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Distinguishing four types of monitoring based on the questions they address

Richard L. Hutto[a,*], R.T. Belote[b]

[a] Avian Science Center, Division of Biological Sciences, University of Montana, Missoula, MT 59812, United States
[b] The Wilderness Society, 503 W. Mendenhall, Bozeman, MT 59715, United States

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ABSTRACT

We describe and label four types of monitoring—surveillance, implementation, effectiveness, and ecological effects—that are designed to answer very different questions and achieve very different goals. Surveillance monitoring is designed to uncover change in target variables over space and time; implementation monitoring is designed to record whether management actions were applied as prescribed; effectiveness monitoring is designed to evaluate whether a given management action was effective in meeting a stated management objective; and ecological effects monitoring is designed to uncover unintended ecological consequences of management actions. Public land management agencies have focused heavily on implementation and effectiveness monitoring and very little on the more ecologically oriented surveillance and ecological effects monitoring. Tradeoffs, in the form of unintended ecological consequences, are important to consider in the management of natural resources, yet lack of ecological effects monitoring data has hindered our ability to fully understand these tradeoffs. Our proposed monitoring classification scheme offers practitioners and stakeholders a framework that explicitly identifies the type of monitoring they are conducting. We also suggest that, as a start, the effectiveness and ecological effects of a particular type of management activity can be approached rapidly and relatively inexpensively through use of a chronosequence approach to learning.

1. Introduction

A series of recent articles (Geupel et al., 2011; Lindenmayer and Likens, 2009; McDonald-Madden et al., 2010, 2011; Nichols and Williams, 2006) raise interesting points regarding the artificial distinction between research and monitoring, the need for question-driven monitoring, and whether monitoring can be equally effective using active vs. passive approaches. Here, we contribute to this discussion by drawing from our own experience with a 20-year-old regional landbird monitoring program (Hutto and Young, 2002) and from our recent experience with one of 10 national collaboratives created in response to Title IV of the Omnibus Public Land Management Act of 2009. A series of Collaborative Forest Restoration Programs were designed to engage diverse collaborative stakeholders in the management and monitoring of the US Forest Service watershed restoration and fuels reduction projects. The act mandates that the collaboratives "use a multiparty monitoring, evaluation, and accountability process to assess the positive or negative ecological, social, and economic effects of projects." As participants in the collaborative, we quickly discovered the need to explicitly recognize and classify different types of monitoring that are required for learning within an adaptive management framework (e.g., DeLuca et al., 2010; Lindenmayer and Likens, 2010a; Nichols and Williams, 2006). Here, we share this framework, which distinguishes four types of monitoring that are fundamentally different in terms of the types of questions they address. We suggest that a careful consideration of the different types of questions addressed by the four types of monitoring is necessary to address different kinds of information needs required by management agencies and diverse members of the public engaged in collaborative adaptive management. Although we draw heavily on our own experience with monitoring programs on lands managed by the US Forest Service, the concepts apply broadly across countries and ecosystem types because most land management agencies are required to operate in a way that does not compromise the ecological integrity of the system. We end with recognition that we can use a number of monitoring approaches to learn about the effects of management practices, and that the comparative, chronosequence approach to learning deserves more attention than it currently receives in monitoring programs.

2. Not all monitoring is alike

The overarching goal of monitoring is not only to provide information in a timely fashion and in a manner that could improve

* Corresponding author.
E-mail address: hutto@mso.umt.edu (R.L. Hutto).

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management decisions (Nichols and Williams, 2006), but to ensure that monitoring results are actually considered in an adaptive management context (Bormann et al., 2007; Holling, 1978; Walters, 1986; Walters and Holling, 1990). The primary weaknesses in most monitoring programs stem from a failure to state explicitly what we would like to learn from monitoring (Lindenmayer and Likens, 2010a; McDonald-Madden et al., 2010; Susskind et al., 2012), a failure to fund the programs (DeLuca et al., 2010; Field et al., 2007), a failure to manage and make the data available for analysis (Kelling et al., 2009; Martin and Ballard, 2010), and a failure to meet formally with decision makers to discuss and incorporate monitoring results into the adaptive management cycle (Hutto, 2005; Hutto and Kowalski, 2006; Susskind et al., 2012). These weaknesses are especially apparent in monitoring programs associated with public land management agencies. We have also come to realize that public land-management agencies sometimes use a single word (monitoring) to refer to different types of monitoring activities that have very different goals. What we strive to know, and the associated monitoring questions, should be driven by what we need to know (McDonald-Madden et al., 2010), and what we need to know requires *different types of monitoring* to address different types of questions.

