ADAPTIVE MANAGEMENT IN THE SIERRA NEVADA: CAN IT BE DONE AND, IF SO, HOW?

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Concern over the conservation and sustainability of Sierra Nevada ecosystems can be traced to well over 100 years ago with the pioneering conservation work of John Muir. Muir recognized the vulnerability of what was then a seemingly endless wilderness of forests, streams, meadows, and granite. However, the land management and policy community has only recently acknowledged limitations on the commercial value and ecosystem services that this vast mountain range can provide. Since the late 1960s, management of national forests has been in an accelerating transition from the utilitarian views from the Gifford Pinchot era toward more diverse objectives for federal lands. The transition has been fueled by increasing public expectations for conservation of natural resources and a concomitant diminishing emphasis on commodities. Fire protection has recently taken center stage to the point where we are trying to balance forest restoration for fire protection with conservation of other resources such as water and wildlife. In the absence of solid science on how to do that, and the perpetual conflict over the choices that have been made, a collaborative approach to adaptive management is emerging as a favored method by which to proceed.

This realization was catalyzed through the findings of the Sierra Nevada Ecosystem Project (SNEP) (University of California 1996). Through the efforts of a large and talented cadre of scientists and managers, key issues of Sierra Nevada conservation were highlighted, including a call for better information on ecosystems, air quality, fire and fuels, watersheds, biodiversity, aquatic systems, old f orest, rangelands, people, and institutions.

From the 1970s to the 1990s, land management direction evolved from a commodity-dominated approach to confusion over the appropriate balance of a wide variety of uses and purposes. In addition to the influence of SNEP, there were some significant events that precipitated the dramatic changes that were to happen as this shift in direction took shape. Some of these events included California Spotted Owl Report (U.S. Forest Service 1993), Federal Advisory Committee Review (FAC 1997), Sierra Nevada Science Review (U.S. Forest Service 1998), Sierra Nevada Framework (1998–2001), which culminated in the Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement (FEIS) and Record of Decision (ROD) (U.S. Forest Service 2001), and Supplemental Sierra Nevada Forest Plan Amendment Final Supplemental Environmental Impact Statement (FSEIS) and ROD (U.S. Forest Service 2004). This series of reviews and planning efforts reflected a period of uncertainty and challenges for the U.S. Forest Service, the land management agency that has responsibility for roughly 70% of the Sierra Nevada. What were the key issues? What needed to change? What were the new priorities?

The primary land management planning exercise for the U.S. Forest Service (2001) was the Sierra Nevada Forest Plan Amendment process. This effort struggled with these aforementioned questions. Several major themes emerged from years of careful consideration, but the primary topics that were the focus of the planning efforts were fire and fuels, old forests and associated species, and ecosystems with aquatic, riparian, and meadow habitats. The overriding theme across all the questions was the nexus of significant scientific uncertainty combined with considerable stakes in the outcomes of land management activities. Therefore, land managers were largely hindered by assertive action even though it was clear that ecosystem degradation was widespread and

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some kind of remediation was necessary. A number of issues drove the discussion.

SPECIES AT RISK IN THE SIERRA

Although California is well known as a diverse collection of ecological conditions with over 300 taxa listed as threatened or endangered in the state, only a handful of listed species occur in the Sierra Nevada ecoregion. Widespread land conversion to agriculture or urbanization has not had much impact on Sierran landscapes. However, a variety of factors have slowly resulted in affecting some key species in the Sierra Nevada, leading to some level of consideration for listing for some species including fisher (*Martes pennanti*), Yosemite toad (*Bufo canorus*), mountain yellow-legged frog (*Rana muscosa*), foothill yellow-legged frog (*R. boylii*), California spotted owl (*Strix occidentalis occidentalis*), northern goshawk (*Accipiter gentilis*), and American marten (*Martes americana*).

The linkage to key habitat types was clear—these species at risk have affinities to either old-forests or aquatic, riparian, and meadow habitats. Changes in these systems over the last century have led to concern over their ability to persist. How do these taxa cope with human activities on what is largely a working landscape with different kinds of human activities? In particular, how do managers take action to reduce hazardous fuels, manage forests for a number of purposes, and restore fire to Sierran systems and not inadvertently cause harm to these sensitive wildlife populations? The answers to such questions are not clear. Therefore, this uncertainty creates a management dilemma for U.S. Forest Service decision makers.

