



United States
Department of
Agriculture

Forest Service

Pacific Southwest
Research Station

General Technical
Report
PSW-GTR-193

December 2004



Proceedings of the Sierra Nevada Science Symposium

Science for Management and Conservation





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U.S. Department of Agriculture

Abstract

Murphy, Dennis D. and Stine, Peter A., editors. 2004. **Proceedings of the Sierra Nevada Science Symposium**; 2002 October 7-10; Kings Beach, CA. Gen. Tech. Rep. PSW-GTR-193. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 287 p.

Land and resource management issues in the Sierra Nevada are becoming increasingly complex and controversial. The objective of the Sierra Nevada Science Symposium was to provide a synoptic overview of the current state of scientific knowledge related to key management issues. Attempts were made to tie recent scientific findings to applications in land management and policy development. The symposium addressed four primary objectives: to highlight ecological research and monitoring activities ongoing in the Sierra Nevada; to provide access for all interested parties to information on Sierran research activities, databases, and web sites; to identify new research needs and priorities of organizations, particularly those interested in managing resources or lands in the Sierra; and to explore opportunities to expand and leverage collaborative research opportunities in the Sierra Nevada, including those that encourage interagency, student, and intern involvement. The papers in this volume are summarized presentations by each speaker, as well as overview summaries provided by the session chairs. Introductory and synoptic papers precede or follow the main presentations of the conference. Poster abstracts for the approximately 100 posters presented at the symposium are also included.

Retrieval Terms: Sierra Nevada, forest, land management, climate change, landscape change, fire, biodiversity, aquatic ecosystems, watersheds, conservation, resource management policy

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Front cover photo: Daniel Perrot

Back cover photo: Dennis Murphy

Proceedings of the Sierra Nevada Science Symposium

Dennis D. Murphy and Peter A. Stine
editors

Published by
**the Pacific Southwest Research Station, USDA Forest Service
in collaboration with
the University of Nevada at Reno**

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Introduction to the Sierra Nevada Science Symposium Proceedings

Appropriately interpreting and applying scientific knowledge in natural resources management require an efficient and effective means of information dissemination. Yet, it proves more difficult each year to keep up with the flow of scientific information. As a result, turning research results into knowledge that managers and policy makers can readily access and use becomes ever more challenging.

The complex and vexing land and resource management issues in the Sierra Nevada that require the best possible scientific information and guidance have increased dramatically in recent years. The days of the Sierra Nevada landscape serving as a limitless resource are becoming a distant memory. Growing numbers of interest groups, with local to national concerns and influence, are weighing in on a variety of issues that land and resource managers must now address.

The Sierra Nevada ecoregion is famous for its vast forests, diverse montane features, and spectacular landscapes of granite. Water, timber, recreation, and grazing have all been important commodities garnered from the natural resources of the Sierra Nevada. And many less economically tangible values have been and remain treasured products of the region. The dominant question for those who develop policy and manage the Sierra Nevada is -- how can we allocate and manage finite resources to meet the diverse demands of an expanding society?

Nearly two-thirds of the roughly 20,000,000 acres within the Sierra Nevada ecoregion are under federal land management. Most of this acreage comprises national forests; some at the lower elevations is managed by the Bureau of Land Management; and the National Park Service manages some of the most recognizable landscapes at Yosemite and Sequoia and Kings Canyon national parks. Although there is a rapidly urbanizing landscape in the foothills of the Sierra Nevada, particularly along major transportation corridors, the bulk of the privately owned lands in the Sierra Nevada are managed as rangelands (at lower elevations) or timberlands (at middle elevations). Most of the Sierra Nevada remains in a relatively wild condition; however, demands for resources from these lands are coming from many different places.

These land ownership and management patterns, considered in the context of the distributions and abundances of existing resources, set the stage for the current management challenge. As various demands for the resources of the Sierra Nevada multiply, we see rapid escalation in conflicts over use of the resources and the attendant need to seek solutions. The Sierra Nevada Ecosystem Project (SNEP) in 1996 provided the first major milestone in assembling scientific information to help address a wide array of management challenges by highlighting management issues, reviewing existing scientific information, and calling for further research and data. In the years since the SNEP report (Sierra Nevada Ecosystem Project. Final Report to Congress. Status of the Sierra Nevada. Wildlands Resources Report, Number 38, Centers for Watershed and Wildland Resources, University of California, Davis. 1996.) management issues have continued to crystallize, while new research has

made additional contributions to the body of science available to managers and policy makers.

The organizers of the Sierra Nevada Science Symposium 2002 intended the gathering to be a forum for bringing forward current scientific research findings on key resource and land management issues of the Sierra Nevada, while simultaneously continuing efforts to communicate the salient findings to managers and policy makers. We believed that, since release of the SNEP report, substantial new scientific information had become available and fruitful new discussions could occur.

