The Unknown Trajectory of Forest Restoration: A Call for Ecosystem Monitoring

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ABSTRACT

Restoration of forest ecosystems is a common objective of land managers throughout the western United States. Unfortunately, limited federal funding and a lack of specific enforcement of existing regulations has resulted in a lack of effectiveness monitoring (monitoring that provides information on the successes and impacts of the activity or project) after forest restoration activities on federal lands, thus inhibiting learning about, and improving the success of, restoration efforts. Monitoring could potentially be conducted on limited federal budgets through use of (1) multiparty teams composed of volunteers on a portion of restoration sites, (2) a statistical sampling strategy on a limited set of sites for intensive monitoring by federal monitoring teams, and (3) remote sensing to monitor a select set of variables across a broad portion of the affected landscape.

Keywords: effectiveness monitoring, forest restoration, adaptive management

Ecological restoration of forests is an increasingly common activity on our nation's forests, with the overall objective of restoring natural structures and processes within degraded or altered forest stands. Unfortunately, the limited occurrence of posttreatment monitoring of restored stands has left us with limited understanding of the successes, benefits, or impacts of these activities. Monitoring of biophysical responses to forest restoration is a costly and time-consuming process and thus, in spite of the legal requirements for its existence, monitoring has suffered because of neglect and shrinking federal budgets.

Ecosystem restoration is defined by the Society for Ecological Restoration as the intentional process that initiates the recovery of an altered ecosystem to a state of ecological integrity (Society for Ecological Restoration 2004). Forest restoration, more specifically, has been promoted as a means of recreating historical forest stand structure and ecological function (and ecological integrity) in ecosystems altered by timber harvest and fire suppression (Mast et al. 1999, Fiedler 2000, Arno and Fiedler 2005). DellaSala et al. (2003) suggest that enhancing ecological integrity, or "a balanced, adaptive community of organisms having a species composition and functional organization comparable to that of natural habitats within a region," should be the "primary objective" of ecological restoration. Determining whether this objective is being met can only be achieved through posttreatment monitoring of abiotic and biotic characteristics in the treated landscape. However, most federal forests that have received restoration treatments have lacked any systematic monitoring (US General Accounting Office [GAO] 2006), thereby eliminating the ability to assess the efficacy of forest restoration efforts and learn from the experience. Forest restoration practices are generally focused on stand structure, timber production, and fuel reduction, with only limited consideration of ecological integrity, natural forest processes, or long-term sustainability of the for-

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est environment (Noss et al. 2006). In the absence of an effective ecosystem monitoring program, there is a limited ability to assess the influence of restoration efforts on ecosystem integrity and sustainability and there is little or no basis for improving these activities.

Several conditions indicate that monitoring of restoration may be especially beneficial: (1) restoration is a process rather than an event; thus, the initial treatments are only the first step in the restoration process; (2) restoration is a new science, therefore, data on the efficacy of such treatments are necessary if we are going to improve confidence in management projections; (3) an increasing number of federal forest plans are being predicated on the application of adaptive management strategies that specifically require monitoring of outcomes to allow for evaluation and reconsideration of design; and (4) unintended negative effects created by restoration activities could be mitigated before they become long-term problems applied broadly across the landscape. Each of these situations argues for increased post-treatment monitoring.

The advent of adaptive management makes monitoring especially relevant. Adaptive management is an iterative approach to management that is based on a series of feedback mechanisms in a continual cycle of evaluation, planning, action, and monitoring (Shindler et al. 1999). Under adaptive management, learning is accelerated because management is conducted in a framework of experimentation, where cause–effect relationships between management actions and outcomes are treated as hypotheses to be tested. Each element of this process is fundamental to the success of the approach, and exclusion of any one element, including monitoring, scuttles the entire process and prevents learning. Ecological restoration holds great potential for improving the condition of the land, but, as a relatively new field in the arena of natural resource management, it would benefit from accelerated development. Adaptive management can help speed learning by combining management and experimentation through the practice of monitoring.

