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# Making Monitoring Count: Project Design for Active Adaptive Management

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**Ongoing environmental change requires that managers develop strategies capable of achieving multiple objectives in an uncertain future. Active adaptive management (AAM) offers a robust approach to reducing uncertainty while also considering diverse stakeholder perspectives. Important features of AAM include recognition of learning as a management objective, integration of monitoring throughout all aspects of project design and implementation, and use of experimental design in project planning. These features facilitate collaborator engagement and adaptive management based on credible inferences about treatment effects. AAM is not research: the primary goal in AAM is to meet management objectives, one of which is to learn about tradeoffs among alternative management approaches. We outline a pragmatic method to enhance the value of monitoring by incorporating experimental design principles into project planning, including a checklist of key questions for decisionmakers and stakeholders, and illustrate these concepts with an example from the Helena National Forest, Montana, USA.**

**Keywords:** collaboration, science-based management, National Environmental Policy Act of 1969 (NEPA)

Forest management on public lands has become increasingly complex with the emergence of ecosystem management (North et al. 2009), restoration (Franklin and Johnson 2012), and resilience (Churchill et al. 2013) as dominant paradigms. Rapidly advancing environmental change requires that managers develop strategies to achieve multiple objectives in an uncertain future (Millar et al. 2007, Vose et al. 2013). These circumstances create a need for innovative approaches that reduce uncertainty while simultaneously meeting the diverse objectives of the public.

The ability of land managers to proactively incorporate input from stakeholders is critical to establishing the social capital necessary for innovation (Schultz et al. 2012). Management approaches that promote shared learning and enable testing and refinement of both manager and stakeholder assumptions contribute to the technical knowledge base while bolstering the social license to actively manage. In addition, a number of new policies, such as the Collaborative Forest Landscape Restoration Program (CFLRP) (Schultz et al. 2012) and the new National Forest System land management planning rule (US Department of Agriculture Forest Service 2012), emphasize adaptive approaches, promote collaborative involvement of stakeholders, and elevate the importance of monitoring.

Adaptive management, the reduction of uncertainty through systematically planned, implemented, and monitored management actions (Holling 1978, Walters and Hilborn 1978), offers an approach to address social and scientific uncertainties, if conducted in a rigorous way. Implementation of adaptive management has taken many forms, spanning a gradient from trial-and-error methods to deliberate integration of monitoring and management interventions using the principles of experimental design (Legg and Nagy 2006, Bormann et al. 2007). Whereas experienced managers accumulate deep understanding without ever using experimental designs, such knowledge is difficult, if not impossible, to standardize and share across stakeholders. An adaptive management approach based on principles of experimental design can overcome these challenges.

Active adaptive management (AAM) offers a framework for integrating monitoring with forest management that is robust to scrutiny and amenable to engaging collaborative stakeholders. Important features of AAM include explicit recognition of learning as a management objective, integration of monitoring throughout all aspects of project design and implementation, and use of basic principles of experimental design to

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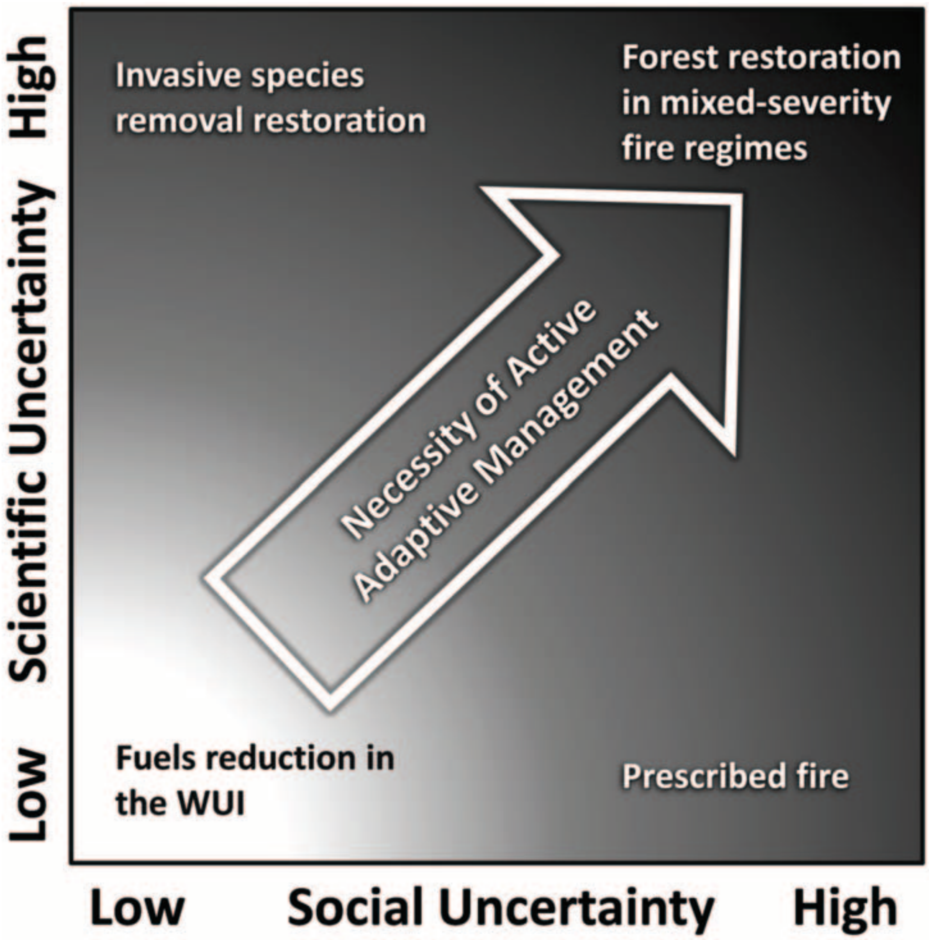


