period we choose to use to guide our restoration may actually be an artifact of resource degradation or overuse by a particular North American Indian village or tribal population. Krech (1999) challenged the myth that all Indian societies were ecologically benign. Gone are the days of historic North American Indian culture and impacts now that 314 million people inhabit the United States.

It is difficult to base restoration on historic conditions in some cases because key components are extirpated and will never return, or fail to operate freely at the landscape scale as they once had for certain ecosystems and landscapes. For example, bison numbering 25 to 30 million once roamed over most of North America, yet by the 1880s there were but 100 wild bison left (Taylor, 2007). Today, small herds graze on restricted lands. Throughout much of the eastern United States, 3 to 5 billion passenger pigeons (*Ectopistes migratorius*) once had substantial impact on eastern forests through consumption of mast and damage to trees on a massive scale, but the last wild bird was seen in 1901 (Ellsworth & McComb, 2003). Wildfire, much of which was human-caused, once spread unsuppressed across large landscapes

(Guyette et al., 2012), but now modern fire suppression has eliminated much of that, and prescribed burning is executed on relatively small parcels. Rivers and streams have been tamed by levees, dikes, dams, and channelization, thus disrupting the natural hydrologic cycle of bottomland forests. And finally, setting restoration endpoints based on a historic period is potentially dubious because the future climate may be quite different than in the past. Climates have varied tremendously over the past 14,000 yr and have included the Younger Dryas, a period of severe cold and drought (12,800 to 11,500 BP), and the Little Ice Age (1350 to 1850 AD). There are many models predicting future climate change, and resultant perturbations must be considered when setting restoration endpoints.

When setting endpoints or targets in forest restoration, it is paramount to consider our desires in terms of ecosystem goods and services, much as the native Americans did less formally when they managed the land for their benefit. It is valuable to reflect back on the past, to understand ecological processes and patterns, to consider the drivers of production, and to realize both positive and negative changes have occurred. Damage to the ecosystem has to be properly assessed; missing components identified; the drivers of dysfunction recognized; the barriers to restoration named; and the stressors of the system understood before restoration goals, objectives, and plans can be written. Consideration of future uncertainties is important in setting restoration endpoints as we strive to promote species in productive communities that function sustainably under new environmental conditions to provide services that enhance society's well-being, with the capacity to be resilient to yet unknown stressors into the future.

Considerations in Setting Targets and Endpoints

Whether restoration is planned for private or public land, well-stated, clear, and explicit restoration goals and objectives that set endpoints and targets, identify issues and concerns, and establish priorities are crucial to facilitate the formation of effective restoration strategies and tactics, and the selection of the best set of indicators for monitoring progress and measuring success. The leading cause of restoration failure is poorly formed and stated goals and objectives (Dale & Beyeler, 2001; Lin, Lin, Cui, & Cameron, 2009). Vague goals and objectives cause confusion in the collective partnership mission, make it difficult to design strategies and practices that are efficient, and hamper the choice of good indicators for monitoring progress and measuring success. Quantitative objectives should be appropriate for both the scale and nature of the restoration. In addition to defining final objectives, key intermediate stages in the restoration process and along the ecosystem trajectory to recovery should be defined quantitatively. If known, benchmarks, thresholds (maximum and minimum), or target levels of key attributes should be identified. Detailed and informative objectives make it easier to identify a suitable set of indicators for monitoring. An appropriate ecosystem model containing the key state components of interest, the processes that define function, the stressors and drivers that cause change, and any barriers to successful recovery is helpful in determining strategic intermediate stages and indicator variables. Intermediate objectives are also important for early detection of undesirable deviations in ecosystem change and afford the opportunity to apply adaptive management to correct the dysfunction caused by stressors or unpredicted interactions and outcomes. For example, forests have a set of developmental stages that can be used to define intermediate stages with objectives and targets—i.e., stand initiation, stem exclusion, understory reinitiation, and old growth stages (Oliver & Larson, 1996).