Although systematic ecosystem monitoring is extremely rare, it must be noted that there are several examples where post-restoration treatment monitoring has been conducted or where intensive monitoring is planned for upcoming restoration efforts. These exceptions serve as excellent models for future monitoring efforts. In the southwestern United States, the Collaborative Forest Restoration Program (a combined effort of the Ecological Restoration Institute, several nongovernment organizations, and the US Forest Service) has made great strides in the area of forest restoration and has published an excellent series on restoration and monitoring (US Forest Service 2003a) based in part on a series of workshops (US Forest Service 2003).

The purpose of this article is to emphasize the need for ecological monitoring after forest restoration activities and propose possible approaches that may be used even when funding is limited for such activities. The following briefly describes the lack of monitoring on federal restoration forestry projects, elaborates on the need for an effective monitoring program to evaluate success and failure as forest restoration management evolves, and provides three possible approaches to a successful monitoring program. Although ecosystem monitoring is essential to any program of adaptive management, we focus here on the common practice of fuel treatment in dry, fire-prone western forests, particularly on opportunities for project-level monitoring to enhance understanding of treatment effects on biophysical site properties. Assessment of broad-scale ecological impacts and of socioeconomic impacts at all scales are also important to understanding restoration effects but are beyond the scope of this article.

Fire History and Forest Restoration in the Western United States

Low-elevation ponderosa pine (*Pinus ponderosa*), mixed ponderosa pine/Douglas-fir (*Pseudotsuga menziesii*), and western larch (*Larix occidentalis*)/Douglas-fir ecosystems historically experienced a relatively frequent, low-severity or mixed-severity fire regime that promoted dominance of large-diameter ponderosa pine and western larch (Agee 1993, Arno and Fiedler 2005, Baker et al. 2006, Crist et al. 2008, Hessburg et al. 2008).

The combined effects of fire suppression and historical stand management (high grading and clearcutting of forest stands in readily accessible, low-elevation forests) have increased presence of ground fuels, increased stand density, and increased presence of ladder fuels (Schoennagel et al. 2004) that have led to an increase in the potential for stand-replacing wildfires in forest types that normally experienced low or mixed fire–severity (Agee and Skinner 2005, Arno and Fiedler 2005, Westerling et al. 2006). Altered disturbance regimes have increased the presence of fire-intolerant species (Agee 1993, Arno and Fiedler 2005), allowed organic matter to accumulate (MacKenzie et al. 2004), caused nutrient cycling rates to slow (DeLuca and Sala 2006, MacKenzie et al. 2006), and increased the susceptibility of historically open forests to stand-replacing wildfire (Agee and Skinner 2005). These negative changes in forest structure and function speak to the need for improved forest stand management. Although there has been an accumulation of a significant body of literature on restoring dry, low fire–severity ponderosa pine ecosystems of the southwestern United States (Mast et al. 1999, Covington 2000, Fiedler 2000, Kolb et al. 2007), there is far less information available on an appropriate approach to restoring the dominantly mixed fire–severity ponderosa pine/Douglas-fir/western larch ecosystem of the Northern and Central Rocky Mountains (Binkley et al. 2007, Fiedler et al. 2007, Kolb et al. 2007, Crist et al. 2008).

Ultimately, we envision that forest restoration efforts will greatly increase the resilience of forest ecosystems to natural processes, such as fire or insect outbreaks and thus increase the resilience of these forests to the effects of climate change (Noss 2001, Noss et al. 2006, Crist et al. 2008). However, forest restoration is a new science, being conducted with only limited understanding of the existing or appropriate trajectories of forest development in the Rocky Mountain West. It is not clear, for example, whether natural stand structure and ecosystem function and process can be achieved in the long run or, instead, if thinning forest stands in the absence of large-diameter trees will actually leave these forests more vulnerable to fire, disease, exotic invasion, or windthrow. Application of the low fire–severity restoration treatment model of the Southwestern US (Covington 2003) to the mixed fire–severity forests of the central and northern Rocky Mountains may have unintended long-term consequences (Crist et al. 2008). Ecosystem monitoring of restoration effectiveness will help accelerate the development of this immature science and reduce the risk of setting our forests—and ourselves—on the wrong trajectory.