Key issues in the Sierra Nevada have not changed dramatically since the SNEP report, although certainly some issues have grown to represent greater and more immediate management challenges than others. Accordingly, the organizing committee identified five major topic areas that could serve well to organize the forum and focus attention. The first session addressed fire and physical processes as a focal topic. Certainly, fire and fuels management has been a prime concern in the Sierra Nevada, where fire exclusion and vegetation manipulations over the past 100 years have changed fuels loadings and fire hazards dramatically. The second session revolved around recent findings in climate change and the concomitant responses of landscapes and biotic resources. New scientific insights in these areas have raised a suite of concerns and management questions. The third session focused on the basics of forest ecology as a fundamental science that informs many other related scientific issues. How do these incredibly complex systems function? How do they respond to a suite of natural and anthropogenic disturbance agents? How can or will future management regimes influence trajectories of forest structure, composition, and function? The symposium's fourth session specifically addressed perhaps the most sensitive suite of ecosystems in the Sierra Nevada -- aquatic, riparian, and wetland systems. These ecosystems are generally considered to be among the most disturbed components of the Sierra Nevada. What is their condition, and what are the needs and prospects for their rehabilitation? Finally, the fifth session addressed the marquis issue in any ecological system or region—its biodiversity. The biota of the Sierra Nevada is generally believed to be more intact than that in many other ecological regions; however, there are warning signs and management concerns that need attention. We have the potential to stave off collapse of biological communities at this juncture; where are the problem areas and what will it take?

We also believed that it would make sense to provide a policy and institutional response for each session, one that would give a practical response to the array of scientific findings reported in each session. Our continuing goal is to make all possible efforts to bridge the gap between the research community and the management and policy community for the overarching goal of better stewardship of the Sierra Nevada. This symposium was one small—but, we believe, worthwhile—contribution to this end. Given the results and feedback received, we expect that it will be time to sponsor another such event in 2007.

We thank the many people who made this effort possible, especially the presenters and authors whose contributions are contained within this volume.

Acknowledgments

An event like the Sierra Nevada Science Symposium 2002 takes a tremendous amount of work to plan and execute. No organization or agency asked to make this event happen. There was no mandate to hold the symposium nor was there any specific funding to support it. The Sierra Nevada Science Symposium 2002 was conceptualized, organized, planned, and executed, and funds were raised to support the event, entirely through the voluntary efforts of many. Without the will and commitment of so many to make this symposium happen, it simply could not have come to pass.

We want to take this opportunity to acknowledge those who generously gave their time or resources, or both, to bring this event to reality.

Core Planning Team

Countless hours were devoted to every detail by Richard Standiford, Larry Ruth, and Joni Rippee from the Wildland Resources Center at the University of California at Berkeley, Connie Millar and Mark Nechodom from the Sierra Nevada Research Center of the Pacific Southwest Research Station, USDA Forest Service, and Jim Quinn from the Department of Environmental Science and Policy, University of California at Davis. The editors of this volume were on this team.

Session Chairs

The Session Chairs did a wonderful job of assembling the stellar speakers and authors who presented at the symposium. The Session Chairs and their respective sessions included:

Fire and Physical Processes Session

- Scott Stephens; Department of Environmental Science, Policy and Management, University of California at Berkeley
- Carl Skinner; Pacific Southwest Research Station, USDA Forest Service, Redding

Climate and Landscape Change over Time Session

- Connie Millar; Sierra Nevada Research Center, Pacific Southwest Research Station, USDA Forest Service
- Scott Stine; California State University at Hayward

Forest Ecosystem Session

- Bob Heald; University of California at Berkeley, Center for Forestry
- John Battles; University of California at Berkeley, Center for Forestry

Aquatic Systems/Watersheds Session

- Fraser Shilling; University of California at Davis
- Rick Kattelman; Sierra Nevada Aquatic Research Laboratory, University of California

Biodiversity Session

- Dave Graber; National Park Service
- Craig Moritz; Museum of Vertebrate Zoology, University of California at Berkeley

Field Trip Planning and Logistics

We organized a number of field trips for the day before the symposium with the help of many people. The field trips were organized by:

- Mike Chapel; Pacific Southwest Region, USDA Forest Service
- Greg Greenwood; Resources Agency, State of California

The actual field trips were led by Jo Ann Fites-Kaufman, Adaptive Management Services, Forest Service; John Keane, Sierra Nevada Research Center, Pacific Southwest Research Station, Forest Service; Connie Millar, Sierra Nevada Research Center, Pacific Southwest Research Station, Forest Service; Jeff Brown, Station Manager, Sagehen Creek Field Station, University of California at Berkeley; and Dave Marlow; Lake Tahoe Basin Management Unit, Forest Service

Administrative and Logistical Support

Many people generously helped to make the details of this event happen. Among these were Joni Rippee, Christie Aldrete, Wendy Yun, Nancy Dias, Donna Luckey, Mitch Riddle, Astrid Hofstadter, and Dai Nakabayashi. These individuals provided important logistical assistance at the symposium.