The process of restoration planning, and setting endpoints and targets may be simplified for a private landowner because they can act autonomously in decision making, but they may lack the ecological, management, and economic expertise. Most family forest owners do forego formal consultation with a natural resource professional or consultant and only 4% have a written forest management plan (Butler, 2008). Ecological restoration is not among the main objectives of these landowners who value aesthetics, privacy, and protection of nature and biological diversity as reasons for owning land (Butler, 2008). Restoration goals may resonate with them but they lack the awareness and expertise to see how their interest fit into a greater perspective for restoring functional ecosystems. However, restoration programs and initiatives offered to private landowners to encourage their use of professional assistance in land planning and increase their awareness of restoration are especially important as they own 83% of the land base in the eastern United States (Smith, Miles, Perry, & Pugh, 2009).

Defining endpoints for restoration becomes complicated on public lands that serve many competing interests. The setting of endpoints and targets is a complex and relatively lengthy process driven by eco-socio-political forces and the scope of the restoration effort. Restoration planning should be accomplished in collaborative partnership with a diversity of experts, users, bureaucrats, politicians, professionals, and others who are important to the acceptance, funding, and long-term support of restoration projects. There is no prescriptive recipe for this undertaking. There are examples that can be studied such as National Forest planning by the U.S. Forest Service, the planning of large-scale regional restorations of the Everglades ecosystem (http://www.evergladesplan.org) and the Chesapeake Bay (http://www.chesapeakebay.net), and development of state and NGO species recovery, restoration, and conservation plans.

INDICATORS OF PROGRESS AND SUCCESS

Indicators are attributes that can be used to assess the condition, function, or output of an ecosystem. Such attributes are grounded in science, are quantitative measures of the trait, which are linked with important ecosystem states, processes, and functions. Those indicators that are most useful can detect small changes in ecosystem traits attributable to specific stressors or disturbances. Preferred indicators have standard protocols that are easy and affordable to use; and produce results that are easily interpretable by lay people. They provide timely information to guide assessments of progress and decisions to adapt the set of restoration practices to keep the ecosystem on a desired trajectory. Not all indicators are equally valuable, or appropriate in any given restoration.

The list of indicators that can be used to measure directly, or by inference and modeling, ecosystem condition, function, and productivity is extensive (Table 1). However, it is not necessary to measure ecosystems in their entirety, nor is it feasible to do so. The Society for Ecological Restoration International Science and Policy Working Group (SER Int., 2004) published a list of nine ecosystem attributes that measure the success of restoration (Table 2). This list is seldom used in its entirety; generally one or two of these attributes are monitored due to budget, expertise, and time constraints. Ruiz-Jaen and Aide (2005) surveyed over 450 restoration studies published in the first 11 volumes of *Restoration Ecology* and found that most studies incorporated indicators for diversity (e.g., richness, abundance within trophic levels) and vegetation structure (e.g., cover, woody density, biomass, height). Ecological processes such as nutrient cycling, and biological interactions such as herbivory, mycorrhizae, and seed dispersal were rarely chosen as indicators. For diversity, plant richness was the indicator in 79% of the studies, and arthropod richness served as an indicator only 35% of the time. They reported that most restoration efforts considered only one group of organisms, and had only one or two indicators of vegetation structure such as plant cover, density, or biomass.

Vegetation is a primary choice for monitoring because it is fundamental to defining the ecosystem state, it is involved in numerous important functions, and it is relatively easy to inventory. Vegetation is correlated with many functional attributes (Cairns, 1986) and the abundance and well-being of so many other organisms (Ruiz-Jaen & Aide, 2005). Also, it is commonly assumed that viable populations need quality habitat. In contrast, ecological processes are seldom employed as indicators because they are slower to recover from disturbances than vegetation, the time required to detect meaningful change often exceeds the funding or publishing cycle, and measurements may be costly and take greater expertise to apply and interpret (Ruiz-Jaen & Aide, 2005). For similar reasons, few studies measure reproducing populations because that requires a long-term commitment to assess and may involve costly field techniques and equipment.