What Is Monitoring and What Can It Teach Us?

There are two fundamental types of monitoring that can be applied to forest restoration efforts: (1) implementation (or compliance) monitoring assesses whether or not a management action has been performed as designed and (2) effectiveness monitoring determines whether an action has achieved its objective (Block et al. 2001). Although implementation monitoring is used to establish whether the mechanical treatments were completed and thus if the initial objectives of the restoration treatments were achieved (e.g., shift in basal area, fuel reduction, and application of prescribed fire), it does not provide any feedback on the long-term success or evolving impacts of the restoration effort. Implementation monitoring only answers whether the initial work has been completed. In contrast, effectiveness monitoring can provide data that specifically allow for the evaluation of the impact of the restoration activities on ecosystem attributes, diversity indices, wildlife health (e.g., fecundity, habitat quality, and migration activities), forest stand metrics, and socioeconomic variables (e.g., jobs, recreational opportunities, and tourism).

Environmental monitoring can not be separated from a movement across disciplines for greater transparency and public learning associated with government-based action and the attendant struggles to conceptualize or "frame" the purposes for management and the distribution of benefits to both ecosystems and society (Daniels and Walker 2001). Monitoring pervades discussions of community-based management of natural resources as well as collaborative processes, and it is recognized as an essential element of a variety of multiparty activities for public engagement, including volunteer data collection, joint fact-finding, citizen science, or community science. The role of monitoring within this movement often has less to do with systematized evaluation of project objectives than with public learning, awareness, and relationship building (Nerbonne and Nelson 2004), but this does not discount the potential management and policy benefits that a more serious investment in monitoring strategies might obtain. Carr (2004) argues that monitoring, as part of community science, fosters additional experimentation and care of natural resources through citizen mobilization. The participation of a spectrum of people in monitoring programs and joint fact-finding can lead to greater understanding among managers, citizens, and scientists regarding the scope of alternative actions, the potential of analytical methods, and the interpretation of end results (McKinney and Harmon 2004).

What Is the General Strategy for Setting up a Monitoring Program?

Creation of an effective monitoring program will require forethought and careful design. Furthermore, the design and execution of an effective monitoring program will take time and will be site specific. Block and others (2001) provide a useful seven-step framework for the establishment of an effective monitoring program:

1. Set monitoring goals. Monitoring goals should be based on the reference condition to which the forest restoration is being ascribed.
2. Identify the resources or variables to be monitored. Response variables used in monitoring efforts must be meaningful and cost-effective.
3. Establish a threshold or trigger points. Exceeding a set benchmark for an ecological impact initiates a change in the approach to restoration as dictated by adaptive management.
4. Develop a sampling design. A sampling design for monitoring must be of a scale appropriate for each individual variable and requires careful consideration of the nature of that variable in terms of the distribution of samples within a stand, number of samples, and frequency interval of sampling (see Legg and Nagy 2006).
5. Collecting data. Data collection must be consistent, systematic, and rigorous. Failure to create a strict protocol for data collection will result in poor data quality and a failed monitoring program.
6. Analyzing data. Decisions on how the data will be analyzed should be made at the stage of identifying variables to monitor. Whether to use monitoring for hypothesis testing or simply for establishing whether a threshold was met or exceeded should be addressed at the design stage.
7. Evaluating the data. Restoration practices are characterized during the evaluation stage and the practices restructured if thresholds were exceeded.

Why Isn't Monitoring Occurring on the Landscape?