Monitoring can be designed independently of any particular land-use activity (i.e., passive monitoring) or can be designed using an experimental framework to uncover effects that are the result of a particular land-use practice (e.g., active monitoring). Land managers can learn from either approach through an adaptive management cycle, and can modify practices if a cause-effect relationship can be reasonably well established. McDonald-Madden et al. (2010) make a similar (active vs. passive) distinction in their reference to monitoring as an activity that might either inform state-dependent management or provide information needed to improve management decisions. We wish to focus on a different kind of distinction, which is based on four fundamentally different types of questions that monitoring can address: one question can be answered through passive monitoring and three through active monitoring. By describing and labeling four very different types of monitoring associated with very different goals, we hope to steer monitoring efforts toward more diverse, useful, and cost-effective ends.

Once we accept that there are fundamentally different types of monitoring questions and goals, we can avoid putting ourselves into a situation, as described by Legg and Nagy (2006), where the costs of acquiring information are deemed to outweigh the benefits of information gained. Many researchers and resource managers equate the word "monitoring" with relatively expensive surveillance monitoring, which involves the collection and analysis of long-term trend data from sample locations that were not intentionally stratified by factors that might drive trends. This one-dimensional view of monitoring can lead one to question whether we should forego monitoring because costs of monitoring may not be justified relative to funding other actions, including strategic research. If we recognize that there are multiple types of monitoring, that each kind has a different purpose, and that some types go hand in hand with strategic research, the question of whether we should invest in monitoring becomes moot. Indeed, monitoring and research need not be mutually exclusive (Geupel et al., 2011); one can conduct targeted monitoring based on *a priori* questions and hypotheses (Nichols and Williams, 2006). As we discuss below, there are informative and inexpensive types of short-term monitoring activities that should go hand in hand with all land management activity, and there is at least one underused monitoring approach (use of a chronosequence design) that combines data from immediately before and after treatment with data from within older patches of the same types of treatments to provide insight into long-term land-use effects in as little as a few years.

3. Distinguishing four fundamentally different types of monitoring

Numerous authors have defined categories of monitoring, but few have attempted to distinguish monitoring types based on goals or questions that the monitoring is designed to address. For example, Nichols and Williams (2006) defined two types of monitoring: targeted monitoring, which involves *a priori* hypotheses about system responses; and surveillance monitoring, which is not guided by *a priori* hypotheses. Lindenmayer and Likens (2009) coin the term "adaptive monitoring" to acknowledge that monitoring can be rigorously designed and question driven, but at the same time flexible enough to accommodate change in questions. Lindenmayer and Likens (2010a) define passive, mandated, and question-driven types of monitoring. In contrast, DeLuca et al. (2010) borrowed terms from Block et al. (2001) to distinguish two types of monitoring based on the types of questions they are designed to address: implementation monitoring, which addresses whether the management action took place as planned; and effectiveness monitoring, which addresses whether stated management goals were achieved. None of the existing monitoring categorization schemes expose the full range of monitoring types that are necessary to address four fundamentally different questions, some of which emerge from requirements embedded in legislation such as the National Forest Management Act (1976) and the Omnibus Public Land Management Act (2009). We take the approach of DeLuca et al. (2010) in defining the types of *questions* that each type of monitoring can address, but for the sake of completeness, we take this exercise a step further by including two additional types of monitoring based on additional questions that they did not include in their discussion.

Four basic types of monitoring can be readily distinguished by the nature of questions that the particular monitoring effort is designed to address—(1) surveillance monitoring, (2) implementation monitoring, (3) effectiveness monitoring, and (4) ecological effects monitoring (Table 1). Each of the four is question-driven and each should involve rigorous statistical design. We now define each of four distinct types of monitoring and include hypothetical scenarios to clarify differences.

3.1. Surveillance monitoring

Here, well-distributed (geographically stratified) locations are surveyed repeatedly across years in an on-going effort to uncover trends in target response variables (see hypothetical point distribution in Fig. 1). District rangers and forest supervisors are in need of information about trends in recreation, local jobs, vertebrate populations, coverage of weeds, etc., and surveillance monitoring is designed to answer such questions. The purpose of this type of monitoring is to assess whether any change in a response variable exceeds some pre-determined threshold requiring management action. The US Forest Service, for example, is legally responsible for maintaining all native vertebrate species (and possibly all species, under the revised 2012 planning rule) across their historical ranges, so surveillance monitoring of as many species as possible should be an on-going process. Simple point-count methods, for example, can be used to track population trends of hundreds of species simultaneously (Hutto, 1998; Hutto and Young, 2002). The proactive inclusion of a broad range of indicator species will probably do more to bring rapid attention to an *ecosystem* or *land condition* in need of attention than will a reactive monitoring program focused entirely on threatened and endangered species (Chase and Geupel, 2005; Hutto and Young, 2002). Surveillance monitoring should also involve a coordinated partnership between private and public land owners because the two land types are

Table 1
Each of four categories of monitoring activity can be distinguished by the type of goal-oriented question it is designed to address. Each type of monitoring should be employed and replicated across all categories of public land management activity.