Useful indicators are Simple, Measurable, Relevant, Reliable and Timely—SM(a)RRT—according to Vallauri, Aronson, Dudley, and Vallejo (2005):

TABLE 1 A Partial List of Indicators That Are Commonly Used to Gauge Progress in Restoring Ecosystems and to Provide Information in Support of Adaptive Management

Hierarchy of indicators		
Landscape		
	Structure	
		Soils, geology, water bodies
		Landform, topography
		Habitat connectivity, corridors, patch size, distribution, juxtaposition
		Community types
		Trophic levels
		Age, size structure
	Composition	
		Area of forest and other cover types
		Ownership
		Biodiversity
		Threatened and endangered species
	Function	
		Production of timber, water, wildlife, air
		Ecological integrity, health
		Economic development—jobs (number, type), economy, markets
		Demographics
		Gene flow patterns and migration
		Disturbance regime
		Nutrient cycling, energy flow
		Social well-being & ecosystem services
		Viable populations
		Policy and law
		Recreation
		Fragmentation (aggregation index, edge density)
Community, stand		
	Structure	
		Trophic levels
		Size structure (height, diameter, weight, volume)
		Age structure
		Density (basal area, number per area, stocking)
		Vegetation cover
		Canopy closure
		Site quality (site index)
		Stand stocking (%)
		Stand type (old growth, mature, early seral)
		Snags and coarse woody debris
		Fuel loading, fuel model class,
		landform, topography, geology
		Soil (pH, organic matter, bulk density, CEC, base saturation, nutrient availability)
		Litter layer
		Water pH, turbidity, conductivity, organic matter, temperature, dissolved O_2 content, flow, yield, velocity
		Stream structure (riffles, pools, bed type, large woody debris, large rock)
		Seasonal hydrology

(*Continued*)

TABLE 1 (Continued)

Hierarchy of indicators		
	Composition	
		Functional groups
		Biodiversity
		Threatened and endangered species
		Natural community type (forest, woodland, savanna, prairie)
		Floristic quality index
		Coefficient of conservatism, native index, importance value
	Function	
		Regeneration
		Productivity (biomass, timber, biofuels, water yield)
		Soil quality (soil enzyme activity)
		Nutrient cycling, energy flow
		Genetic diversity and
		filtration (sediment, nonpoint pollution)
		Disturbance regime
		Soil erosion, deposition
		Soil hydrology, groundwater movement, available water content
		Soil microbial populations, decomposition, mycorrhizae
Population, species		
	Structure	
		Age structure
		Size structure
		Habitat amount, quality, connectivity
		Density
		Occurrence
	Composition	
		Genetic diversity
		Sex ratio
		Juvenile/adult ratio
	Function	
		Viable populations
		Reproduction, breeding success
		Gene flow, adaptation
		Mortality
		Productivity
		Recreation

Indicators are listed in no particular order of importance or usefulness; that will be determined on a case-by-case basis. The list was derived from much of the literature cited in this article and from the experience of the authors.

- simple to measure such as percent cover, number of species, etc.;
- measurable with ease, requires little expertise, and are affordable;
- relevant by being linked to key stages of ecosystem change, management actions, succession, and function;
- reliably related to ecosystem state and function in predictable ways with known certainty;
- timely in that their remeasurement can be done coincident with key stages of ecosystem change, and they provide data for preemptive adaptive management.

TABLE 2 Set of Ecosystem Attributes to Guide Determination of Success in Restoration (SER Int., 2004)

	Ecosystem attributes that denote success in restoration
1	Diversity and community structure similar to a reference
2	Presence of indigenous species
3	Presence of functional groups necessary for long-term stability
4	Capacity of physical environment to sustain reproducing populations
5	Normal functioning
6	Integration with landscape
7	Elimination of potential threats
8	Resilience to natural disturbances
9	Self-sustainability

SELECTING INDICATORS

Selection of a suitable set of affordable and effective indicators is a crucial and iterative process that takes time and is not unlike the development of the restoration plan endpoints and targets in that it should be a collaborative interdisciplinary result of cooperative and diverse partnerships. It can be a messy and time-consuming process with large partner groups that have competing or conflicting interests. Some have even tried to streamline the process and minimize the subjectivity of human relations by developing objective mathematical models using either a causal network (pressure-state-response), ecological hierarchy network, or integrated approach to select ecological indicators (Lin et al., 2009). However, selecting indicators is inherently a human process and therefore hard to manage. But it can be accomplished within a reasonable processing time and with acceptable outcomes. In a real world example, Doren and Best (2009) provided an effective example for selecting indicators for restoration of the Florida Everglades.