Existing laws require that monitoring be conducted to ensure the proper management of public resources on national forestlands [1]. The National Forest Management Act of 1976 requires the use of research (based on continuous monitoring and assessment) to evaluate "the effects of each management system to the end that it will not produce substantial and permanent impairment of the productivity of the land." Furthermore, many forest management plans are being written to emphasize an adaptive management approach (see US Forest Service 2006, Bormann et al. 2007), which, by definition, requires monitoring of management activities and outcomes. Despite these legal requirements, effectiveness monitoring is rarely conducted at the project level. One reason often cited is that monitoring of individual projects is time-consuming and costly (Bormann et al. 2007) and can not be sustained in an era of shrinking federal budgets and a historical lack of federal support for project-level monitoring (US GAO 2004), even though monitoring programs associated with implementation of other major environmental policies have proven to account for a fraction of the total cost and yield extremely important information (Lovett et al. 2007). Perhaps more important is the difficulty in organizing and sustaining the necessary pool of talent and cadre of participants to manifest monitoring programs, which by definition are long-term enterprises. Especially in times of budget constraints, voluntary or cross-organizational contributions will be necessary, and each of these participating groups will demand trained, capable staff to design, oversee, and troubleshoot monitoring operations. Allocating field staff to the cumbersome work of orchestrating monitoring teams and ensuring quality control has hardly been the priority of many land management agencies, even though government-based sponsorship is vital to the success of voluntary organizations such as watershed groups (Kenney 1999), and the common, internal value conflicts within volunteer groups require active interventions by skilled facilitators (Mutimukuru et al. 2006).

Although financial resources and institutional capacity surely play a part, cultural factors also play a role. Bliss et al. (2001) speculate that it is the lack of a personal incentive that frustrates monitoring because, historically, monitoring results have been used to find fault with management action, rather than to reward; thus, managers would rather not create a record. Also, Stankey and Clark (2006) suggest that adaptive management has not yet lived up to its potential because of a lack of leadership commitment and anemic agency support. Perhaps providing some hope of overcoming these barriers, recent attention to adaptive management in federal forest plans (US Forest Service 2006, Bormann et al. 2007) suggests an opportunity to incentivize monitoring through the performance review process.

Stewardship Contracts and the Absence of Effectiveness Monitoring

In an effort to overcome disincentives for monitoring, Congress specifically required project-level monitoring in its protocols for the "Stewardship Contracting Pilot Program" in 1999 (Section 347 PL 105-277, the Omnibus Consolidated and Emergency Appropriations Act 1999). Stewardship contracting is designed to integrate aspects of timber sale and service contracting authorities to foster restoration and collaborative project design. Stewardship contracting requires contracts be awarded based on the best value to the government and permits the exchange of goods for services, the use of receipts for additional restoration, greater involvement of contractors in implementation decisions, and extended contract periods (up to 10 years). This situation is credited with creating an environment where restoration is used to beget restoration by reducing the cost to the government of restoration work on federal lands. In the Stewardship Contracting Pilot Program, monitoring was specifically, and appropriately, dictated as a fundamental part of the management process (Pinchot Institute 2005). Therefore, an analysis of stewardship contracts conducted under the pilot program should provide the best possible examples of ecosystem monitoring on US Forest Service–supported forest management contracts.

To assess the extent of effectiveness monitoring conducted on forest restoration projects, we collected available data on 18 stewardship contract projects (primarily established during the Pilot Program) completed in Montana by the end of 2007 by visiting the US Forest Service Region 1 stewardship contracting website and then contacting each individual ranger district responsible for hosting a stewardship contract. Of the 18 contracts completed by December 2007, nearly 83% involved some type of timber harvest, 41% had some type of road decommissioning, and less than 30% used prescribed fire. Importantly, we found that only 3 of the 18 projects (16%) had completed monitoring reports on file (Figure 1), and of those projects that filed monitoring reports, none provided effectiveness monitoring data. For the three monitoring reports that were filed, only implementation monitoring results were recorded. Generally, the type of monitoring output that was reported was anecdotal and included no actual biophysical monitoring. The reporting reflected statements as to whether original objectives were met, a description of the satisfaction of participants in field tours, lessons learned on project implementation, and length of time to complete the project. Data were provided on total costs and receipts, volume and value of timber sold, miles of roads built or obliterated, length of streams restored, acres sprayed for weeds, and acres seeded for forage.