**Figure 1. Active adaptive management is of the greatest potential value in situations where both scientific and social uncertainty (i.e., disagreement) are high.**

join monitoring with forest management project planning.

We begin by noting that AAM is just one tool of many available to forest managers, and we do not suggest that AAM should be used in all projects (Figure 1) . However, we see an increasing role for AAM in public forest management to address the uncertainty associated with future environmental change and also to deal with the increasing prominence of monitoring and adaptive management in new policies such as the new National Forest System planning rule. Thus, the purpose of our article is to provide an introduction to the AAM concept and to illustrate its potential use in forest management project planning and monitoring. Our specific objectives are to discuss when and why to use AAM, to examine the relationship of monitoring to adaptive management, to review the basic elements of experimental design relevant to planning and implementation of forest management activities in an AAM framework, to outline pragmatic approaches to integrate monitoring with forest management project design, and to illustrate these concepts with an example from the Helena National Forest, Montana, USA.

## What, When, and Why of AAM

AAM is a management approach in which uncertainty is explicitly recognized and then confronted by monitoring the outcomes of alternative policies or interventions (Walters and Hilborn 1978, Parma et al. 1998). AAM offers a constructive and transparent way forward when multiple values and scientific uncertainty intersect with social uncertainty (Figure 1). AAM represents an approach to forest management that is fundamentally science-based (Parma et al. 1998, Shea et al. 2002): silvicultural interventions are deliberately planned as experiments and monitored to efficiently and confidently learn (Murray and Marmorek 2003).

Reducing social and ecological uncertainty through AAM occurs most effectively by simultaneously comparing multiple alternative management approaches using the principles of experimental design and monitoring. Such an approach enables confident learning about the effects of alternative treatments, including tradeoffs and relative costs and benefits. An AAM framework also facilitates collaborative forest management. Different stakeholder perspectives, including no treatment (i.e., untreated controls), can be represented as alternative treatments. Such an approach honors diverse collaborator perspectives and serves as a platform for active joint fact-finding, a key to successful collaboration (McCreary et al. 2001). Evaluating multiple alternative treatments simultaneously also functions as a hedge against uncertainty by creating a variety of

### Management and Policy Implications

Active adaptive management (AAM) offers a framework for meeting societal objectives for forest landscapes in an uncertain future that is defensible, is grounded in the scientific method, and provides a mechanism to incorporate diverse collaborator perspectives. Use of AAM involves elevating learning about treatment effectiveness and effects to the level of a management objective. Meeting the management objective of learning necessitates that monitoring, the process through which new information is generated, be integrated throughout all stages of project planning and implementation. The most defensible and probably most cost-effective framework to achieve this integration involves comparing multiple alternative interventions (i.e., treatment types) using principles of experimental design. Such an approach conveniently offers a framework to meet the policy objective of incorporating diverse stakeholder perspectives into forest management project design because different perspectives can be represented as alternative treatments or management regimes. Incorporating basic elements of experimental design into project planning can be accomplished with just modest alterations to the typical planning process. A significant implication of use of the AAM model to confront uncertainty and engage collaborative stakeholders is that forest managers become practitioners of the scientific method, rather than just consumers of scientific information.

conditions across the landscape (Millar et al. 2007).

Our experience suggests that a major obstacle to implementing AAM within the USDA Forest Service National Forest System lies in the perception that such an approach is research, not monitoring, and therefore lies beyond the scope of responsibilities and interest of forest managers. This is a major and very serious misconception that distracts stakeholders and managers away from the key benefits offered by AAM, namely, its ability to reduce uncertainty and increase transparency in an efficient, cost-effective manner. In AAM the primary goal is still to meet management objectives, one of which is to learn about the efficacy and effects of alternative treatments or management approaches.