It is singularly important in selecting indicators that one starts with clearly stated specific goals and quantitative objectives in the restoration plan (Dale & Beyeler, 2001). Poorly developed goals and objectives can result in the selection of indicators that are not useful for monitoring, informing decision making, nor in communicating with the public (Lin et al., 2009). The end result should be the smallest set of indicators that gets the job done (Hagan & Whitman, 2004)—i.e., that demonstrate achievement of goals and objectives, that provide information to make timely necessary adjustments to restoration management, and that clearly communicate the benefits to society and stakeholders in strong relevant practical terms.

Ruiz-Jaen and Aide (2005) concluded that a reasonable set of indicators includes some measures of diversity, vegetation structure, and ecological function. It is better to include in the set of indicators more than one organismal group from several different trophic levels or ecosystem hierarchies. The set of indicators should characterize key elements and functions of the ecosystem that include pertinent variables representing the organism, population, ecology, physical environment, key stressors and drivers of disturbance, response to management, and the socioeconomic aspects of the restoration project. A review of literature on selecting indicators in ecosystem restoration produced a strategic list of criteria for evaluating indicators according to their relevance to goals and objectives, effectiveness in representing ecological states and functions, efficiency in application, ability to guide management activities, and power to communicate with a diverse group of partners and publics (Table 3).

Indicators for restoration have often been focused on the ecology, physical environment, and biodiversity of the ecosystem. Often lacking are indicators of the socioeconomic aspects of restoration. In a meta-analysis of over 1,500 papers, Aronson et al. (2010) concluded that the majority of restoration projects failed to include socioeconomic benefits and values; neither did they communicate the benefits to society of building natural capital and the value of ecosystem services provided by the restoration. Lost was the ability to link improvements in ecosystem services and increases in natural capital and describe them to the beneficiaries (i.e., the public) in tangible, easily understood terms. Too often, the public doesn't see the value of the returns on their investments in restoration, or the importance of the restoration experience as feedback to inform public policy. Such understanding improves the ability to conduct future restoration work more efficiently and effectively. The failure to consider the economics of restoration by treating it purely as an ecological endeavor is a major oversight because a chief barrier to implementing restoration at the scale most likely to elicit change is a lack of funds and public support.

Utilization of products of restoration activities such as small diameter woody material is important and is part of the suite of ecosystem services. The challenge often is that the type and size of material being removed during restoration is not commercially viable and this necessitates the development of new lines of manufacturing, methods of transportation, product development, and expanding markets. Alternative tactical approaches to restoration are needed to utilize any currently commercial material that is made available during restoration. For example, instead of using only prescribed burning to reduce overstory density in restoring savannas, why not harvest the overstory trees in conjunction with burning to capture the value in timber products? Simple as this approach seems, it is not always used, in part because some managers strive to use natural (not human) disturbances in restoration. As Vallauri et al. (2005) remind us though, restoration is for people as well as biodiversity; and Hobbs (2007) emphasizes that realistic goals for restoration are grounded in the current social and ecological realities of today and hedging our decisions on how they will change in the future.