LAND MANAGEMENT DECISIONS NEED CREDIBLE SCIENTIFIC INFORMATION

This dilemma has resulted in slow, inconsistent progress toward implementation of any kind of land management strategy. Little debate exists over the question of the need to thin forests because virtually everyone agrees that some kind of intervention is needed. Over 100 years of fire suppression, combined with contributing factors such as climate change and past logging practices, has changed the fuel profiles in western coniferous forests to an alarming degree. However, there is considerable debate over the appropriate silvicultural prescriptions necessary for restoring forest health. In particular, what sizes of trees should be removed and retained? The debate is fueled with a mixture of existing scientific evidence and passionate speculation over the efficacy and potential impacts any given treatment may cause. Recent and ongoing research is making some progress toward informing this debate. However, the complexity of these issues combined with the difficulties of accomplishing scientifically credible findings make this challenging. More information is needed and credibility of this work is paramount. The public's trust of land management agencies is at stake. An important test arises from this challenge. Can the U.S. Forest Service and other land management agencies find an approach that will escape the endless string of appeals and lawsuits surrounding each land management project that reflects the public's lack of confidence? Is there a way to reduce expenses, time, and frustration associated with almost every proposed project? Is it possible to have more effective and, in particular, more efficient resource management?

KEY RESEARCH QUESTION

There are many scientific uncertainties that pose questions affecting land management decisions. Appendix E of the FEIS for the Sierra Nevada Forest Plan Amendment (U.S. Forest Service 2001) contained hundreds of monitoring and research questions that pertain to contemporary land management decisions. Since then, land managers have considered this array of questions and certain issues have arisen as priority. Certain key issues have significant meaning and therefore command particular attention. Perhaps the most compelling issue revolves around the efficacy of fuels treatments and their associated potential effects on sensitive resources such as species at risk. How can this issue be most effectively addressed? I address this below.

WHAT IS ADAPTIVE MANAGEMENT?

"The first step to knowledge is the confession to ignorance" (Weinberg 1975). This is the first quote in Chapter 1 of Carl Walters' seminal work, *Adaptive Management of Renewable Resources* (1986). This sorely overused term in natural resource management actually has many different definitions, depending on who uses the term and the context of their work. C. S. Holling and Carl Walters are credited with the original development of the concept and its application to natural resource management in the 1970s, and their intent was to suggest a way that could lead to an "experiment to learn the boundaries of natural systems." Walters (1986:9) outlined the adaptive management process as beginning "with the central tenant that management involves a continual learning process." Walters (1986) saw the value of adaptive management as questioning some of the basic management assumptions. Designing adaptive management, in his view, involves 4 basic issues:

1. Bounding management problems; what are the possibilities?
2. Representing existing knowledge in models that identify assumptions and predictions so experience can further learning.
3. Representing uncertainties and identifying alternate hypotheses.
4. Designing balanced management policies to address management objectives while also providing learning opportunities.

Walters (1986) believed that "… management is an adaptive learning process, where management activities themselves are the primary tools for experimentation." Macnab (1983) suggested that little can be learned about the dynamics of systems at equilibrium, and manipulation is helpful to understand how systems respond to change. Assuming one adopts this philosophical approach, any land management activity can be fashioned into an adaptive management experiment. The outcome of this tactic can yield powerful results, particularly when managers and researchers collaborate to create rigorous experimental conditions to apply to any given management prescription. It is with this philosophy that key questions of land management are most effectively addressed. There are some basic steps in executing the adaptive management process that many people agree should be part of a successful template. These basic steps are:

1. Determine current management goals.
2. Gather and synthesize existing knowledge to develop working model(s) about how the ecosystem works to make first approximation predictions of management outcomes.
3. Design and implement management in accordance with principles of experimentation.
4. Monitor and evaluate the results of the management action.
5. Incorporate what is learned into the working model of how the ecosystem works, basing future management on improved understanding of ecological processes.
6. Adjust management as indicated by results, evaluation, and reassessment of project goals.
7. Cycle through the whole process again.

DESIGN CHALLENGES IN ADAPTIVE MANAGEMENT

The key questions that we confront deal with complex systems over large time-and-space dimensions. Typical management activities are manifested over large areas and take many years to complete. How could we possibly expect to understand how a complicated system will respond without actually testing it? Extrapolation of results to large or small scales is risky. We need observations and experiments that are scaled at the optimum management regime, and our primary questions revolve around landscape-level treatments. This kind of research is largely unprecedented and creates significant experimental design challenges.