Type of monitoring	Goal-oriented question	Design approach	Examples
Surveillance	Are ecological properties changing in some undesirable way through time, or do we perceive an association between a particular land-use activity and a negative indicator?	Re-sampling ecological response variables through time; establishing time series data; looking for correlations between land-use and the presence or absence of some indicator	Forest Inventory and Analysis (FIA) plots, Breeding Bird Survey (BBS) routes, Northern Region Landbird Monitoring Program (NRLMP) points
Implementation	Was management prescription implemented according to contract specifications?	Project-specific qualitative and quantitative data collection (not necessarily requiring statistical design)	Typical agency monitoring following treatment implementation
Effectiveness	Did management actions achieve the social, economic, or ecological goals and objectives outlined in the prescription?	BACI design of treatments (ANOVA); chronosequence study of past treatments (correlation or hierarchical statistical modeling)	Very rare; typically involves one or a few treatment sites over a brief time period; chronosequence studies are notably absent
Ecological effects	Did management actions result in ecological tradeoffs or unintended ecological consequences?	BACI design of treatments (ANOVA); chronosequence study of past treatments (correlation or hierarchical statistical modeling)	Very rare; usually relegated to the research arm of an agency or to universities; chronosequence studies are notably absent

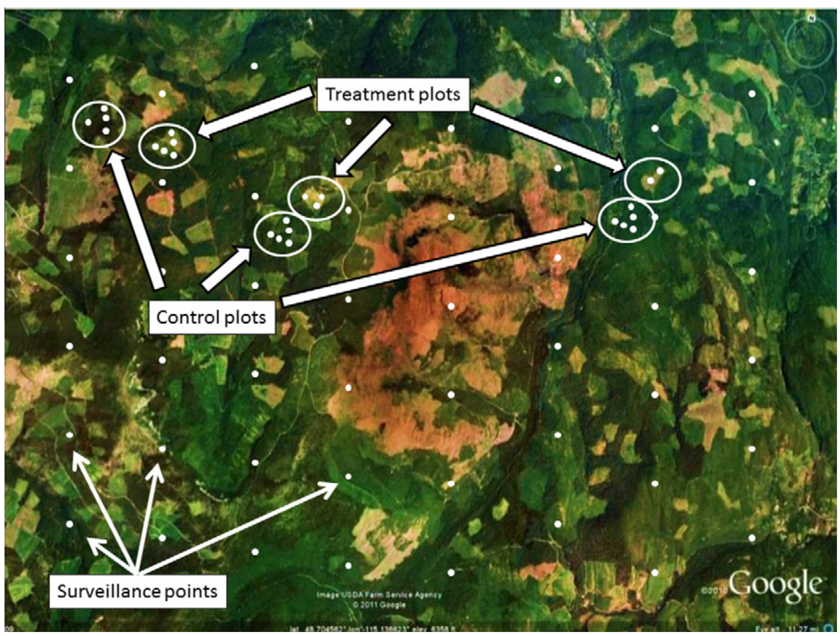

Fig. 1. This aerial view of forested land in the Northern Rocky Mountains can serve to illustrate the four different kinds of monitoring, and can also serve to highlight the difference between a traditional before–after/control-impact "monitor as we go" approach and a chronosequence approach to learning about land-use effects. The encircled sites represent three replicates of a single forest restoration treatment type and three replicate control sites. The uniformly distributed dots represent surveillance monitoring points. (1) Implementation monitoring is conducted when a monitoring crew visits a plot after treatment to see if the work was implemented as prescribed. (2) Effectiveness monitoring involves conducting before–after/control-impact comparisons to see if treatments were effective in achieving stated management goals. Insight into "average" effectiveness of any particular management goal can come only after effectiveness monitoring is repeated across many different applications (ideally, many more than the three plots illustrated here), and only after enough time has passed following future natural disturbance events for effectiveness to be broadly assessed. Note that there is a gold mine of already existing information scattered across the landscape (plots that were treated similarly at some point in the past), and that one could learn about treatment effectiveness most rapidly by using a chronosequence approach, where similar-aged treatment plots of the same type are grouped for analysis. This requires accurate descriptions of past land use, however, so that treatment plots can be correctly grouped for meaningful analysis. (3) Ecological effects monitoring is conducted to see whether the treatment has any unintended ecological consequences, and those are revealed through comparison of indicator metrics with indicator metrics from similar-aged reference stands that represent ecological target conditions. As is true with effectiveness monitoring, insight into the "average" ecological response can come only from replication of treatments and reference conditions. Because the landscape is filled with a large number of similar-aged treatments of any particular type, one of the fastest and most meaningful ways to learn about the ecological consequences of any particular land-use practice is to use a chronosequence approach to learn about immediate, short-term, and longer-term ecological effects by comparing metrics from multiple treatment plots with metrics from multiple, similar-aged reference plots. (4) Surveillance monitoring is an ongoing process that occurs independently of any particular treatment, involves measurements of fairly generic parameters that do not necessarily reflect ecological effects. Data for surveillance monitoring are collected from geographically stratified points that are sampled repeatedly across extended periods of time. Note that one can gain insight into both effectiveness and ecological effects of particular land-use practices using surveillance monitoring points if one classifies each point so that values of indicator metrics from groups of similar-aged points following a specified treatment can be compared with values of the same indicator metrics from groups of similar-aged points that fall within reference conditions. The points in the central, brownish part of the scene fall within a recent fire, for example, and can be used in a proactive way to learn about fire effects when combined with many other surveillance points that happen to be placed in areas that were also recently disturbed by fire.