TABLE 3 A Partial List of Criteria That May Be Helpful in Selecting the Smallest Best Set of Indicators for Monitoring Restoration Progress and Measuring Final Success

Selection critieria for indicators	
Relevant to the restoration plan	
	Is the indicator relevant to plan goals and objectives?
	Does it address priority issues, concerns, and outcomes, both social and ecological?
Ecological considerations	
	Are they grounded in ecological theory and application in the particular region?
	Are they backed by scientific statistical analyses and models?
	Do they reveal current conditions for structure, composition, or function?
	Are they sensitive to small changes in specific stressors or management levels?
	Are they responsive to single ecosystem stressors or drivers?
	Are they sensitive to small changes in ecosystem trajectory (structure, composition, & function)?
	Can they be integrated with other indicators?
	Are the indicators linked to specific ecosystem stressors or drivers?
	Are they appropriate to the size and complexity of the restoration?
	Do they represent key information about ecosystem structure, composition, & function?
	Does the set of indicators include more than one organism or trophic level?
	Does the set of indicators cover several of the ecosystem hierarchy levels (gene to landscape)?
	Are they correlated with multiple components of the ecosystem?
	Is the indicator appropriate for the specific level or scale of ecosystem hierarchy (gene to landscape)?
	Does it respond to stress in a predictable manner?
	Is the indicator commonly used to characterize reference ecosystems, stands, or sites?
Application of indicator	
	Are they practical to use? Are skills required to use common in the workforce?
	Are they readily accessible and widely applicable?
	Is the indicator commonly used in other similar restoration projects?
	Are they well-defined, widely accepted, and have standard protocols?
	Does the indicator have known benchmarks, target levels for key intermediate and final stages in the restoration process and in ecosystem developmental stages?
	Are they affordable? Do they require expensive instruments or laboratory analysis?
Managing restoration	
	Do they aid in decision making?

(*Continued*)

TABLE 3 (Continued)

	Selection critieria for indicators
	Are the indicators linked to or responsive to management activities? Can they be used to make predictions or used in simulations? Can changes in the indicator be interpreted and acted upon? Can indicators predict, give early warning to irreversible shifts in ecosystem trajectory? Do they support adaptive management?
Indicators as tools for communication	
	Are they understood by a diversity of people? Are they indicative of future ecosystems states, services, or outputs? Can they be linked in common language to tangible ecosystem services, values, and societal well-being?

Based on Dale and Beyeler (2001), Hagan and Whitman (2004), Vallauri et al. (2005), Groffman et al. (2006), Briske, Fuhlendorf, and Smeins (2006), Doren et al. (2009), Doren and Best (2009), and Lin et al. (2009).

REFERENCE SITES AND OTHER TOOLS TO GUIDE RESTORATION

We do not always have the quantitative knowledge of thresholds, benchmarks, structural and compositional metrics, or functional mechanics that would help us write explicit goals and objectives, or interpret absolute values of indicators in assessing ecosystem change. In these cases, reference sites are used by comparison to help us set endpoints and targets, and monitor our progress. In fact, 70% of the restoration studies reviewed by Ruiz-Jaen and Aide (2005) used reference sites. Using more than one reference site is practical and helps to account for the variability in ecosystem states and responses to a given set of stressors, management actions, and disturbances. There are drawbacks and precautions to using reference sites that must be kept in mind (Stanturf, Schoenholtz, Schweitzer, & Shepard, 2001). Reference sites such as eastern hardwood old growth stands or bottomland forest remnants are often small-sized relics that have limited capacity to buffer against environmental changes. They are experiencing unprecedented changes due to dramatically altered disturbance regimes. For example, bottomland forest remnants may occur in floodplains where the natural hydrology has been totally altered by wetland drainage, river channelization, and other flood control activities. Other threats to reference sites include modified regeneration and competitive dynamics due to invasive species; modified stand development due to fire suppression; or overbrowsing by unnaturally high density herbivore populations. For these and other similar reasons, available reference areas may be altered systems that are not sustainable or even desirable to emulate. They may not be good examples of what is possible or what would be best adapted to novel environments. Reference sites may be relevant for defining endpoints but they do not provide information about critical intermediate stages of ecosystem development for the several different pathways that may lead to nearly the same endpoint. Nonetheless, they are widely used to guide restoration.