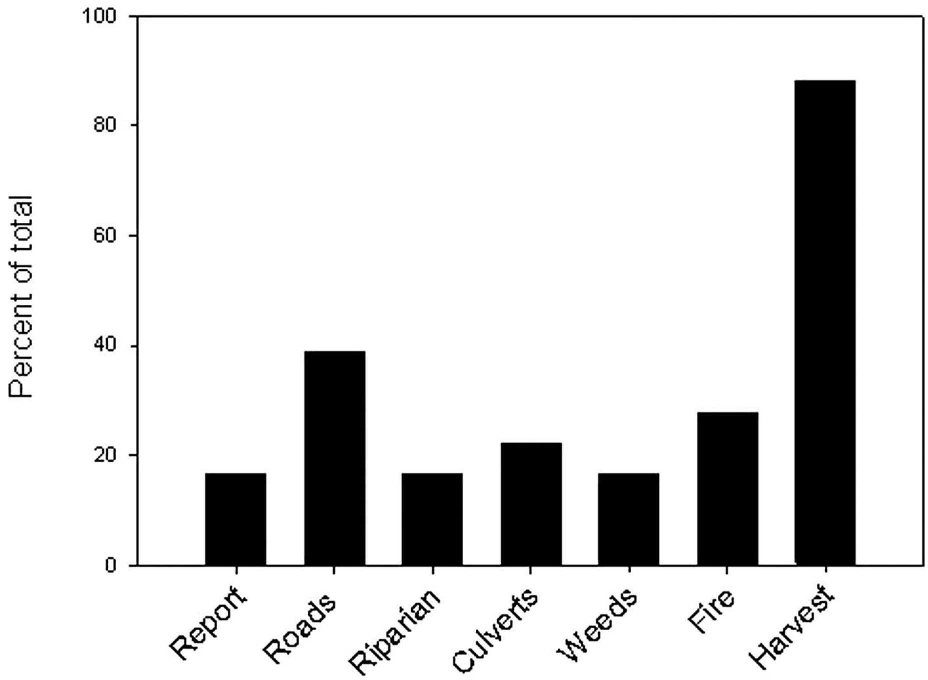

Figure 1. Project-level results recorded in worksheets on all stewardship contract agreements in Montana from 1999 to 2006. "Report" refers to the percentage of projects where a final monitoring report was filed. The remaining categories refer to the percentage of projects where activities included road restoration, riparian or stream restoration, culvert removal or replacement, weed treatments, use of prescribed fire, and some form of timber harvest.

The lack of effectiveness monitoring was formalized in law when stewardship contracting authority was extended to all US Forest Service and Bureau of Land Management (BLM) lands for a 10-year period in 2003 (PL 108-7). In Section 323 of the Consolidated Appropriations Act for Fiscal Year 2003, the Pilot Program's language describing project-level monitoring was dropped, and "programmatic monitoring" (ongoing forest level monitoring) was described as the tool by which restoration work would be monitored in association with stewardship contracting (Pinchot Institute 2005). Under programmatic monitoring (e.g., forest inventory plots), the sampling intensity is insufficient to detect site-level changes in understory vegetation or habitat conditions associated with restoration (Johnson et al. 2006), undermining the ability of the monitoring program to determine the precise effects of treatment. Further, after Congress extended stewardship contracting authorities, the US Forest Service restricted the use of retained receipts for monitoring programs in an attempt to maximize the availability of funds for the actual restoration work. Although retained receipts could be used in implementation monitoring, there was no provision to allow for effectiveness monitoring with these funds. This ultimately ensured that stewardship

Table 1. Examples of the type of ecological variables that could be monitored under one of four ecosystem attributes and some benefits and limitations of each of three approaches to restoration monitoring: (1) multiparty (citizen), (2) intensive sampling, and (3) spatial/remote sensing.