Convenors, Sponsors, Supporters, and Cooperators

Many organizations provided vitally important logistical and administrative support for this event as well as financial support that reduced registration costs for students. Organizations providing various kinds of support for the symposium included:

Symposium Convenors

- Wildland Resources Center, University of California
- Pacific Southwest Research Station, Forest Service

Symposium Sponsors

- The Resources Agency, State of California
- California Biodiversity Center, University of California at Berkeley
- Information Center for the Environment, University of California at Davis
- National Biological Information Infrastructure, Biological Resources Division, U.S. Geological Survey
- Biological Resources Research Center, University of Nevada, Reno
- Center for Forestry, University of California at Berkeley
- Pacific Southwest Region, Forest Service
- University of Nevada Cooperative Extension
- University of California Cooperative Extension

Symposium Supporters

- Division of Agriculture and Natural Resources, University of California
- Western Ecological Research Center, U.S. Geological Survey
- The Yosemite Fund
- Lake Tahoe Environmental Education Coalition
- Berkeley Natural History Museums, University of California at Berkeley

Acknowledgments

- The Wildlife Society, Western Section

Symposium Cooperators

- Pacific West Region, National Park Service
- The Watershed Management Council
- John Muir Institute for the Environment, University of California at Davis

Symposium Proceedings

Preparing a proceedings from a symposium or conference is always a daunting task. We, however, had the deft and indispensable assistance of Laurie Perrot from the U.S. Forest Service's Vegetation Management Solutions. Laurie joined the editors in assembling, reviewing, and formatting the material in this volume. Laurie's tireless work and unbounded enthusiasm for this project provided the energy needed to complete the task. It should be noted that photos from her family's wilderness sojourns deep in the Range of Light provided some of the very fine photo plates used in this volume. A very special thank you to Laurie! Many thanks to all who joined us in this endeavor!

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Achieving a Nexus of Science, Management, and Policy in the Sierra Nevada

Peter A. Stine¹ and Dennis D. Murphy²

The policies and strategies that guide the use and management of lands in the Sierra Nevada ecoregion depend on objective scientific information. In recent years, the region has attracted increasing attention from visitors, developers, environmentalists, businesses, scientists, and politicians as well as local residents, resource managers, and research groups. And the effects of management decisions on the status and trends of lands and natural resources in the Sierra Nevada seem to carry more weight each year. Accordingly, a great deal of new ecological information has been collected and synthesized for many different purposes. Efforts such as the Sierra Nevada Ecosystem Project (Elliot-Fisk and others 1996) and the Lake Tahoe Watershed Assessment (Murphy and Knopp 2000) illustrate both the interest and effort that have been devoted to gathering and using scientific information to support regional management. Links between science and policy, however, are often extremely difficult to forge. They require collaboration among institutions and individuals that have different traditions, needs, and goals. The potential for collaboration between scientists and managers to resolve increasingly critical challenges has not yet been fully tapped.

No single conference or institution can provide a thorough overview of current scientific insights or ensure their application to management. The intent of the organizing committee for the 2002 Sierra Nevada Science Symposium was to present a sample of current scientific work, facilitate access to more detailed sources of information, and provide a forum for application of such information in the context of land and resource management. The content of presentations ranged from recently gathered scientific data to planning and management processes and tools based on such data. The symposium provided a valuable opportunity for disseminating scientific evidence to managers, policy makers, scientists, and the public—and ultimately, perhaps, influencing policy decisions. The organizing committee supports the many other efforts intended to achieve similar goals and acknowledges the need for integration.

The four specific objectives of this symposium were

1. To highlight current ecological research and monitoring in the Sierra Nevada;
2. To provide access to information on research, databases, and Web sites related to research in the Sierra Nevada;
3. To identify research needs and priorities of organizations, particularly those with a stake in managing resources or lands in the Sierra Nevada; and
4. To explore the potential to expand research opportunities in the Sierra Nevada, including identifying possibilities for collaboration among multiple agencies, institutions, students, and interns.

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The three days of the 2002 Sierra Nevada Science Symposium (October 8–10, 2002) did not provide sufficient time to address these objectives in detail; however, we hoped that the meetings and interactions facilitated by the symposium would catalyze many more. A somewhat distinct issue, however, is what may be needed to make an effective, productive, and lasting connection between the scientific and management communities. In the following pages, we explore this question before delving into the substance of the presentations made during the symposium itself. We hope this section will serve as a foundation for bridging the sometimes deep chasm between science and management.

The Respective Roles of Science and Policy

Scientific approaches and processes differ from the approaches used to manage resources and execute policy in several fundamental ways.

Approach to resolving issues

Throughout their professional development, scientists are trained to think critically and probe the unknown. Posing questions and testing hypotheses is the substance of scientific inquiry. Encouraging curiosity and innovation breeds free thinkers who question the status quo. In contrast, managers and policy makers are required to reconcile often contentious issues through compromise and collaboration. These professionals must seek input from, and eventually facilitate agreement among, an array of positions on any given issue. In practice, independent thought and opinion, although always an asset at some levels, can hamper progress toward collaborative solutions.

Interpretation of information

Scientists work in the realm of data sets and statistical analyses that produce probability statements rather than absolute answers. Outcomes are never certain, particularly when dealing with natural systems in which variation can be overwhelming and results difficult to interpret. Yet managers and policy makers are under pressure to make decisions that have definitive outcomes. These two approaches to using and evaluating information can be diametrically opposed.