inextricably intertwined. There are some excellent agency-based surveillance monitoring programs (e.g., the Forest Inventory and Analysis program coordinated by the USFS, the water resources monitoring coordinated by the USGS, and the air quality monitoring coordinated by the US Environmental Protection Agency), but the range of ecological metrics associated with these programs is limited. Fortunately, some ecological gaps are filled nicely by excellent NGO-based bird surveillance monitoring programs, some of which have been conducted continuously for more than 40 years (Porzig et al., 2011). There are also newly organized national efforts involving citizen monitoring, such as the National Phenology Network, which was developed to uncover trends in the timing of biological events (Schwartz et al., 2012). Likens and Lindenmayer (2011) also recently called for a more coordinated national effort in Australia to meet more comprehensive goals that could be attached to surveillance monitoring programs.

Nevertheless, a number of authors (e.g., Lindenmayer and Likens, 2010a; McDonald-Madden et al., 2011; Nichols and Williams, 2006; Van Horne et al., 2007) have argued in one form or another that that passive monitoring should be replaced by active monitoring (monitoring that includes management interventions in the experimental designs) because of the time, cost, and lack of causal understanding associated with the former. While we agree that active monitoring will result in a directed use of information gained, we also recognize that passive surveillance monitoring can expose patterns of change caused by local management activity and disturbance events through the use of correlative approaches. Passive surveillance monitoring can also inform the design of more mechanistic hypothesis-driven monitoring, and (unlike active monitoring) is the only way one can uncover change that is the result of activity outside the local management area and independent of local management activity (e.g., climate change or management activity in a wintering area that affects a breeding population that the local land management agency is legally responsible for maintaining).

The perception that surveillance monitoring cannot provide answers to "targeted" questions is unfounded. Even though sampling associated with surveillance monitoring is generally stratified independently of management activity, it would be a mistake to think that such data have little relevance to local or regional land management decisions, or that an understanding of management threats "... is a long shot and could result in years of wasted effort" (McDonald-Madden et al., 2011), or that there is some kind of inherent inability to use surveillance monitoring data to identify environmental drivers leading to ecosystem change. Indeed, if designed properly, passive surveillance monitoring data can become part of a chronosequence database, and can be used post hoc to assess impacts of management actions and disturbance events by looking for statistically significant associations between response variables and land conditions of different ages following any particular treatment or event. Chronosequence approaches have been criticized primarily because of the lack of control of numerous variables when selecting replicate conditions (e.g., Johnson and Miyanishi, 2008), but it is the large levels of treatment replication that can make this an extremely powerful approach to learning, even in the face of significant environmental variation among sites. For example, Young and Hutto (2002) compared results from an experimental study of partial logging effects on birds (a study involving an enviable level of treatment replication—35 cut and 37 uncut plots) with results of a comparative analysis using a surveillance database and found that the results were indistinguishable. In Montana, the fires of 2000 burned through a large number of already existing surveillance monitoring points, leaving Smucker et al. (2005) with a nice interspersion of large numbers of affected and unaffected points, which allowed them to couple already existing surveillance data with additional data from the same points in a before–after/control-impact design that uncovered the effects of fire severity on a variety of landbird species. The results served to transform our understanding of fire effects on birds by making it clear that species previously classified as "mixed" responders (those that sometimes show positive and sometimes negative responses to fire) actually respond consistently and unambiguously to fire, once fire severity is known. Indeed, the power associated with post hoc analyses based entirely on a passive surveillance database can be impressive. Short of having long-term data from multiple replicate sites in hand, a chronosequence approach is also the only way to assess long-term effects within a short time frame and to discover obvious management triggers (or thresholds) that could be used within an adaptive management framework. Because long-term manipulative studies spanning decades are rare and ecological thresholds usually unknown (Groffman et al., 2006), a chronosequence approach can offer ecological insights that would otherwise be unavailable to managers and collaborative stakeholders. More direct study of potential mechanisms driving patterns can follow, but the patterns uncovered through surveillance monitoring can serve as a first step in the process of better understanding the ecological effects of land-use patterns.