Lack of funding for monitoring may limit implementation of AAM in some situations (DeLuca et al. 2010). An AAM approach, however, encourages cost-efficient monitoring guided by specific questions. AAM allows managers, researchers, and stakeholders to evaluate whether changes in forest characteristics or processes are caused by treatments, site-specific conditions, or other broad-scale shifts in forests caused by, for example, regional insect outbreaks or climatic variability. This feedback of new information into future management can lower costs over the long-term (Nichols and Williams 2006).

## Relationship of Monitoring to Active Adaptive Management

Monitoring involves systematic observations (i.e., measurements and data collection) of resource conditions and subsequent analysis and interpretation, all guided by specific monitoring question(s), leading to new information. Adaptive management occurs when adjustments to future management, based on the new information provided by monitoring, are implemented. In AAM, monitoring is integrated throughout the entire lifecycle of a management intervention: it is a parallel set of activities that occur at all stages of project planning and implementation (Figure 2). To be clear, we mean that some consideration for and elements of monitoring programs are always occurring throughout project planning and implementation, not that all stages of planning and implementation need to be monitored.

Several types of monitoring are used in natural resource management, depending on the types of questions being addressed (Lindenmayer and Franklin 2002, DeLuca et al. 2010, Hutto and Belote 2013). Effectiveness monitoring asks whether treatments are accomplishing the stated goal of the plan or prescription. Effects or validation monitoring is used to determine whether the measured resource responses are actually outcomes of the management plan and implemented treatments, as opposed to natural variation or chance. Both of these types of monitoring can be improved through AAM. Implementation monitoring, which asks "Was the treatment carried out as planned?" does not require AAM but can usually be accomplished using data collected through it.

The first step in monitoring for AAM is to recognize that prescribed treatments are, in fact, hypotheses. Particular treatments are prescribed by a manager because they are expected (hypothesized) to result in a desired outcome, for example, increased tree growth and vigor, reduced fuels and fire hazard, or enhanced wildlife habitat. Recognition of prescribed treatments as hypotheses connects the management objective of learning to the planning and implementation of management interventions (Figure 2).

Monitoring questions should be developed early in project planning and based on predictions about forest ecosystem responses to treatments. The likelihood of implementing a successful monitoring program will increase by involving collaborative stakeholders early and often in the question development process and also by ensuring that monitoring questions are tractable. Monitoring questions should address the biggest knowledge gaps and uncertainties. However, in any given AAM project, the complexity and scope of the questions should be relatively limited: break complex problems into smaller pieces and only tackle a few of the most pressing monitoring questions. A short list of carefully chosen questions can be investigated in detail, providing greater value, both in terms of cost and information gained, than a long list of monitoring questions that can only be addressed superficially due to limited resources.

It is crucial that the same body of scientific knowledge used to design and justify prescribed treatments also be used to formulate monitoring questions. This is the initial conceptual linkage required to eventually generate new information and learning about the system (Figure 2). Ideally, monitoring questions should emphasize physiological and ecological mechanisms. Such mechanistic questions often begin with "how" or "why" as opposed to beginning with "do" or "what." It is also important to identify potential unintended treatment effects for which to monitor (Hutto and Belote 2013); recurrent stakeholder concerns can help identify potential unintended treatment effects. Finally, we note that monitoring is itself an adaptive process in which questions and methods are adjusted as new information and understanding accrue (Lindenmayer and Likens 2009) (Figure 2).

## Experimental Design for Active Adaptive Management

Use of experimental design principles in forest management projects enables efficient and confident learning about the complex ways forests respond to treatments. Such an approach is grounded in the method of multiple working hypotheses (Chamberlin 1890), in which a family of related plausible hypotheses (e.g., alternative silvicultural prescriptions) are evaluated to understand complex tradeoffs associated with choosing one approach over the other. Here, we describe the key elements of experimental design relevant to AAM: inclusion of untreated controls, replication of treatments, and unbiased treatment assignment. We also discuss monitoring the effectiveness and effects of treatments at different spatial scales, from individual trees to entire watersheds.

### Untreated Controls

An important experimental design element relevant to AAM is the use of untreated control units. Control units are selected from the same "universe" of candidate sites that are otherwise targeted for treatment: control units meet all the same criteria used to identify candidate units for treatment but are left untreated to provide a fair comparison with treated sites. Many environmental factors may change during and after project implementation (e.g., year to year fluctuations in temperature, precipitation, insect outbreaks, or wildlife population dynamics). Control units allow identification of actual treatment effects from such "background" changes that occur naturally through time (Figure 3). Although untreated control units may not be necessary if the goal is only to compare different treatment alternatives, including control units in