Timeframe for activities

Research endeavors tend to follow a predictable pathway. A question is posed, hypotheses are developed, experiments are designed, data are collected and analyzed, and results and conclusions are ultimately published in peer-reviewed journals. This process takes time, often long periods of time, depending on the question and conditions under which the work is conducted. Ask a question today, and expect a scientifically defensible, although perhaps equivocal, answer some years later. In contrast, policy makers and natural resource managers make decisions daily, with little time for contemplation, much less for experimentation. They must sort through the body of available information rapidly, arriving at an ostensibly definitive answer (which may or may not lead to concrete action) within a limited timeframe. All decisions have implications for resource management and conservation, including decisions that result in no action taken.

Measures of success

Scientists are responsible for conducting their work in an objective and scientifically credible manner and are judged by their peers on the merits of their research. The number, as

well as the quality, of an individual scientist's peer-reviewed publications is an important metric of success, as is the proportion of those publications on which he or she is the single or lead author. Policy makers and managers, too, are influenced by the weight of scientific evidence, but this is not the only criterion by which they make decisions. Managers are judged primarily, if not solely, by whether they reach appropriate solutions and accomplish goals. The ability to work productively with others and facilitate collaboration is highly valued within the policy and management community.

The Commensal Relationship Between Science and Management

We argue there is a commensalism between science and management. Management and policy making in the field of natural resource management, ipso facto, require scientific information. Managers need facts to first inform and later assess the results of their decisions. For their part, scientists who direct their efforts toward applied questions can receive not only intellectual and personal satisfaction but also social, political, and often financial recognition for their achievements.

Decisionmaking in other scientific disciplines has a closer and better-defined relationship to reliable information. Public health policy, for example, is tightly linked with experimentation and peer-reviewed results. Natural resource management does not have the same stringent requirement; nevertheless, research can be the foundation of many management decisions. Thus, managers and policy makers will frequently support research programs at some level. Scientists can and often do sustain their professional output without management-oriented motivation. As environmental problems have become more pressing, however, the scientific community has been increasingly attracted to questions that are generated by management needs. Tackling these questions can not only be scientifically challenging but also may allow researchers to contribute to resolving crucial issues.

Furthermore, the issue of funding cannot be ignored. In this regard, the relatively nonchalant attitude of some scientists toward management concerns is slowly shifting. Although management issues are not required to drive scientific research agendas, scientists may be drawn to sources of funding that accompany applied research. Accordingly, the bond between the scientific community and the management community can be strengthened over time. However, when scientists investigate applied or politically charged questions, they and their collaborators must strive to maintain objectivity. Scientific credibility will remain the primary, if not exclusive, currency of the scientific process, regardless of the social, legal, or economic context in which inquiry occurs.

Obstacles to Collaboration Between Scientists and Managers

There are many obstacles to making the relationship between the scientific and management communities congenial, let alone operational. Many of these obstacles relate to differing roles and responsibilities of scientists and managers. From the perspective of a scientist, successful field research is:

- well-designed; (Field experiments must surmount challenges, including but not limited to identification of uniform sampling units, discrimination of treatment effects from background environmental stochasticity, and establishment of controls and replicates.)
- conducted over a sufficient number of years to identify ecologically significant trends or causative relationships;
- not compromised by land use pressures and restrictions external to the experimental design or application of treatments; and

- adequately funded. (Expenses may accrue in field ecology because of the difficulty of collecting data, in remote locations, on study organisms that are often cryptic, have low densities, or have large home ranges.)

Characteristics of successful field research viewed from the perspective of a manager may differ from those viewed the perspective of a scientist. To meet their responsibilities, managers need:

- flexibility over when and how to manage any given piece of land or resources;
- the ability to rapidly respond to identified management needs;
- guidelines for management that can be easily interpreted and executed;
- the ability to meet annual production quotas;
- information on risks and uncertainties associated with specific decisions; and
- accountability with the public and stakeholders.

Differences in perspectives between scientists and managers are admittedly difficult to overcome. Successful relationships between research and management cannot be achieved in the absence of a set of advantageous circumstances.

Elements of a Successful Relationship Between Scientists and Managers

An enduring dialog between scientists and management exists in many different professional disciplines. At best, the outcomes can be productive and mutually satisfying. At worst, the relationship can be clumsy and ineffective, with frequent breakdowns in communication between collaborators. We believe that several attributes are typical of successful working relationships between scientists and managers.

Clearly defined roles. Scientists and managers have distinct roles and responsibilities both within their respective institutions and in partnerships. We need to acknowledge, respect, and appreciate these roles, develop clear and realistic expectations for each partner's contributions, and allow each to execute their responsibilities with minimal interference.

Cooperation. We need to develop systems that facilitate planning and logistical cooperation between science and management. Challenges include scheduling and design of treatments and subsequent data collection, logistical arrangements to support workers in the field, and efficient transfer of funds and management of shared budgets.