Monitoring type	No. sites/date quality	Ecosystem health	Aquatic integrity	Fire hazard	Biodiversity indicators	Other benefits (+) or limitations (−)
Multiparty monitoring	Most sites/limited data of moderate quality	Tree mortality Disease Soil organic matter Soil compaction	Aquatic invertebrates Water temperatures	Surface fuel load Fuel moisture Ladder fuels	Invasive species Size, age, diameter	+, Positive community engagement −, Need for extensive oversight and data management and analysis
Intensive sample monitoring	Few sites/extensive data of high quality	Tree mortality Forest structure Coarse woody debris Regeneration Cause of death Disease indices Trail widening Soil erosion Nutrient availability Infiltration rates Soil organic matter	Aquatic invertebrates Water temperature Water chemistry Fish counts Turbidity	Surface fuel load Crown base height Fuel moisture Live fuels	Vegetation composition Invasive species Endangered species Size, age, diameter Distribution change	+, Internally managed, high quality control −, No community engagement, limited geographic coverage, and dependence on statistical interpretation
Spatial monitoring	All sites/limited data of limited quality	Tree mortality Stress	Turbidity Temperature	Fire hazard ratings	Potential vegetation	+, Minimal annual cost and broad geographic coverage −, No community engagement, limited numbers of attributes, and no ground-level experience

contracting would be saddled with the dearth of both financial and institutional resources that hinder the application of monitoring activities in other types of projects.

Three Possible Approaches to Effectiveness Monitoring

The lack of mandatory effectiveness monitoring on restoration projects and the lack of federal funds available for effectiveness monitoring has created a challenging situation; however, the need—from the ability to conduct adaptive management to the desires of local communities to realize the benefits of stewardship contracting—demands that solutions be found. We believe that one or a combination of the following three approaches might be used under the limitations of a tight federal budget to evaluate the efficacy of forest and watershed level restoration:

1. Pursue low-cost multiparty monitoring conducted by a collective of stakeholders including citizens, conservation groups, timber interests, and agency personnel.
2. Conduct highly detailed ecosystem monitoring on a statistically selected number of forest restoration sites by region.
3. Conduct spatial analysis of remotely sensed data as direct or proxy variables to evaluate ecosystem response to restoration activities.

For any of these three approaches to be successful, the ecological monitoring program must have clear objectives, be of a sound statistical design, and retain quality control for data collection and management (Legg and Nagy 2006). There are a number of indicators of ecological condition that could be measured, including those selected under the "Montreal Process" to monitor sustainable forestry (US Forest Service 2004). It is important to note, however, that there is no "single best" or universal set of indicators to represent forest condition; indicators are most likely to be viewed as legitimate when they derive from an open process of public involvement (Hagan and Whitman 2006). Table 1 provides a summary of the types of ecological variables that could be monitored, along with the relative benefits of using each of these three approaches. In practice, these three approaches to monitoring might be best performed in an integrated fashion. For example, spatial monitoring could provide contextual data, while multiparty monitoring and intensive sampling could examine cause and effect relationships of restoration treatments. Use and interpretation of monitoring results must be encouraged by all interested parties. This type of effective and open access is essential to an effective monitoring program (Legg and Nagy 2006).

Multiparty Monitoring

Multiparty or participatory monitoring represents the range of activities that are motivated by a perceived need for information on ecological factors affecting a community and that involve participation by community members (Bliss et al. 2001, US Forest Service 2003b, Piltz et al. 2006). Multiparty monitoring may be as simple as community assessment of the actual restoration activities or can involve the collection of a variety of ecological data conducted by a wide range of stakeholders (those individuals and organizations that have an interest in the outcomes of the given activity). We believe multiparty monitoring could be used on treated landscapes for multiple objectives allowing for both systematic tracking of treatment effectiveness and community learning regarding restoration activities. Through measurement of simple, but scientifically defensible, biophysical response variables, community members can complement other findings conducted by managers and scientists at other levels of resolution (Fernandez-Gimenez et al. 2008). Their participation and organization will not come without cost, because agency personnel will be required to enable the collection, organization, and storage of data. However, the association of citizens and agencies within the process of monitoring can lead to a creative discovery of variables heretofore overlooked as essential indicators of restoration success. This sharing of the science process can lead to greater "ownership" of restoration treatments, such that the obligations and commitments involved with treatments, as well as the distribution of project benefits, become more of a responsibility of participants (Lachapelle and McCool 2005).