There is a growing body of literature that gives increasingly detailed information on historic vegetation structure (density) and composition, and probability of tree species occurrence based on ecological and environmental factors. This derives from spatially explicit methods to model vegetation and location data from General Land Office surveys (circa 1800–1850s; Hanberry et al., 2011; Hanberry, Dey, & He, 2012; Hanberry, He, & Dey, 2012; Hanberry, Kabrick, He, & Palik, 2012; Hanberry, Yang, Kabrick, & He, 2012). For example, Hanberry et al. (2012) have developed models of presettlement forests to aid in the restoration of bottomland forests in the Mississippi River Alluvial Valley. They present maps of the probability of a tree species occurrence and tables of structural attributes by species such as the mean and range in overstory density, basal area and stocking, and mean diameter at breast height (dbh). Similar work for upland forests, woodlands, and savannas in the Missouri Ozark Highlands and Plains eco regions has been done by Hanberry, Dey, and He (2012, 2014), and Hanberry, Kabrick, and He (2014a, 2014b). Other modern models of forest structure also exist. These include stocking charts for upland *Quercus-Carya* forests in the Central Hardwood Region (Gingrich, 1967) and for bottomland forests of *Populus deltoides-Acer saccharinum-Platanus occidentalis* in the Midwest (Larsen, Dey, & Faust, 2010). Stocking can be used to define desired tree structure in forest, woodlands, and savannas, and to set structural thresholds that would trigger management action. Other such practical tools and models in wildlife, fisheries, limnology, and other disciplines can be used to help define a clear set of goals, objectives, and indicators for intermediate critical stages and final endpoints in restoration.

LINKING TIERED PLANS TO AN ECOLOGICAL HIERARCHY

Parallel to an ecological hierarchical approach to classifying ecosystem attributes from the regional to the site-level, and population to organismal-level; there is also a hierarchical approach to forest planning that is well-suited to defining restoration goals and objectives at each ecological level. Forest plans are appropriate for addressing regional and landscape-scale restoration goals and objectives. These plans are appropriate for properties that range from thousands to millions of hectares; that are complex with mixed ownerships, provide services to industry and urban cities, and have diverse natural communities serving as home for migratory wildlife and species with large home ranges. The forest plan serves as the foundation analysis and document that establishes goals and objectives at the highest levels, and from which all other subsequent plans arise. With each step down in the size of the project area and ecological hierarchy to a finer scale of organization, there is a coincident step down in the scope of planning. Landscape or watershed level activities can be defined in project plans, which are used to implement the forest plan and hence are tiered to its goals and objectives. Within the watershed or landscape, goals and objectives for individual forest stands or specific natural communities are detailed in the stand prescription or site restoration plan. Species conservation and recovery plans set direction for management at the organism level. Clear and specific goals and objectives are important at each level of planning, with increasing orders of quantification and temporal and spatial specificity as plans become more site and species oriented, and result in on-the-ground action.

ROLE OF MONITORING AND ADAPTIVE MANAGEMENT IN RESTORATION

Adaptive management and monitoring partnerships are an apt way to deal with the current unknowns and future uncertainties we often face when drafting goals, setting objectives, and selecting indicators in ecosystem restoration. There will never be enough timely research to meet the information needs of every manager wishing to plan and conduct restoration of a specific ecosystem. In the absence of intermediate benchmarks, thresholds, and targets for key ecosystem developmental stages, a pertinent set of indicators and monitoring program can provide the information managers need to adapt management to correct ecosystem trajectories that are leading toward undesirable outcomes (Yaussy, Nowacki, Schuler, Dey, & DeGayner 2008; Nowacki, Ablutz, Yaussy, Schuler, & Dey, 2009).