Sustained support. The ability to obtain defensible results is usually predicated on stable and continuous research. Shifts in funding or logistical support hamper collective efforts to achieve explicit goals.

Integrated structure. Planning and executing scientifically defensible field research requires commitments that may be atypical of traditional land management endeavors. This obstacle may be easier to surmount if partnerships focus on testing questions associated with the effects of common management practices. An understanding that clear hypotheses and rigorous application of treatments increase the practical value of research results and the strength of statistical inferences is essential.

Coordination of timing. Timeframes for planning and executing management activities are usually different from those of research projects. More effective synchronization of efforts is necessary to achieve both scientific and management objectives.

Shared expectations of results. Research often has a relatively extensive lead time for development of experimental design and logistics, followed by long periods of data collection, subsequent analysis, and preparation of reports, manuscripts, and other products.

As a result, the timetable for outcomes is often perceived as slow relative to the need for answers by managers. Additionally, scientific results are customarily presented in qualified or conservative terms; rarely does research provide categorical support for subsequent management decisions. Nevertheless, scientific information can provide the evidence necessary to make defensible, incremental decisions. We need to explore mechanisms for meeting the expectations of both scientists and managers with respect to research results.

Implementation of adaptive management. Management objectives and scientific research that address the same issues can be pursued independently, but success is far more likely when they are pursued in concert. Planning efforts, expectations, and outcomes need to be integrated, especially in facilitating adaptive management.

Shared accountability for returns on investments. If scientists and managers are to work together in the Sierra Nevada, public accountability must be shared. We need to consider how to develop an accountability framework in which each partner takes some responsibility for the success of the others

Application of Science to Management in the Sierra Nevada

Land management issues in the Sierra Nevada are gaining national and even international attention. Controversy over appropriate land stewardship for the present and future is growing. Science has contributed significantly to this debate; in fact, the Sierra Nevada Ecosystem Project in 1996 made a landmark initial impact on the discussion of ecological sustainability. In recent years, this debate has intensified over such topics as conservation of the California spotted owl, fisher, goshawk, American marten, and other vertebrates thought to be dependent on old-growth forest conditions; management of fuels and wildfire; conservation and restoration of aquatic systems and riparian areas; sustainable harvest of forest products; and extensive and growing demand for an array of recreational uses. Currently, the most important resource issue in the Sierra Nevada may be sustaining the reliable production of water for domestic and agricultural uses.

The Sierra Nevada, like most other ecosystems around the world, has long passed a threshold of apparently inexhaustible natural resources. Competition for resources to support different land uses, whether real or postulated, is increasing. As a result, the timeframes in which managers must make decisions are shrinking. The real merits of “good science” are taking on a new meaning. As managers venture into the crossfire, they need the products of well-developed scientific inquiry. Simultaneously, scientists have unprecedented opportunities to contribute meaningfully to an expanding knowledge base.

Notwithstanding the mixed success of previous relationships between scientists and managers, we believe that an adaptive management strategy that is well constructed, well funded, and well supported offers the best hope for achieving diverse objectives. We envision programs in which scientists and managers collaborate to identify monitoring and research priorities. The resulting investigations generate scientific information, which in turn allows managers to assess the performance of management strategies relative to management objectives. Strategies can be continued, modified, or discontinued accordingly; further testing maintains the cycle by providing a flow of information that can justify and validate future decisions.

Collaborative efforts between scientists and managers can begin modestly, attempting to confront small suites of key issues. But partnerships must have support and encouragement from the overwhelming majority of stakeholders concerned with the future of the Sierra Nevada, and these partnerships must have opportunities to adapt to the expectations and needs of diverse interest groups. Such partnerships do not require establishment of a new bureaucracy but rather require a collaborative venture among existing organizations and interests. Policy makers, managers, scientists, and the public must work together to define

initial objectives and expectations and commit to supporting what will be a very long process. While appropriate adaptive management may eventually become fairly complex, a prudent approach at this juncture is to pursue collaboration on a relatively short list of the highest priorities, execute monitoring and research with the highest scientific standards, and build from initial partnerships as other needs are identified.

In the chapters that follow, we believe there is substantial cause for optimism that a new collaboration between science and management can help us achieve sound stewardship of the unique natural resources in the Sierra Nevada ecoregion.

Confronting the Implications of Wicked Problems: Changes Needed in Sierra Nevada National Forest Planning and Problem Solving¹

Hal Salwasser²

Thirty years ago, the fate of migratory deer in the Sierra Nevada was thought to be the major forest wildlife issue. Ten years later, agencies were building the California Wildlife Habitat Relationships System to allow managers to integrate all terrestrial vertebrates with timber management in comprehensive National Forest planning. Another ten years after that, Tom Knudsen wrote his Pulitzer Prize-winning series, “Sierra in Peril,” describing the complexity of environmental problems. Now, managers are trying to improve the lot of all native species in the Sierra Nevada, address fire hazards and a host of ecological processes, and deal with the complex interactions of people and nature in forest planning. The past three decades have been a turbulent ride for those who work and live with the National Forests of the Sierra Nevada. Why have we not been able to solve the Sierra Nevada’s problems? I propose that it is because we have not been using the right methods for solving such complex problems.