Multiparty monitoring is a form of citizen science in which researchers or land management agencies engage volunteers to expand data gathering capacity and possibly, more importantly, engage citizens in both science and conservation (Cohen 2008). In the case of restoration monitoring, citizen volunteers would provide a workforce both at the local or project level as well as dispersed participation in monitoring the efficacy of forest restoration efforts at a national level. The use of dispersed volunteers (groups of volunteers at restoration projects across the West) to assist in data collection creates the capacity for research at an ambitious scale (Cooper et al. 2007) and may allow for long-term, geographically extensive evaluation of restoration success and impacts. Volunteers would not be responsible for data analysis or report preparation, but rather information gathering and data collection where budgets or lack of workforce would otherwise constrain their completion (US Forest Service 2003b). The quality of data collection by multiparty teams is the responsibility of the managing agencies. Citizen volunteers must be given clear, realistic protocols, must be properly trained, and the results must be tested for reliability if the data are to be effective and meaningful (Cohen 2008). Data storage, access, and utilization is a key weakness in many monitoring programs (Lovett et al. 2007). Strict protocols for data storage, sample archiving, and data access will need to be established, and data collected with pubic funding should be made available for public review and use.

Multiparty monitoring requires a consistent, dedicated, and focused workforce, a factor that should not be taken lightly (Bliss et al. 2001). Thus, to succeed, multiparty monitoring should address attributes that have direct relevance to restoration objectives that can be negotiated in an inclusive, fair process; it should be perceived as a generally positive or enjoyable process; and it must have a clear relationship to locally important places and features. These types of incentives will support community participation in monitoring but in and of themselves are insufficient. Multiparty monitoring must be viewed as a process by which education and empowerment are priority outcomes, and there is a direct connection between this learning and the quality of the restoration program. More detailed background on the nuances, potential, and limitations of multiparty monitoring can be found elsewhere (US Forest Service 2003b, Piltz et al. 2006, Fernandez-Gimenez et al. 2008).

Sampling Approach

A statistically robust approach to monitoring restoration success could be conducted through intensive monitoring on a *sample* of restoration projects being performed on national forests across the country. Although extensive sampling is already being conducted under the Forest Inventory and Analysis (FIA) program, these data are collected on too coarse of a scale to be useful in project-level monitoring (Johnson et al. 2006), though FIA could possibly be useful in monitoring restoration effects at broader scales. A sampling approach could involve a limited number of sites randomly selected from a pool of sites that are deemed representative of restoration being conducted within the region based on size, location, objectives, and phase of completion. A reasonable number of sites nationwide would be selected for intensive monitoring and then funded appropriately to allow for replicated, long-term analysis of outcomes on individual restoration sites (Legg and Nagy 2006). Monitoring would likely be conducted by trained US Forest Service staff and contractors. Intensive monitoring of a set of ecosystem attributes would be performed based on prior selection of easily measured, quantifiable variables that show a relatively low level of variance between sites. Under the realm of intensive monitoring, numerous variables could be measured quantitatively and consistently following strict data quality guidelines. For ecosystem health, restoration units could be monitored more intensively for changes in ecosystem attributes including soil quality attributes, stream and water quality attributes, riparian zone integrity, habitat condition, populations of key indicator species, endangered species, species indices (e.g., community structure or species richness), invasive plants, and native plant cover (Table 1). Data could be collected at spaced intervals (e.g., every 5 years) with start dates offset to allow for monitoring on multiple sites each year. Data could be centrally compiled and analyzed by specialists within the US Forest Service or the BLM and presented as interim and final reports both internally and to the public. The Fire and Fire Surrogates research program is a multiagency, university joint project that was established to provide regional applied research on the efficacy of forest restoration treatments nationwide (Youngblood et al. 2007). Although this project is a research program (e.g., replicated, 10-ha study plots) rather than actual on-the-ground restoration work, this program provides an excellent example of what can be done with intensive monitoring of restoration projects (Boerner et al. 2008) when sufficient funding is put behind a given effort and effective central coordination is provided (Youngblood et al. 2007).