3.2. Implementation monitoring

This kind of monitoring is relatively straightforward and is necessary to determine whether prescriptions were implemented as prescribed or stipulated by a contract. We recognize that implementation monitoring is necessary, and that some form of implementation monitoring is routinely conducted by federal land managers. Unfortunately, this is often where monitoring efforts end, which is a concern that has been expressed by the US General Accounting Office (2006). Because the specific methods (e.g., type of logging equipment used) and timing of management treatments vary and may influence the effectiveness or ecological effects of those treatments, we suggest that implementation monitoring include GIS data layers that provide detailed information on how, when, and where treatments were conducted.

3.3. Effectiveness monitoring

This type of monitoring is designed to assess whether the management activity was effective in reaching the stated goal, which could entail social, economic, and ecological components. If, for example, fuels reduction to reduce fire severity is the reason for a treatment, then effectiveness monitoring should be undertaken to determine whether the action was effective. That requires assessing the effectiveness of achieving both the short-term goal of reducing vegetation density and surface fuels, and the long-term goal of reducing fire severity. If a stated goal is to "enhance" conditions for wildlife then, by definition, the target wildlife species or some surrogate will have to be part of an effectiveness monitoring program (did conditions improve for the target species?). Effectiveness monitoring is thus targeted monitoring (sensu Nichols and Williams, 2006) that addresses the effectiveness question related to a stated management goal. It is important to note that effectiveness of a treatment should be assessed across both short and long time frames. The usual approach involves conducting a before–after/control-impact design involving several years of sampling before and after treatment in any one site (see hypothetical sample points within control and treatment plots in Fig. 1). Short-term effects can be assessed in a matter of several years, but the replication of treatments takes many more years. Long-term effects require a commitment to repeated sampling for many years and in many sites both before and after treatment. If a type of treatment is brand new and has never been applied previously to the land, then there is no alternative but to monitor multiple applications of a treatment through time, and wait 50 years to understand the 50-year "average" effectiveness of the treatment. If, however, similar treatments have been applied repeatedly across the landscape, a reasonable initial assessment of long-term effectiveness can be obtained by gathering data from a chronosequence of plots that differ in time since treatment. We believe this approach represents an underused but potentially powerful learning tool.

3.4. Ecological effects monitoring

Ecological effects monitoring seeks to uncover unintended ecological consequences of management activity, and should be an integral part of any program designed to monitor management practices. A project can be well-implemented (as determined through implementation monitoring) and effective (as determined through effectiveness monitoring), but can still produce ecological consequences that compromise what would otherwise be considered a successful project (Roccaforte et al., 2010). Tradeoffs between multiple resource values and management objectives are increasingly being recognized and incorporated into management decisions (e.g., Bradford and D'Amato, 2012). Explicitly considering and monitoring potential ecological effects will help agencies and stakeholders make more informed decisions to minimize tradeoffs, seek complementarities among values, and optimize benefits among objectives. There is, therefore, a strong need for some kind of rapid, meaningful, ecological effects monitoring. Unfortunately, it is ecological effects monitoring that has generally been ignored; in the words of Lindenmayer and Likens (2010b), we have achieved a "truly appalling record of ecological monitoring." Bliss et al. (2001) suggest that the most powerful disincentive for ecological effects monitoring can be traced to the word's root—to warn. While ecological effects monitoring results can yield negative news about land management activity, the failure to conduct this type of monitoring can make it difficult for an agency to conduct meaningful "cumulative effects analyses" (Schultz, 2010; Smith, 2006).

Although DeLuca et al. (2010) distinguish "implementation" from "effectiveness" monitoring, they wrap many of the types of questions that we believe fall under "ecological effects" monitoring into their "effectiveness" monitoring category. If the goal of a project is to "restore" the ecological integrity of a system, then the two types of monitoring are, indeed, synonymous because an "effective" treatment would be one that does not deviate ecologically from conditions expected for a restored system. Nevertheless, the "effectiveness" of a project is most often judged quite differently from the "ecological effects" of a project, so the two types of questions and two types of monitoring need to be distinguished. For example, common management practices like planting trees, supplying the local mill with timber, enhancing populations of game species, salvage logging after fire are *not* ecologically based management goals, so without ecological effects monitoring, there is no way to know if tradeoffs exist in the form of unintended ecological effects. Ecological effects monitoring should be based on conceptual understanding of ecosystems, and that understanding should lead to targeted predictions (Lindenmayer and Likens, 2010a) involving indicators that are likely to expose any unintended consequences of the particular management action. It is important to note that the goal of ecological effects monitoring is not to monitor some kind of plant or animal species for its own sake or because it is on a sensitive species list, but to be strategic about picking indicators that are likely to yield information about ecological consequences of a given treatment (sensu Simberloff, 1998). Lindenmayer and Likens (2009) capture this thought when they recommended that we not monitor indicators for their own sake; we should monitor something that gives the greatest chance of answering whether there might be unintended ecological effects.