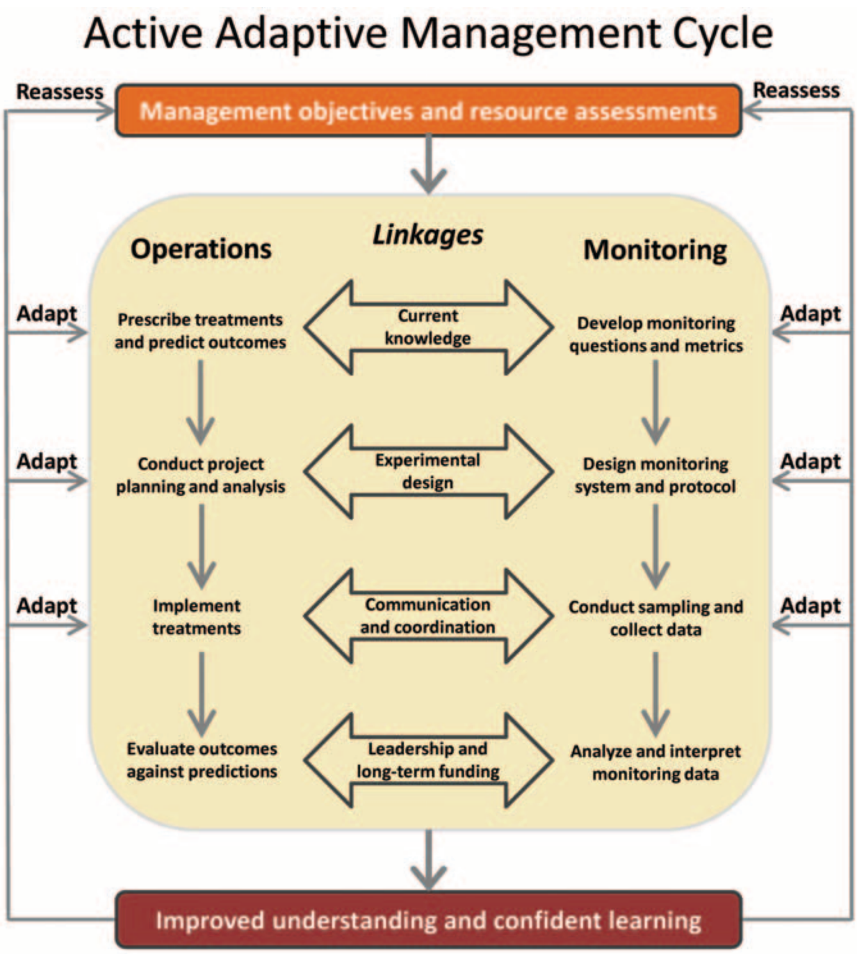


**Figure 2. Conceptual diagram illustrating the interconnected nature of monitoring and operations in active adaptive management. Note that aspects of monitoring occur at all stages of project planning and implementation and that there are multiple opportunities for feedback for learning and adaptation.**

a project increases the value of monitoring and possibilities for learning.

Including untreated control units in forest management projects can help build social capital for managers. Controls provide a means to determine whether undesirable or unintended consequences were the result of natural fluctuations or ecosystem dynamics rather than treatment impacts. For example, if large ponderosa pine were to be attacked and succumb to mountain pine beetle infestation after a thinning treatment, untreated control units would verify whether this response may have been caused by the treatment (if trees in the untreated control units were not attacked by beetles) or represent a response of an entire area to regional drought or bark beetle epidemic (if trees in both the thinned and control units were attacked) (Figure 3C and D). Another example illustrating the importance of untreated controls occurred in an experimental forest where, after a harvesting treatment, small mammal populations declined, but they also declined in an untreated control (Amacher et al. 2008). Without including untreated controls within their experiment, the researchers might have mistakenly concluded the treatment alone caused the decline. Deliberate inclusion of untreated controls in projects also represents a common stakeholder perspective: that no silvicultural intervention is needed. Stakeholders with this view may be more likely to endorse or at least accept a proposed project if their perspective is legitimized and included in project design and monitoring, rather than being dismissed by the planning team and responsible official.

## Replication of Treatments

The second important element of experimental design for AAM is replication: the systematic repetition of treatments in time and space. Repeating treatments (and untreated control units) in different locations at the same time is important because some responses depend on site-specific conditions such as soil fertility. Replication in time is important because some responses, such as tree radial growth or timing of understory plant flowering (Ellwood et al. 2013), are variable from year to year.

The generality and credibility of monitoring results are greater when treatments and controls have been replicated at several sites in multiple years. Replicating treatments in space and time allows managers to generalize their monitoring results to similar forest conditions. Without replication, managers risk inappropriately applying lessons learned to other areas: the response of a treatment may be caused by special circumstances or conditions unique to the single treatment unit (Figure 3D) or to a single year (e.g., a particularly wet or dry year). Replication also has the practical benefit of providing insurance against lost treatment units, for example, unavoidable disturbance (e.g., a hurricane), a change in regulation or policy that prevents treatment implementation, or a change in land ownership.