The benefit of using the intensive sampling approach would be the collection of high-quality, defensible, statistically sound biophysical data that would have the greatest potential to be of long-term use and significance (Legg and Nagy 2006). Shortcomings of this approach would be that some projects would not be monitored and financial constraints would limit what variables could be selected for monitoring.

Spatial Analysis Approach

Remote sensing and geographic information system technology allows for observation and synthesis of large areas observable from space and therefore holds tremendous promise for ecological monitoring of forest restoration activities, especially those factors that are difficult to observe from the ground. However, there is such an overwhelming array of potentially useful spatial information that identifying a practical suite of reliable, relevant, and repeatable ecological metrics can be difficult. As a first step, it is important to identify the key ecological factors that, if monitored, could inform the need for management alternatives. To monitor changes in spatial patterns, there exist a variety of tools to calculate landscape metrics (McGarigal 2007). These metrics include a wide variety of measures, some very complex (e.g., double-log fractal dimension) and others more intuitive (e.g., edge–area ratio and core area). For obvious reasons, the more intuitive landscape metrics represent simple, practical tools for monitoring ecosystem structure.

Appealing as it is to be able to peer down using state-of-the-art satellite imagery to detect the effects of restoration treatments, there are some important limitations associated with spatial monitoring that must be kept in mind. Monitoring large-scale ecological processes requires the identification of key structural and physiological characteristics of ecosystems that can be linked to underlying processes *and* that those characteristics must be measurable using remote sensing (Wessman 1994). For example, monitoring of the effects of fire suppression is a difficult task because the ecological process in question is actually a stand-scale process. In most studies aimed at detecting the effects of fire suppression, scientists measure individual stand-scale variables, e.g., percent canopy closure, percent cover, and understory (Romme 2000). However, these ecological variables are extremely unlikely to be detectable using commonly available satellite data sets [2]. If these stand-scale factors are important goals of the monitoring strategy, more intensive analyses can be conducted, relying on finer-scaled imagery and stand examinations. However, drawbacks remain in terms of higher costs, more time, and greater potential for errors in extrapolating sample data across the broader landscape and this, in turn, inhibits repeatability. Designing an effective and robust sampling protocol is especially important when interpreting and interpolating high-resolution spatial data sets.

The following basic guidelines should be considered before designing a spatial restoration monitoring plan: (1) carefully identify the monitoring goal, (2) evaluate limitations of scale and the consequences of misinterpretation, (3) consider cost, and (4) assess repeatability. The benefits of a spatial monitoring program are broad geographic coverage, dependence on a small workforce, and, although potentially high in initial start up costs, a relatively low long-term financial demand.

Conclusions

Restoration of western forest ecosystems is being conducted with minimal systematic ecosystem monitoring. Unfortunately, the lack of this crucial activity eliminates the potential for the long-term evaluation of the trajectory of ongoing forest restoration efforts. Furthermore, any interest in the application of adaptive management is dependent on the implementation of effectiveness monitoring to allow for adjustments and restructuring of the restoration practices being used. Failure to conduct effectiveness monitoring on forest restoration projects may lead to unintended long-term impacts and uncorrected errant trajectories in the restoration process. Current financial limitations should not be allowed to eliminate ecosystem monitoring on forest restoration activities. Multiparty monitoring, statistical sampling, or spatial analysis could be used individually or in combination to accomplish effectiveness monitoring, enable adaptive management, and help accomplish long-term restoration objectives.

Endnotes

[1] National Forest Management Act of Oct. 22, 1976 (P.O. 94-588, 90 Stat. 2949, as amended; 16 US Code).

[2] Landsat 30-m satellite imagery is the standard for most landscape-scale imagery data sets. These data are largely free and available to public land-management agencies at no cost.

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