Coordinated regional monitoring projects can collectively provide data for scientists to develop or calibrate models, establish linkages between indicators and ecosystem structure and function, and stressors, or identify thresholds representing irreversible shifts in ecosystem trajectory (Yaussy et al., 2008; Nowacki et al., 2009). Partnerships in united efforts in restoration can be invaluable in implementing adaptive management especially on larger scaled restoration projects of up to millions of hectares (Doren, Trexler, Gottlieb, & Harwell, 2009). It takes the collective resources of multiple partnerships to plan and implement adaptive management on the scale of ecosystems and landscapes. There are several networks of experimental forests and landscape-scale conservation initiatives currently in place that can be used to focus efforts on monitoring for adaptive management in ecosystem restoration. The U.S. Forest Service has a series of 80 experimental forests and ranges (http://www.fs.fed.us/research/efr) located nationally in major forest landscapes where long-term research has been conducted for the past 100 yr. Some are highly developed and instrumented (e.g., Hubbard Brook, H. J. Andrews, and Coweeta) to monitor changes in soils, hydrology, and other resources at the watershed level. The U.S. Forest Service has also recently launched the establishment of Collaborative Forest Landscape Restoration Programs (http://www.fs.fed.us/restoration/CFLRP/index.shtml) to develop and demonstrate restoration of priority forest landscapes nationally. Currently there are 23 projects nationwide and $40 million annually for 10 yr to establish the program. A major goal of the program is to provide science-based examples of restoration and each project includes a monitoring component. The U.S Fish and Wildlife Service hosts several initiatives that represent large scale cooperatives of diverse partnerships dedicated to conservation at the regional and landscape levels: 18 Joint Ventures (http://www.fws.gov/birdhabitat/Jointventures/index.shtml) and 22 Landscape Conservation Cooperatives (http://www.fws.gov/landscape-conservation/lcc.html) have been established nationally. All these existing networks of restoration and conservation partnerships are ideal vehicles for developing monitoring to support adaptive management. The well-developed partnerships would be advocates for such an effort. The project areas are opportune places for doing the types of testing and calibrating of indicators that are expensive, involve long-term remeasurements, and require a high-level of expertise to implement and interpret; those that managers are unlikely to ever do in their restoration areas. The existing institutional infrastructure could facilitate monitoring and evaluating management practices. Indicators can be monitored, tested, calibrated, or modeled on these cooperative restoration sites and experimental forest networks and used by inference or imputation in other similar restorations within the appropriate ecological regions. Collaborative monitoring efforts on these long-term experimental and restoration sites can be used to discover benchmarks, thresholds, quantitative reference conditions, and determine the range of natural variability.

ROLE OF MANAGEMENT IN MAINTAINING RESTORED ECOSYSTEMS

The endpoint of restoration is the transition to ecosystem management and sustainability of the desired outcomes and states. Although the term restoration is often used as if it were something different than management, it is actually a focused subset of goals, strategies, and approaches within the domain of land or forest management. And the restorationist who sets desired future conditions, endpoints, and targets, whether by looking backward to some historic time and condition, or by incorporating the needs of society, today and in the future, is still practicing forestland management.

Once restored, ecosystems still need to be managed because they are seldom self-sustaining in a stable state—i.e., persistent without human influence—especially on smaller properties or watersheds that are influenced perhaps more so by external factors that affect ecosystem processes. Some ecologists refer to this state of eco-self-regulation and stability as the "ultimate goal of restoration . . . to create a self-supporting ecosystem that is resilient to perturbation without further assistance" (Urbanska, Webb, & Edwards, 1997; Ruiz-Jaen & Aide, 2005). However, Jackson and Hobbs (2009) concluded that there are no inherently natural ecosystems or landscapes for any region, none that have persisted for any great length of time; and that is why restoration ecologists are beginning to emphasize restoration of ecosystem function, goods, and services.

Ecosystems and landscapes are dynamic and are constantly in flux responding to changing environments and disturbance regimes; and for the past 13,000 yr or so in North America many of the ecosystems were influenced to various degrees by human manipulations. To try and recreate a self-sustaining (without human intervention) ecosystem that in and of itself is an artifact of human intervention may be impossible. That's one reason why Aronson et al. (2010) found that most restoration efforts involved active management, and scarcely <9% relied on passive methods of restoration. Not only does it take management to repair ecosystem damage and restore function, but it takes continued management to sustain these human-mediated ecosystems. SER Int. (2004), in their primer on ecological restoration, recognized that management may be necessary after restoration is complete to keep ecosystems on the desired trajectory.