Few examples of successful adaptive management of natural resources at this scale exist. Some of the reasons for this include large space and time scales, expenses to study such large areas for long periods of time, and significant results that are slow to develop. Some research paths in the natural resources arena are deeply trodden while others remain largely untouched. One example of a proven program is the adaptive management and assessment for migratory waterfowl under the direction of the Patuxent Wildlife Research Center. In this program, researchers face the challenge of adaptive management of waterfowl harvest and habitat management to conserve these resources. This program entails managing a system in the face of several sources of uncertainty, while trying to reduce uncertainty about the system to make better management decisions in the future. Output from this adaptive management effort includes development of tools such as predictive models, decision support, and expert systems for science-based management of waterfowl populations and their habitats. This program has functioned for many years in guiding the setting of waterfowl bag limits and subsequent investments in habitat protection and management.

SAMPLING DESIGN CONSIDERATIONS

Work at a landscape scale creates especially challenging sampling constraints. Under any circumstance, however, it is crucial to begin with a clear and feasible definition of the question that is under study. It cannot be overemphasized that one needs to be clear and precise about the objectives of the investigation. Issues that are relevant to determining an appropriate sampling design are:

1. What are the expected or desired spatial and temporal scales of inference? (Conceptual models can significantly help with this issue.)
2. How will information be applied?
3. What data will be collected including the response variables, and what attributes will be measured?
4. Do the selected response variables relate adequately to the fundamental research or management questions?
5. Are there defined or standardized measurement protocols?

In advance of proceeding with a field study, there are some useful exercises that improve the opportunities to collect useful information within a successful study:

1. Devise a sampling plan including the schema for sampling unit size, location, etc.
2. Sample size will depend on prior knowledge of the population, desired precision, and costs. Simulation efforts based on available data can help refine what is needed.
3. Develop protocols for quality assurances and quality control.
4. Anticipate the analytical approach before data collection and consult with statisticians on the design and analysis methods.
5. Develop a work plan and budget that include staffing needs and schedules.
6. Establish the outputs and the target audience for this research.

ADAPTIVE MANAGEMENT IS AN OPPORTUNITY

Is adaptive management a panacea? Clearly it is not. It is an investment in the future, and the return on that investment is likely to be years into the future. Is there an up side to engaging in adaptive management? There is potentially a huge advantage in both the quality of results that can provide scientifically defensible information for subsequent decision making as well as the tangible increase in public ownership of such an approach. But success in adaptive management will not be easy or keep us in our comfort zone. It requires significant allocation of funds, extraordinary cooperation and collaboration, and a long-term commitment with ability to be patient while research feedback comes years later. With vision and perseverance, these investments can be meaningful for large-stakes land management projects, such as is found in the Sierra Nevada.

CURRENT STATUS IN THE SIERRA NEVADA

Recent initiatives to address land management challenges in the Sierra Nevada have been fairly significant. The U.S. Forest Service, which manages almost 70% of the land base in this ecoregion, has been at the forefront of land management challenges. In the 1990s, the U.S. Forest Service made a decision to amend the land use plans of all the national forests in the Sierra Nevada in one coordinated action. The Sierra Nevada Forest Plan Amendment FEIS and ROD (U.S. Forest Service 2001) was a milestone in providing direction to address key land management issues within the entire ecoregion. The FEIS included an adaptive management strategy that provided the overall design for addressing key uncertainties pertaining to land management questions within the Sierra Nevada Forest Plan Amendment. Initial implementation of the 2001 decision concentrated on status and change monitoring issues including: (1) range-wide fisher and marten distribution and abundance; (2) mountain meadow condition; (3) high-elevation amphibians, including the Yosemite toad and mountain yellow-legged frog; (4) landscape mapping of fire severity; (5) willow flycatcher (*Empidonax traillii*) populations; (6) air quality; and (7) spotted owl demography.

In 2004, the U.S. Forest Service revised the 2001 decision with the FSEIS (U.S. Forest Service 2004). In this revised decision, the original adaptive management strategy was brought forward, but some adjustments were made to focus efforts more on the key questions addressing uncertainty. The shift was away from simple "status and trend" monitoring toward more focused questions of cause and effect. An example of this shift includes the research question on how California spotted owls respond to changes in forest structure resulting from thinning. The revised adaptive management priorities became the following issues:

1. Spotted owl response to changes in canopy cover within their home range core area.
2. Yosemite toad response to cattle grazing in high mountain meadows.
3. Fisher response to fuels treatments.
4. Efficacy of fuels treatments at a landscape scale.
5. Landscape mapping of fire severity.
6. High-elevation amphibian status and change.
7. Spotted owl demography.
8. Range-wide fisher and marten distribution and abundance.
9. Willow flycatcher populations.