Two challenges in managing public natural resources are especially vexing: improving the prudence and sustainability of resource management direction for Federal lands and improving institutional effectiveness in carrying out that direction. On the basis of my first-hand experiences as a regional executive with shared responsibility for guiding the Interior Columbia Basin Ecosystem Management Project and the Sierra Nevada Framework and Forest Plan Amendment environmental impact statement (EIS) process and my review of the Sierra Nevada National Forest Plan Amendment Record of Decision and its supporting documents, I suggest three lessons for future problem solving. First, we have been trying to solve natural resource problems with methods insufficient to handle their multi-dimensional complexity by continually applying more and better science (or new and improved models), reanalyzing the problem(s) *ad infinitum*, and making decisions through political or judicial power plays. Secondly, we can improve the utility of science in helping us solve natural resource problems but only within the context of social and managerial tools useful in addressing multi-dimensional complexity. Finally, these tools include coping strategies and structured decision analysis leading to the continuous improvement process of “learn by doing” and “learn by using,” which is called active adaptive management.

Multiple Dimensions of Natural Resource Problem Complexity

Difficulties in solving complex problems often start with describing the problem itself. Natural resource problems are inherently complex and messy (Gunderson 1999, Shindler and Cramer 1999). There is often no definitive statement of what the problem is. Absent a definitive problem statement, there can be no definitive solution. Clearly articulating the problem to be solved through continual iteration and refinement of the problem statement is

¹ This paper is based on the keynote address presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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key to successful planning. Typically, multiple problems and multiple objectives characterize natural resource plans, each framed by a particular stakeholder pursuing a distinct mission.

The first Sierra Nevada National Forest Plan Amendment Record of Decision (USDA Forest Service 2001) is by no means the first or only example of this, but it does illustrate the situation well. Five problem areas are described:

1. Protect, increase, and perpetuate old-forest ecosystems and provide for the viability of native plant and animal species associated with old-forest ecosystems,
2. Protect and restore aquatic, riparian, and meadow ecosystems and provide for the viability of native plant and animal species associated with these ecosystems,
3. Manage fire and fuels in a consistent manner across the National Forests, coordinate management strategies with other ownerships, integrate fire and fuels management objectives with other natural resource management objectives, address the role of wildland fire, and set priorities for fire and fuels management actions,
4. Reduce and, where possible, reverse the spread of noxious weeds, and
5. Maintain and enhance hardwood forest ecosystems in the lower westside of the Sierra Nevada.

These “problem areas” read more like multiple objectives to be met than a definitive statement of what “the problem” is. The Record of Decision says that these are “areas where National Forest management needed improvements.” Thus, the problem must be that existing management direction does not adequately address these multiple objectives and that a better solution is needed. But these problem areas are not consistent in stating an expected outcome. “Protect, restore, and increase” refer to both processes and outcomes. Viability is an outcome that cannot be measured. The expected outcome for fire and fuels is unstated; process goals are to manage, coordinate, integrate, and set priorities. Unstated in the “problem areas” is the possibility that goals for old-forest and aquatic systems and species could conflict with goals for fuels and fire. Clearly, there are multiple objectives, and a definitive statement of “the problem to be solved” is not clearly articulated.

The Record of Decision also says that the Chief of the Forest Service instructed the Regional Forester to “develop a strategy to ensure ecological sustainability.” The assumption here must be that existing direction for Sierra Nevada National Forests did not do this; thus, the problem is lack of ecological sustainability. The standard for “ensure” and what, exactly, “ecological sustainability” means must be deduced from other statements in the Record.

From the five problem area statements, one can deduce that sustaining ecosystems must mean, at a minimum, providing for old-forest and aquatic ecosystems and the viability of their native species first, managing fire and fuels second, and reversing the spread of noxious weeds and enhancing hardwood forests as a third-tier action. The rationale for the decision given later in the 2001 Record attests to these as the priorities used in weighing tradeoffs. Other components of the ecosystems in question, such as water, wood, recreation, cultural resources, diversity of human lifestyles, local communities, and local economies, all commonly considered to be integral parts of sustainable forest ecosystems, are addressed through discussion of impacts or effects on them posed by the solutions proposed for the five problem areas.

The deciding officer set some conditions for the solution: “amendments (must) be scientifically credible, legally sufficient strategies for sustaining National Forest ecosystems.” The implication here is that prior plan directions (that is, solutions to the

problem) are not scientifically credible or legally sufficient for the purpose of sustaining ecosystems.

No mention is made in the Record of Decision about a desire to improve institutional effectiveness. The Record briefly outlines a decade-long history of attempts to develop adequate protection for California spotted owls in Sierra Nevada forests, work that actually began in the late 1970s, not just in the 1990s. Large investments of time, people, and financial resources have been made in planning to bring us to a decision that, in 2004, easily 30 years after the first species concerns surfaced, is still under review and potentially subject to litigation. This is evidence of institutional ineffectiveness, yet there are no goals or strategies for addressing this “problem.” Society is confronting a very complex problem, and even its definition eludes clarity.