CONCLUSION

When considering the desired future endpoints and targets for our forest ecosystems we cannot just look backward to a time when we intuit natural systems were functioning at optimal capacity, for example, at pre-European settlement. Doing so is fraught with challenges and problems. We will never know with enough specificity the structure, composition, diversity, function, or productivity of historic ecosystems to establish quantitative endpoints and targets, identify ecological thresholds, or select effective indicators of progress and success. Much of our knowledge of historic conditions stems from anecdotal journal entries by pioneers and early settlers, remnants of oral tradition from North American Indian elders, paintings and early photographs, and data from the first land surveys. And with all this we can get but a glimpse of the historic landscape, disturbance regime, and vegetation at a relatively small time interval, a static view of the past. Trying to restore and fix in time and space a specific ecosystem state is unnatural since ecosystems are spatially and temporally dynamic. Fragmentation of the landscape and mixed land ownerships has disrupted the spatial scale that some historic disturbances operated at. Disturbance agents responsible for shaping ecosystem character such as bison and wildfire no longer operate as they once did, and they never will. Restoring historic conditions does not ensure that the land will produce what society needs and values today or into the future without a conscious intent to do so. Historic conditions may not be well-adapted to future environments or threats. All of these realities and challenges to restoring historic ecosystem state and function may be overcome with contemporary management which mimics historic disturbances and processes, but it will be increasingly expensive, and require innovative practices and commitment to long-term intensive management.

If the philosophy of naturalism defines the desired future endpoint it subsequently will characterize endpoint states that result from a disturbance regime that does not include human influence, or where human manipulations are overwhelmed by "natural" factors. We have to go back some 13,000 yr or more before a time on the North American continent when there were no humans; back to a time at the last glacial maxima when most of the continent was buried under ice and boreal forest and steppe conditions extended deep into the southern United States. This is an unrealistic target for no other reason than the current climates cannot support the historic flora and fauna; not to mention that excluding humans as a significant driver of ecosystem state and function is equally short-sighted. Humans are part of the natural world. Yes, we have the awesome capacity to change our environment on a planetary scale for better or worse. There are plenty of examples where we have caused damage to our environment, much as a deer population can exceed the carrying capacity of the land and degrade the quality and capacity of it to support them. But we also have the capacity to learn and understand the world we live in, and to become good stewards of the land.

Setting endpoints and targets in forest restoration is a complicated task that is best accomplished in cooperative partnerships that account for the ecology of the system, production of desired ecosystem goods and services, economics and well-being of society, and future environments. Clearly described and quantitative endpoints and intermediary targets are needed to manage restoration of ecosystem structure, composition, function, and production. Selecting indicators of key ecosystem attributes that are linked to endpoint and target condition, function, sustainability, health, integrity, resilience, and production is important to monitoring restoration success. Indicators are used to track ecosystem trajectory, assess progress toward achieving endpoints and targets, adapt management, and communicate with external publics. Reference sites can be used to help set endpoints and targets with caution. Other science-based ecosystem models or management tools are available to help quantify intermediate targets and endpoints. Continued work to better understand historic ecosystem conditions is fundamental to assessing change, extent of damage, and restoration potential. A hierarchy of forest plans from regional and landscape to site specific are useful for defining endpoints, targets, and indicators at appropriate ecological scales and to consider populations, ecosystem function, and socioeconomic factors that operate at a variety of scales.

A felicitous approach to restoration is to develop plans that are: (a) grounded in science and knowledge of the past; (b) have clear goals and tangible objectives that consider the future of changing environments; (c) able to provide services for society and enhance human well-being; and (d) flexible and able to adapt management based on a monitoring program to correct for undesired variations due to inherent uncertainty. We can manage for ecosystem conditions that are capable of adapting to changing environments by conserving native biodiversity, restoring ecosystem function, enhancing productivity and health, and increasing ecosystem resilience; these are general ecological tenets embodied in restoration strategies for the future.

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