## Unbiased Assignment of Treatments through Randomization

A third key element of experimental design for AAM is to ensure that treatments are assigned to candidate units without bias. By far, the best way to accomplish this is through randomization—the random assignment of alternative treatments (e.g., thinning, prescribed burn, or no treatment [control]) to individual candidate units.

There are many misconceptions about randomization. Chief among them is the idea that randomization ignores scientific knowledge and professional expertise and is an unplanned, haphazard approach to natural resource management. This could not be further from the truth. Randomization only occurs after a very detailed and careful stratification process has been used to identify a pool of candidate treatment units. Randomization is the final step in which alternative treatments and untreated controls are assigned to the candidate units in an unbiased way.

Randomization is used in AAM for two main reasons. Treatment responses may be confounded by known, or even unknown, gradients of environmental and site conditions within the pool of candidate treatment units. Randomization across these gradients ensures that monitoring results and conclusions can be generalized. More importantly,

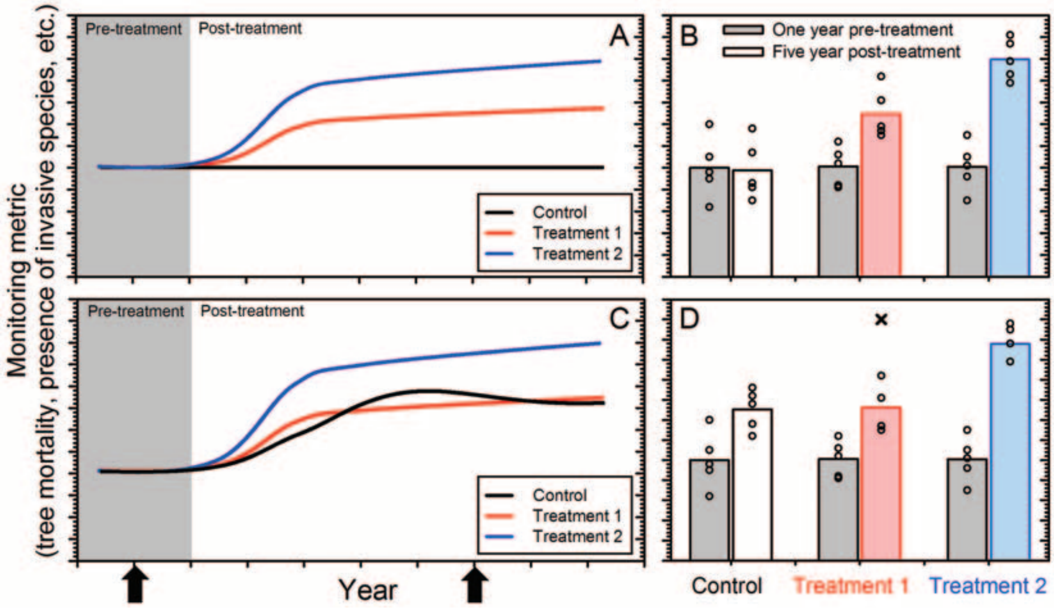


**Figure 3. Use of an experimental design yields reliable conclusions about forest responses to alternative treatments. A and C. Change through time of a monitoring metric among different treatments and untreated controls. B and D. Corresponding (to A and C, respectively) average response (bars), as well as variability among experimental replicates (open circles represent observations among different stands receiving the same treatment), during 1-year pretreatment and 5-year posttreatment measurements (sampling times are indicated along the x-axis of A and C as black arrows). The situation shown in A and B is strong evidence that the measured change in forest conditions resulted from impacts of treatments because the untreated control sites did not change through time, whereas the treated sites did. C and D illustrate the importance of including untreated controls: the monitoring metric in treatment 1 and the untreated controls changed in a similar way through time, indicating that background changes in forest conditions, and not treatment 1, caused the changes detected with monitoring. In this case (C and D), treatment 2 caused a significant change in addition to the natural background variability represented by the changes detected at the control sites. Without controls one would falsely conclude that treatment 1 caused the observed change detected with monitoring (C and D). One observation in D is an outlier (✖) and illustrates the importance of replicating treatments. Without replicates, site-specific conditions that resulted in the outlier observation might lead one to believe that treatment 1 and treatment 2 caused similar outcomes, when in reality their average effect across multiple replicates is significantly different.**

randomization protects against the criticism that managers biased monitoring results to achieve a predetermined outcome. If a manager decides what units within the pool of candidates receive particular treatments, critics are then able to make the irrefutable argument that the manager "cherry picked" the sites to find what she or he wanted the monitoring results to show.