Social Complexity—Fragmented Stakeholders

Part of the complexity reflects our society. Stakeholders for Federally managed natural resources are often highly fragmented in their interests and in the tactics they use to pursue those interests. This includes specialists within the various agencies with responsibilities for resource stewardship. There is essentially no stakeholder group for balance among the multiple problems and multiple objectives except for the agency line officers mandated to create that balance. In some cases, such as wildlife, fish, and recreation, there are multiple stakeholder subgroups that do not agree on which aspects of “their” resource should be featured in the National Forest System, for example, recreationists who use mechanized vehicles versus backpackers or horsemen.

Collectively, the multiple stakeholders see “the problem” and objectives differently; in other words, they are not likely to agree on the definitive “problem” to be addressed. Conklin (in press) calls this aspect of a problem social complexity. Stakeholders are also likely to have different value preferences and different tolerances for risk; not only do they not see “the problem” alike, they do not see “the solution” alike either. Roberts (2001) says that disagreement on both the problem and its solution characterizes a wicked problem, a concept first articulated by Rittel and Webber (1973), extended to forestry by Allen and Gould (1986), and recently discussed in relation to natural resources issues by Gunderson (1999) and Shindler and Cramer (1999).

Scientific Complexity

From a scientific perspective, natural resource problems are also complex because multiple factors are at work, influencing each problem area or objective. For example, the condition and trend of a wildlife population are a result of interactions among the prior population, habitat, weather, predators, disease, off-site factors, and chance events. Resource managers can influence only some of these factors, and scientists only vaguely understand how they all operate together to affect a population outcome for many, if not most, species. Most of what affects wild plant and animal populations falls into the arena of uncertainty and unknowns. This point has important implications for how biological diversity is addressed, especially attempts to estimate species viability on the basis of projections of habitats only.

Wildlife populations are not the only example of scientific complexity. The vulnerability of a forest or rangeland to uncharacteristic fire is a result of past fire suppression, past land management, climate/weather, perhaps invasive species, and chance events. The hazard that risk poses depends on how close the forest or rangeland is to something of value that could be harmed by the fire, such as houses, sensitive natural resources, or municipal watersheds, and how easy it might be to get initial-attack firefighters to where ignitions start. But the fire-prone forest or rangeland is also habitat for certain wildlife species, and any action or inaction taken for one objective, say fire risk or wildlife habitat, affects the outcome for the

other. Thus, natural resource problem areas or objectives are not independent; they are linked. How science from multiple disciplines is handled and integrated in planning will influence the effectiveness of a plan in problem solving.

Uncertainty

Regardless of how much is known about a problem or objective and the factors influencing its status and trends, areas of uncertainty will always exist. Uncertainties can take two forms: (1) we do not know but can eventually learn through observation or research, or (2) we cannot know until it occurs, such as future weather events. Uncertainties are typically more significant to planning than what is known. When there is uncertainty, we are as uncertain about the potential for positive outcomes as we are about the potential for negative ones. This adds to the complexity. Brooks (1996) describes three types of surprises, or potentials for unknowns to occur: unexpected discrete events, discontinuities in long-term trends, and emergence of new factors.

The Mount St. Helens volcanic eruption is an example of an unexpected discrete event. An example of a discontinuity in a long-term trend is the climate shifting from cooling to warming. We cannot know for certain where or when the discontinuity is going to occur or how long it will last, but when it does occur, it shifts ecosystems to a new trajectory of change. An example of a new factor is the arrival of an invasive species that radically changes the ecological structure and process of a place, for instance, cheatgrass, chestnut blight, or white pine blister rust. To be successful in coping with a dynamic and largely unpredictable world, land and resource management planning needs to be resilient to uncertainty and surprises.

Gunderson (1999) talks about building “robust responses” to uncertainty by building system resilience. The way in which people choose to deal with uncertainty either increases or decreases a system’s resilience to surprises. One approach is to choose to do nothing by ignoring or assuming uncertainty away. Another is to choose to replace uncertainty with faith that the matter will resolve itself. A third approach is to choose to confront the uncertainty in a systematic way and try to restore resiliency to the system.

Ignoring the fire risks in Western dry forests is an example of the first choice. Having faith that nature will fix the problem is an example of the second choice. An example of the third approach is to choose to do something to change the behavior of a fire when it occurs, from catastrophic to something less transforming. Planning, either implicitly or explicitly, involves deciding which of these choices to make when confronted with uncertainty, risk, and unknowns. The 2001 Sierra Nevada Forest Plan Amendment Record of Decision appears to have favored the first two choices over the third in regard to fire risks outside the urban interface and long-term wildlife habitat suitability in densely stocked mixed conifer forests. The revised 2004 Decision for the Sierra Nevada Forest Plan Amendment favors the third choice.