Region 5 of the U.S. Forest Service is currently spending approximately $2.5 million per year on these adaptive management–related tasks. In addition, the Pacific Southwest Research Station of the U.S. Forest Service is conducting research on other key questions in the Sierra Nevada, with annual expenditures of approximately $2 million including:

1. The life-cycle analysis of forest biomass utilization for generation of electricity.
2. The Plumas-Lassen Study where owls, fire and fuels, vegetation, small mammals, and bird responses to treatments in the Quincy Library Group Pilot Project area are being studied.
3. The Lake Tahoe Basin Restoration project.
4. The Kings River Project, where watersheds, owls, fisher, and birds are studied.
5. The Teakettle Experimental Forest Project.
6. The response of native aquatic species to introduced trout (*Salmo trutta* and *Salvelinus fontinalis*) in high mountain lakes.
7. The effects of climate change at tree line in the Sierra Nevada.

Other land and resource management organizations are also active in acquiring data in the Sierra Nevada. The California Department of Fish and Game's Resource Assessment Program has a number of active monitoring programs in the Sierra. These are:

1. The inventory and assessment in montane meadow, and quaking aspen (*Populus tremuloides*) communities of the Sierra Nevada.
2. Sierra Nevada amphibian and fish surveys.
3. A mule deer (*Odocoileus hemionus*) study using GPS collars to evaluate potential development impacts on deer.
4. A study of patterns of species and habitat richness and diversity in grazed meadows in the Golden Trout Wilderness Area.
5. A study of changes in wildlife habitat in mixed-conifer forests from the central Sierra Nevada.
6. Various forestland resource assessment efforts in the southern Sierra Nevada.
7. Remeasurement and analysis of habitat changes using U.S. Forest Service Vegetation Type Map plot data from the central Sierra Nevada.
8. A variety of assessment and data programming efforts.

The National Park Service, through activities within Sequoia and Kings Canyon National Parks, Devils Postpile National Monument, Yosemite National Park, and Lassen National

Park, is implementing its national Inventory and Monitoring Program (IMP). The 5 goals of the IMP are to: (1) inventory natural resources in these units; (2) monitor park ecosystems; (3) establish natural resource inventory and monitoring as a standard practice; (4) integrate natural resource inventory and monitoring information into planning, management, and decision making; and (5) share accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

The IMP has 11 main objectives for monitoring resources such as air and climate, geology and soils, water, biological integrity, and landscapes. The top 12 vital signs being monitored are (1) weather and climate, (2) snowpack, (3) surface-water dynamics, (4) wetland-water dynamics, (5) water chemistry, (6) alien invasive plants, (7) forest–tree population dynamics, (8) meadow and wetland ecological integrity, (9) amphibian distribution and abundance, (10) birds, (11) fire regimes, and (12) landscape mosaics. Clearly, there are significant resources being devoted to better understand the ecological condition of the Sierra Nevada ecosystem. Furthermore, it is clear that there is some considerable overlap in purpose and execution of these efforts and the agencies involved. Can these objectives be addressed more efficiently and effectively through more extensive collaboration? This is a challenge for the resource management community to carefully consider.

FUTURE OPPORTUNITIES FOR ADAPTIVE MANAGEMENT IN THE SIERRA NEVADA

Despite the considerable efforts of the responsible land and resource management agencies to collect relevant data in the Sierra, there is a large interest in engaging an independent assessment of resource conditions. The State of California and the U.S. Fish and Wildlife Service have engaged the U.S. Forest Service in a partnership to develop a third-party evaluation of land management being implemented under the U.S. Forest Service's 2004 ROD. The credibility of a collaborative, interagency effort with participation of the University of California (UC) system presents an enormous opportunity for complementing existing monitoring and research efforts. With the involvement of the UC, a valuable opportunity was created to provide important depth to the overall adaptive management program and focus on a set of key unaddressed questions.

Specifically, this collaboration was designed to investigate the adaptive management processes through testing perhaps the most important issue in the Sierra Nevada—the efficacy of Strategically Placed Landscape Treatments (SPLATs). This fuels and fire management strategy has been chosen in both the 2001 and 2004 Sierra Nevada Forest Plan Amendments as the primary forest remediation method for the near-term treatments of U.S. Forest Service lands in the Sierra. Furthermore, there is a strong interest in investigating how 3 key response variables—wildlife, water, fire and forest health—will respond to these treatments. Finally, there is also interest in determining how the public participation process works in engaging meaningful participation of interested parties.