## Integrating across Scales

Many forest processes and responses to management interventions operate at scales both smaller and larger than forest stands. In some cases, responses of individual trees to treatments is of interest, for example, populations of ecologically and socially significant large, old trees (Lutz et al. 2012). In just such a case Harrington (2012) used an experimental design to implement monitoring within an operational-scale forest restoration project to quantify the effects of duff mound consumption during prescribed fire in terms of injury and mortality of large, old larch (*Larix occidentalis*) trees. In that study, 90 trees were randomly assigned to one of two treatments, burned and unburned. Duff mounds of burned trees were left intact and allowed to burn while the duff mounds of unburned trees were removed with a leaf blower.

Understanding how treatments influence landscape processes, such as fire behavior, water chemistry, or aquatic habitat features may require that treatments and monitoring are planned at larger spatial scales (Hobbs 2003). The Ellsworth Creek Forest Restoration project in southwest Washington, USA, exemplifies such a large-scale AAM design. There, managers assigned different treatment regimes to watersheds within The Nature Conservancy's Ellsworth Creek Preserve, including active management with thinning and untreated control watersheds (Rolph and Davis 2008) to monitor outcomes of alternative approaches to forest restoration.

Within treated watersheds, experimental designs can be implemented at lower levels of ecological organization. This type of nested monitoring design, with treatments and controls monitored at, for example, the tree (Harrington 2012), stand (Larson et al. 2012), and watershed (Rolph and Davis 2008) scales, will probably become increasingly important, given the emerging emphasis on forest landscape restoration.

## Other Considerations

The collection of data before treatments are implemented is another important consideration (Figure 3). Pretreatment data allow managers to account for the initial conditions when interpreting treatment effects. This is important because the initial conditions can sometimes influence the response to treatments. Accounting for variability in pretreatment conditions among sites allows more nuanced and confident interpretation of monitoring results. Although pretreatment data are not essential in every case, pretreatment data can increase value from investments in posttreatment data because managers are better able to disentangle

**Table 1. Checklist of questions for stakeholders and decisionmakers to ask for projects that include active adaptive management and associated monitoring.**

1. Are learning and information generation identified in the purpose and need statement as management objectives?
2. Do conceptual or quantitative models guide linked proposed treatments, predicted treatment effects, and monitoring questions?
3. Do proposed treatments and monitoring questions incorporate stakeholder input and represent a range of social and scientific perspectives?
4. Are scientists and statisticians involved directly in project development or indirectly as reviewers? External review enhances transparency and credibility even if sufficient in-house expertise exists to achieve robust experimental and monitoring designs.
5. Does project design reflect the stated management objectives of learning and information generation by incorporating basic principles of experimental design? If not, what mitigates the reduced information quality and potential for learning?
6. Does the project planning team (i.e., the interdisciplinary team) include someone designated to represent and advocate for monitoring and experimental design criteria throughout the project planning process?
7. Will monitoring include collection of pretreatment data? If not, what mitigates the reduced potential for learning and why is this acceptable?
8. Does the monitoring plan address data management, including metadata standards and a long-term data storage and backup protocol?
9. Does the monitoring plan include a timeline for analysis, interpretation and dissemination of monitoring data and results?
10. Who will analyze monitoring data and report the results, and who is responsible for ensuring that these activities receive adequate resources and staff time?

These questions should be answered early in the project design process. For federal agencies, this means during project scoping—prior to NEPA analysis and a final decision.

treatment responses from the effects of differing initial conditions among treatment units.

It is important to ensure that alternative treatments are sufficiently different from each other so as to reasonably expect detectable differences in the responses. Alternative treatments that differ only slightly do not provide as many opportunities to learn about tradeoffs as do strongly differing alternatives.

## A Practical Approach to Project Design

Incorporating the principles of experimental design into forest management projects can be accomplished with just modest changes to the typical planning process. There are three steps that will help ensure smooth integration of experimental design with project planning: identify the forest types and conditions to which managers hope to apply learning in the future; budget additional areas for untreated controls so promised timber volume and acreage targets can still be achieved; and screen candidate treatment units for conflicting management objectives or restrictions. We recommend engaging collaborative stakeholders early and often in this process. A checklist of key questions for managers and stakeholders to ask during the project design process is provided in Table 1.

Begin by using existing inventory and environmental data to stratify groups of potential treatment units (e.g., trees, stands, or watersheds) sharing broadly similar community composition and biophysical conditions and for which treatment is indicated to achieve management objectives. The goal is to identify sites that are predicted to respond in a manner that is desirable and similar to that for treatments. For example, fire-excluded ponderosa pine stands that could be treated with thinning, mowing, prescribed fire, or a combination of these treatments to restore forest resilience and reduce the risk of extreme fire behavior.