We acknowledge that federal land management agencies gather monitoring data on threatened, endangered, and sensitive species, but the associated data are unlikely to yield a solid understanding of the ecological effects of their management activities either because those species are not effective indicator species for the management activity of interest or are not abundant enough to generate reliable statistical inference. If monitoring activity were focused less on species for their own sake and more on land-use effects, federal agencies would probably find themselves monitoring a much broader variety of indicators of land condition than they currently do. This is because meaningful indicators of ecological integrity are not necessarily species that appear on sensitive species lists—they are species (or other response variables) that are likely to reveal unintended deviations from the composition, structure, or function of a reference ecological condition. While potential legal challenges emanating from threatened and endangered species influence the kinds of indicators that are chosen for monitoring purposes, we would still encourage agencies to explore the utility of adding a few non-threatened species as indicators of ecosystem condition—as tools that will enable us to better understand whether we are managing to maintain natural systems in a way that can sustain us into the future. Fortunately, a broader view of indicators is reflected in the preferred alternative of the final Programmatic Environmental Impact Statement associated with alternatives listed in the new National Forest System Land Management Planning Rule (2012).

Monitoring the ecological effects of a treatment should be assessed across both short and long time frames in a manner that mirrors the design outlined for effectiveness monitoring. Once again, unless one has accumulated ecological monitoring data from multiple, independent applications of a given treatment over both the short and long term, the only way to gain insight into short- and (especially) long-term ecological effects in the meantime is to use a chronosequence approach. Specifically, by sampling not just from currently treated sites, but from sites that were similarly treated at various times in the past, we can group treatments into age categories and learn quickly about ecological effects, and without having to monitor for extended periods to gain some insight into possible long-term effects.

4. How the four types of monitoring fit into an adaptive management loop

If land management agencies are serious about conducting adaptive management, then they will fund, and will seek partnerships to conduct, each of the four types of monitoring outlined above. The clearest way to understand the purpose of each of these types of monitoring is to place them within the context of an adaptive management framework (Fig. 2). Within this framework, the land being managed is always in one of three states: desired condition, undesired condition, or unknown condition. Knowledge of current land conditions emerges from surveillance monitoring results (the weed problem is growing, or the owl population seems to be declining to a trigger point of concern), or from recent research results (current forest structure is out of the range of natural variation). If current conditions are undesirable, then the remedy may require on-the-ground activity. And if there is any kind of on-the-ground activity, the other three types of monitoring should be conducted. Implementation monitoring will be necessary to determine whether the agency paid for something that was actually done according to contract specifications. Effectiveness monitoring will be necessary to determine whether the activity achieved the explicitly stated short-term and long-term goals. And ecological effects monitoring will be necessary to determine whether there were any unintended ecological consequences of the management action in the face of success otherwise—consequences that threaten the long-term ecological sustainability and biological diversity of the larger system. A dearth of ecological effects monitoring data has left management agencies and