This program has been developed through efforts of a number of UC faculty members in collaboration with the agencies to initiate this effort at 2 locations in the Sierra. There are 4 fundamental questions being addressed:

1. Do the SPLATS work to modify fire behavior over the landscape and improve or maintain forest ecosystem health?
2. What is the response of selected wildlife species to changes in habitat structure and composition resulting from SPLATS?
3. How do different SPLAT treatment strategies affect water quality and yield?
4. How can we engage stakeholders in the adaptive management process in a way that provides for mutual learning and feedback and leads to collaboration?

Execution of this research program with the UC will be challenging. The experimental design of research at a landscape scale presents challenges that are atypical of most ecological research. The spatial and temporal context of the questions being addressed requires that the research design must consider some alternatives to the traditional experimental methods of scientific research that employ replicated samples with controls.

In this proposed research, the basic unit of a forest management treatment strategy will be a roughly 4,050-ha watershed. Such large units cannot be truly replicated, and only a limited number of such locations can be studied at a given time. Therefore, an observational approach will be employed that integrates all response variables across the entire experimental watershed. A new perspective on landscape-level research will be employed using an analytical strategy that is referred to as "metareplication" (Johnson 2002). Metareplication involves replicating different studies that may represent different years, locations, field methods, and investigators. Such an approach reduces the chance that some artifact of time or place caused the observed results. Robustness is gained from assessing results from numerous independent studies. The intent is to use the principles of experimental design for each study as much as possible (e.g., controls, randomization, and replication). The scientific results, however, are safeguarded by repeated studies to ascertain what is real and what may be a spurious result of an individual study.

This emerging collaborative effort with the UC has established the following 5 primary objectives that are measuring sticks for an adaptive management and monitoring program that successfully incorporates public input: (1) building public understanding and trust; (2) measuring physical and natural processes at relevant management scales; (3) addressing and incorporating competing public interests; (4) identifying conflicting outcomes; and (5) building an academic and management partnership where information needs and information products are disseminated to interested parties and the general public.

Identification of a suitable site or sites for conducting this program was not easy. The research team, in conjunction with the consortium of management agencies, developed a set of criteria to guide the selection of suitable study locations. To be a suitable site, the research team looked for a site with the following characteristics: (1) had old-forest habitat; (2) had potential for recruiting large tree structure; (3) occurred in a wildland-urban interface; (4) was adjacent to significant amounts of private land; (5) was in a fireshed and watershed; (6) was in a typical Sierran mixed-conifer landscape; (7) possessed the organizational capacity of the U.S. Forest Service to execute treatments; (8) had the presence of existing data/studies/infrastructure; (9) had a history of land and resource management agencies involving community interest in forest management; (10) had the potential for positive and detectable changes; and (11) had minimal costs of development and implementation of treatments.

These criteria, plus much discussion with staff on the various units of the national forests in California, led to the selection of 2 preferred locations: the North Fork American River drainage on the Tahoe and Eldorado National Forests; and the Fresno and Merced River drainage on the Sierra National Forest. This effort is also intended to be integrated with other related ongoing work, including all of the Region 5 monitoring by the Pacific Southwest Research Station, research by other academic institutions, and all related activities by National Park Service, California Department of Fish and Game, U.S. Geological Survey, and others. There is also a potential for this effort to be linked to emerging national efforts such as the National Ecological Observatory Network (NEON). This National Science Foundation program is proposed as the first national ecological measurement and observation system designed to both answer scientific questions from regional to continental scales and have the interdisciplinary participation necessary to achieve credible ecological forecasting and prediction. The anticipated California location for the NEON program is in the central or southern Sierra.

CHALLENGES

This collaborative adaptive management program is not without challenges, and there are significant barriers to successful completion. One challenge is the sheer magnitude of the task, in terms of both space and time. Another is the time commitment for agency and university coordination. This leads to relatively large financial requirements and significant commitments from many involved parties. Other challenges include the experimental design and data analysis, achieving definitive results within reasonable timeframes, communicating results and feeding information back into the decision-making process, and addressing expectations of a diverse, and sometimes polarized, public. There are some suggested steps for success. The effort should begin relatively modestly and should proceed slowly and achieve successes before expanding. The effort should strive to build partnerships in funding and executing the program with others who have overlapping interests. It should also expand "ownership" in the success of the program to as many parties as possible. Finally, it seems inevitable that, to succeed, those leading this effort need to be brave and take some risks. There are consequences with our inability to proceed with adaptive management in the Sierra Nevada.

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