After the initial stratification process, screen candidate treatment units within the project planning area for social, ecological, cultural, or legal constraints. When risk associated with action or inaction is great, care should be taken to remove those sites and proceed using best judgment. For instance, locating untreated control units in high-risk wildland-urban interface (WUI) areas near residential properties would not be socially acceptable. Similarly, mechanical treatments in areas occupied by disturbance-sensitive wildlife species may be socially unacceptable and may also be precluded by regulation. Areas found to have these types of restrictions need to be removed from the pool of candidate units before further implementation of the experimental design.

Institutional policies and social expectations to achieve specific outputs, such as the number of acres treated or volume of timber harvested, create tremendous pressure to use particular treatment types in some situations. To account for these known output targets while designing projects using elements of experimental design to meet learning objectives, we recommend beginning with a larger project area than would be needed only to meet the mandated (or promised) acreage or timber targets. By accounting for untreated controls and replications of alternative treatments that do not produce timber or revenue (e.g., prescribed fire) early in project planning, delivery of other management outputs can be maintained.

Successful project implementation requires integration of the planning and implementation phases, including clear communication between the planning and implementation staff. Such organizational integration and communication will help ensure that monitoring is carried out during and after project implementation (Figure 2).

## Collaborative Forest Landscape Restoration on the Helena National Forest: A Case Study

Commitment to collaborative restoration forestry in Montana led to the formation of the statewide Montana Forest Restoration Committee (MFRC)[1] and associated local collaborative efforts throughout Montana. The MFRC developed a "zone of agreement" articulated in 13 restoration principles that form the foundation of collaborative forestry projects with an emphasis on treating low-elevation ponderosa pine, Douglas-fir, and western larch stands that historically burned under a low-severity fire regime. MFRC efforts gave rise to the founding of the Southwestern Crown Collaborative (SWCC),[2] one of the original 10 collaborative groups selected for funding under the CFLRP.

The Lincoln Restoration Committee (LRC), located in Lincoln, Montana, and organized to collaboratively design and monitor projects on the Lincoln District of the Helena National Forest formed in 2008 and serves under the MFRC guiding principles. The Lincoln District is one of three ranger districts encompassed by the SWCC. Much of the forest on the Lincoln District is composed of midelevation lodgepole pine and mixed-conifer types thought to have historically burned under mixed-severity and stand-replacing fire regimes. Since the mid-2000s, the Lincoln District has experienced widespread tree mortality caused by mountain pine beetle and spruce budworm.

**Figure 4. Members of the LRC and USDA Forest Service staff discuss the Dalton Mountain project during early stages of collaborative project development.**

In response to this mortality and fire managers' assessment of crown fire risk and spread, the LRC collaboratively evaluated conditions in a 40,000-acre landscape southwest of the town of Lincoln (46.86° N and 112.76° W). With an interest in restoration of this mixed-conifer landscape and recognizing the contentious nature of restoration in mixed- and high-severity fire regimes, the LRC approached this collaborative project using an experimental design framework. The LRC would offer a candidate project design that could be brought to the public through a commenting period and a typical National Environmental Policy Act of 1969 (NEPA) process. Unlike in the lower elevation, dry forests, a clear zone of agreement among the MFRC and SWCC was not fully developed for restoration treatments in lodgepole pine and mixed-conifer forests with historically mixed- and high-severity fire regimes. The MFRC, however, had developed guidelines for mixed-severity fire regimes that were helpful in focusing the collaborative group on appropriate scales (MFRC n.d.). These mixed-severity guidelines emphasize scientific uncertainty and the need for careful monitoring.

Given the scientific uncertainty and associated lack of a social zone of agreement (Figure 1), the LRC embarked on a series of weekly meetings over the course of a 2-month period to discuss options for forest management and restoration in the area (Figure 4). Prescribed fires were proposed and accepted by the collaborative in inventoried roadless areas, as was mechanical thinning with prescribed fire in stands where old legacy ponderosa pine trees occurred on southern exposures. However, lodgepole pine and mixed-conifer forests where mountain pine beetle mortality was widespread remained areas of contention. About 2,000 acres represented in ~40 stands of 15–250 acres within the proposed project boundary were occupied by this forest type. With an interest in restoration of this mixed-conifer landscape and a stated commitment to collaboration, the LRC decided to approach these contentious stands using an AAM framework that included an experimental design.

As a first step, stands adjacent to nearby homes and cabins and representing high-risk WUI interface were removed from the pool of candidate stands to be included in the experimental design. These stands were considered separately outside the AAM framework (Figure 1), but still within the overall project planning process. Thirty stands remained after this initial screening.

A variety of perspectives represented on the LRC were incorporated into the design. These diverse perspectives were lumped into three alternative treatment types: regenerate stands of high mountain pine beetle mortality through seed-tree harvests; create within-stand spatial heterogeneity and structural complexity while also regenerating a new cohort using aggregated retention harvest; and retain untreated controls to provide a means to isolate treatment effects from background variability (and because some stakeholders did not consider lodgepole pine/mixed-conifer forests a priority for restoration). These three treatment types were randomly assigned to the 30 carefully screened stands, allowing for 10 replicates of each treatment (Figure 5).