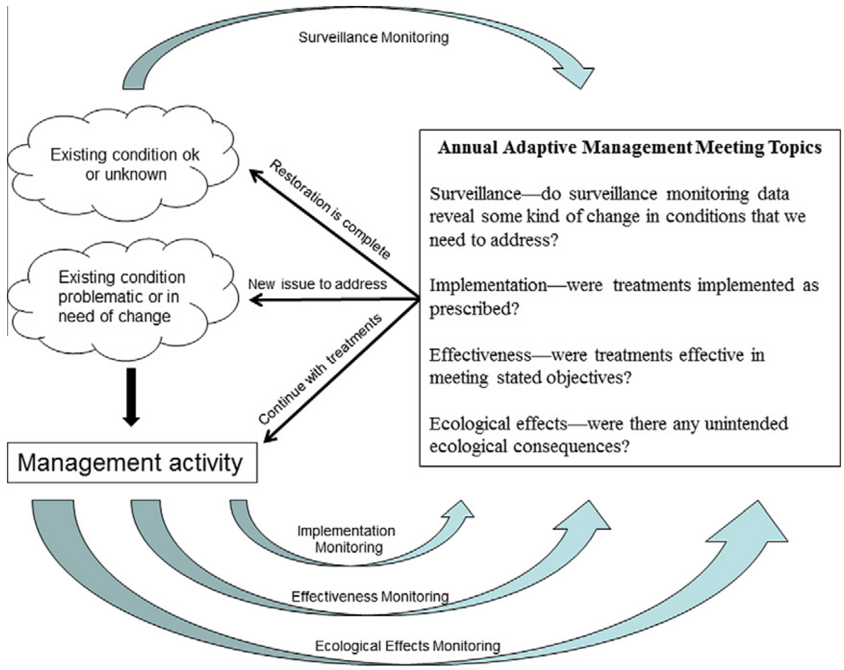

Fig. 2. A model of how the four different types of monitoring fit into a broader adaptive management loop. The starting point for our conceptual model is the clouds, which indicate the current condition of resources, as determined through surveillance monitoring or some other kind of assessment. Although surveillance monitoring occurs independently of any particular management activity, it can also inform management if response variables are linked to conditions on the ground. The other three types of monitoring are tightly linked with management activity, and are designed to answer very different types of questions, as indicated in the box. The arrows between the box and the clouds are where results from each kind of monitoring are discussed with management during an annual adaptive management meeting where local and regional land managers meet with various monitoring group leaders to discuss results, articulate questions, and continue to build personal relationships.

collaborative stakeholders ill prepared to predict cumulative effects of various land management activities on biological diversity and ecosystem function. Not surprisingly, in the US, the bulk of legal challenges to federal agencies stem from a failure to provide information that would emerge from ecological effects rather than implementation monitoring (Smith, 2006; Schultz, 2010). We hope this attempt to explicitly recognize and classify differences in the types of questions that monitoring can address will make clear where current gaps in monitoring efforts exist and will serve to promote the development of more effective monitoring programs.

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References

Bliss, J., Aplet, G., Hartzell, C., Harwood, P., Jahnige, P., Kittredge, D., Lewandowski, S., Soscia, M.L., 2001. Community-based ecosystem monitoring. J. Sustain. Forest. 12, 143–167.

Block, W.M., Franklin, A.B., Ward Jr., J.P., Ganey, J.L., White, G.C., 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. Restor. Ecol. 9, 293–303.

Bormann, B.T., Haynes, R.W., Martin, J.R., 2007. Adaptive management of forest ecosystems: did some rubber hit the road? BioScience 57, 186–191.

Bradford, J.B., D'Amato, A.W., 2012. Recognizing trade-offs in multi-objective land management. Front. Ecol. Environ. 10, 210–216.

Chase, M.K., Geupel, G.R., 2005. The use of avian focal species for conservation planning in California. USDA For. Serv. Gen. Tech. Rep. PSW-GTR-191, pp. 130–142.

DeLuca, T.H., Aplet, G.H., Wilmer, B., Burchfield, J., 2010. The unknown trajectory of forest restoration: a call for ecosystem monitoring. J. Forest. 108, 288–295.

Field, S.A., O'Connor, P.J., Tyre, A.J., Possingham, H.P., 2007. Making monitoring meaningful. Aust. Ecol. 32, 485–491.

Geupel, G.R., Humple, D., Roberts, L.J., 2011. Monitoring decisions: not as simple as they seem? Trends Ecol. Evol. 26, 107.

Groffman, P., Baron, J., Blett, T., Gold, A., Goodman, I., Gunderson, L., Levinson, B., Palmer, M., Paerl, H., Peterson, G., Poff, N., Rejeski, D., Reynolds, J., Turner, M., Weathers, K., Wiens, J., 2006. Ecological thresholds: the key to successful environmental management or an important concept with no practical application? Ecosystems 9, 1–13.

Holling, C.S., 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York, NY.

Hutto, R.L., 1998. Using landbirds as an indicator species group. In: Marzluff, J.M., Sallabanks, R. (Eds.), Avian Conservation: Research and Management. Island Press, Covelo, CA, pp. 75–92.

Hutto, R.L., 2005. Northern Region Landbird Monitoring Program: a program designed to monitor more than long-term population trends. USDA For. Serv. Gen. Tech. Rep. PSW-GTR-191, pp. 956–962.

Hutto, R.L., Young, J.S., 2002. Regional landbird monitoring: perspectives from the northern Rocky Mountains. Wildlife Soc. Bull. 30, 738–750.

Hutto, R.L., Kowalski, S., 2006. Northern Region Landbird Monitoring Program: a USFS-University of Montana partnership designed to provide both short-term and long-term feedback for land managers. In: Aguirre-Bravo, C., Pellicane, P.J., Burns, D.P., Draggan, S. (Eds.), Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere. 2004 September 20–24, Denver, CO. Proceedings. U.S.D.A. For. Serv. RMRS-P-42CD, Fort Collins, CO., pp. 936–943.

Johnson, E.A., Miyanishi, K., 2008. Testing the assumptions of chronosequences in succession. Ecol. Lett. 11, 419–431.