After LRC consensus on this project design, the district wildlife biologist updated area lynx habitat maps, which eliminated some of the replicates (modified design not shown in Figure 5). Although this elimination left the project with less statistical power, it illustrates one important benefit of replication: unanticipated events may remove some units without compromising the management objective of learning.

In sum, this project design screened out areas of high risk, eliminated bias by randomly assigning treatments within a carefully selected pool of candidate treatment units, considered variability by replicating treatments, and provided an opportunity to compare alternative mixed-severity restoration approaches and stakeholder perspectives by comparing different treatments including an untreated control. This robust statistical design enables confident learning and thus represents an application of "the best available science" in designing projects as called for in the MFRC principles.

## Conclusion

When managers and stakeholders identify learning as a management objective, they will be best served by the AAM approach in which alternative treatments are simultaneously monitored using an experimental design. AAM offers a route to credible, transparent learning that protects managers from many criticisms.

Simultaneously evaluating alternative treatment types has three main benefits: it

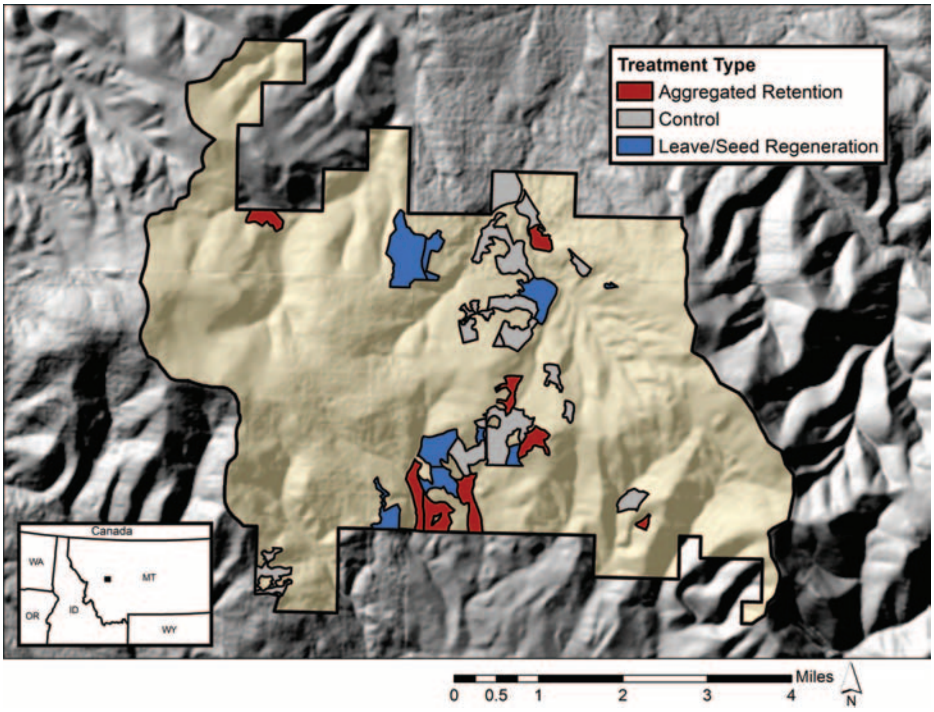


**Figure 5. Map of the Dalton Mountain project area where elements of experimental design (e.g., use of untreated controls, replication, and unbiased assignment of treatments) were collaboratively incorporated into treatment plans for 30 stands of lodgepole pine-mixed conifer forests.**

engages the collaborative process by representing diverse stakeholder perspectives; it accelerates learning by implementing different treatments concurrently; and it hedges against an uncertain future by creating diverse landscape conditions through replicated alternative treatments. Integrating monitoring into all phases of project design using experimental design ensures that the metrics assessed are of direct relevance to the questions asked by managers and stakeholders and that the changes in those metrics can be reliably attributed to the management actions.

There are three important implications of the AAM approach for the practice and profession of forestry. First, AAM involves elevating learning to the level of other management objectives: when AAM is used, learning is placed on equal footing alongside traditional management objectives such as revenue generation, fuel reduction, or habitat improvement. Second, in AAM, monitoring is integral throughout the entire forest management process, including the earliest project planning stages. Finally, the AAM model recasts the forest manager as a practitioner of the scientific method. This expanded role necessitates that foresters, and forestry educators, cultivate a professional ethos that values humility, acknowledges uncertainty, and prioritizes learning.

### Endnotes

1. Montana Forest Restoration Committee: www.montanarestoration.org.
2. Southwestern Crown Collaborative: www.swcrown.org.

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