Kelling, S., Hochachka, W.M., Fink, D., Riedewald, M., Caruana, R., Ballard, G., Hooker, G., 2009. Data-intensive science. a new paradigm for biodiversity studies. BioScience 59, 613–620.

Legg, C.J., Nagy, L., 2006. Why most conservation monitoring is, but need not be, a waste of time. J. Environ. Manage. 78, 194–199.

Likens, G.E., Lindenmayer, D.B., 2011. A strategic plan for an Australian long-term environmental monitoring network. Aust. Ecol. 36, 1–8.

Lindenmayer, D.B., Likens, G.E., 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends Ecol. Evol. 24, 482–486.

Lindenmayer, D.B., Likens, G.E., 2010a. The science and application of ecological monitoring. Biol. Conserv. 143, 1317–1328.

Lindenmayer, D.B., Likens, G.E., 2010b. Improving ecological monitoring. Trends Ecol. Evol. 25, 200–201.

Martin, E., Ballard, G., 2010. Data Management Best Practices and Standards for Biodiversity Data Applicable to Bird Monitoring Data. North American Bird Conservation Initiative. <http://www.nabci-us.org/aboutnabci/bestdatamanagementpractices.pdf>.

McDonald-Madden, E., Baxter, P.W.J., Fuller, R.A., Martin, T.G., Game, E.T., Montambault, J., Possingham, H.P., 2010. Monitoring does not always count. Trends Ecol. Evol. 25, 547–550.

McDonald-Madden, E., Baxter, P.W.J., Fuller, R.A., Martin, T.G., Game, E.T., Montambault, J., Possingham, H.P., 2011. Should we implement monitoring or research for conservation? Trends Ecol. Evol. 26, 108–109.

National Forest System Land Management Planning Rule, 2012. Final Programmatic Environmental Impact Statement. <http://www.fs.usda.gov/planningrule>.

Nichols, J.D., Williams, B.K., 2006. Monitoring for conservation. Trends Ecol. Evol. 21, 668–673.

Omnibus Public Land Management Act, 2009. <http://www.gpo.gov/fdsys/pkg/PLAW-111publ11/content-detail.html>.

Porzig, E.L., Dybala, K.E., Gardali, T., Ballard, G., Geupel, G.R., Wiens, J.A., 2011. Forty-five years and counting: reflections from the Palomarin Field Station on the contribution of long-term monitoring and recommendations for the future. Condor 113, 713–723.

Roccaforte, J.P., Fulé, P.Z., Covington, W.W., 2010. Monitoring landscape-scale ponderosa pine restoration treatment implementation and effectiveness. Restor. Ecol. 18, 820–833.

Schultz, C., 2010. Challenges in connecting cumulative effects analysis to effective wildlife conservation planning. BioScience 60, 545–551.

Schwartz, M.D., Bentancourt, J.L., Weltzin, J.F., 2012. From Caprio's Lilacs to the USA phenology network. Front. Ecol. Environ. 6, 324–327.

Simberloff, D., 1998. Flagships, umbrellas, and keystones – is single-species management passe in the landscape era? Biol. Conserv. 83, 247–257.

Smith, M.D., 2006. Cumulative impact assessment under the National Environmental Policy Act: an analysis of recent case law. Environ. Pract. 8, 228–240.

Smucker, K.M., Hutto, R.L., Steele, B.M., 2005. Changes in bird abundance after wildfire: importance of fire severity and time since fire. Ecol. Appl. 15, 1535–1549.

Susskind, L., Camacho, A.E., Schenk, T., 2012. A critical assessment of collaborative adaptive management in practice. J. Appl. Ecol. 49, 47–51.

US General Accounting Office (GAO), 2006. Wildland fire rehabilitation and restoration: Forest Service and BLM could benefit from improved information on status of needed work. U.S. Government Accountability Office, Washington, D.C., p. 43.

Van Horne, B., Schmidt, P., Andres, B., Barnhill, L., Bart, J., Bishop, R., Brown, S., Francis, C., Hahn, D., Humburg, D., Koneff, M., Peterjohn, B., Rosenberg, K., Sauer, J., Szaro, R., Vojta, C., 2007. Opportunities for Improving Avian Monitoring U.S. North American Bird Conservation Initiative Committee, p. 41.

Walters, C.J., 1986. Adaptive Management of Renewable Resources. MacMillan Publishing Co., New York, NY, p. 374.

Walters, C.J., Holling, C.S., 1990. Large-scale management experiments and learning by doing. Ecology 71, 2060–2068.

Young, J.S., Hutto, R.L., 2002. Use of a landbird monitoring database to explore effects of partial-cut timber harvesting. Forest Sci. 48, 373–378.