Conflicting Risks

As if this is not enough complexity, we usually encounter conflicting risks to each objective, and these risks vary over the short and long terms and among objectives. An example of multiple objectives and variable risk is the intersection mentioned above between wildlife habitats and wildfire created by the conditions of dry, fire-prone forests throughout the West. Managers and stakeholders want to sustain healthy populations of all wildlife species, especially those associated with old forest, native shrub lands, and aquatic ecosystems. Most also want to restore forests and rangelands to conditions more resilient to the inevitable fires, droughts, and insect epidemics, in which the characteristics of disturbance events do not create unacceptable risks to life, property, natural resources, or County, State, and Federal

treasuries. Pursuing either the wildlife protection objective or the fire risk–reduction objective changes the short- and long-term risks to the other. Inaction lets the risks accumulate. This intersection of objectives and risks for wildlife (or water or biological diversity) and wildfire (or drought or invasive species) is typical of the major tensions in planning for National Forest and National Grassland management in many parts of the western United States. Any plan to solve complex and wicked problems must address how conflicting risks are handled.

System Dynamics

Ecosystems are dynamic. Social systems, economic systems, and public attitudes are also dynamic. Our state of knowledge and technologies is dynamic; therefore, plans and their management strategies must also be dynamic. They must be designed for local application and continual adaptation to change. According to Lindbloom (1979), Wildavsky (1995), and others, the only way to make steady progress and improve problem solving in dynamic and uncertain situations is to take incremental actions that are bold enough to have the potential for errors so that we can learn from those errors and make course corrections. Furthermore, these actions need to actively involve users of plans, and not just designers of plans, because most innovations come from users trying out novel solutions to local problems. This means that active adaptive management must engage every field unit that implements a plan, not just a few for the benefit of others.

The weaker the knowledge about system dynamics and the greater the uncertainty, the stronger the need for action-based learning to reduce uncertainty in the future. The 2001 Sierra Nevada Forest Plan Amendment Decision appears to do just the opposite: its premise appears to be the greater the uncertainty, the greater the caution in taking action that could lead to learning, which could reduce uncertainty. Unfortunately, as Gunderson (1999) and Stankey and others (2003) have pointed out, natural resources professionals have yet to demonstrate great capacity for making adaptive management work, and this must be taken into consideration in assessing the effectiveness of a plan that depends on adaptive management. The more prescriptive and constraining a plan is on permitted actions or on processes required to get to action, the less likely adaptive management is to succeed. This is the major reason why adaptive management in the Northwest Forest Plan has failed. A similar undesired outcome for Sierra Nevada National Forests could occur if the revised plan amendments are overly prescriptive and cautious.

Diagnosing Wicked Problems Correctly

For the past two decades, National Forest planners and managers have been misdiagnosing or underdiagnosing the nature of the problems they are trying to “solve.” They have been thinking that the problems are simple enough or maybe insufficiently complex that they are solvable with traditional scientific tools and plans, for example, linear programming models and increasingly sophisticated analyses. While such tools are necessary, they are not sufficient. Too frequently, Federal agencies get stuck on analysis and planning without ever getting to the implementation and learning stage (Cortner and others 1996). Addressing the more intractable social aspects of adaptive management is even more problematic under current policies and practices (Shindler and others 2002). For example, the current procedural requirements of the National Environmental Policy Act (NEPA) and easy access to judicial review of forest plans actually hinder collaboration as a tool for dealing with social complexity.

Conklin (in press) says the failure to recognize and deal with “wicked problems” leads to organizational pain—a sense of futility in expecting things to get done one way and repeatedly banging into a different reality, or, in the case of recent Forest Service planning,

making only minor changes in how planning is done, yet expecting different results. This pain may be caused in part by misunderstanding the complexity of the problems at hand and trying to solve them with tools and methods useful only for simpler problems, for example, attempting to solve problems fraught with social complexity or value conflicts by adding more science or running more sophisticated systems models. It may also be explained in part by agency managers who actually do understand that they are dealing with wicked problems but are constrained by law, rule, or policies to employ methods that still empower special-interest combatants who use traditional power tactics suitable for simpler problems.

This description of the complex and wicked nature of natural resource problems, depicted in *figure 1*, characterizes the decision environment for National Forest plans. It was certainly true for the Pacific Northwest Forest Plan, Interior Columbia Basin Ecosystem Management Project, and Sierra Nevada National Forest Plan Amendment. Complexity and wickedness in natural resources problems will not go away. Organizational pain is clear in the Forest Service. We need to learn how to function well in such a world.

Simple	Complex	Wicked
clear, all agree	Problem	fuzzy, disagreement
single	Objectives	multiple
aligned	Stakeholders	fragmented
few, controllable	Factors Influencing Objectives	many, beyond control
low	Uncertainty	high
low variability	Relative Risks	high variability
leads to clear choice	Role for Science	informs choices
not contentious	Coping Strategies	contentious
less valuable	Decision Analysis	more valuable

Figure 1— Spectrum of complexity involved in natural resources problems.

We need to develop effective methods to improve (1) the quality of our decisions, (2) the degree to which decisions are deemed prudent by the various stakeholders—in other words, the degree to which they garner enough support and commitment to action so that learning is possible, and (3) the health of our institutions of governance for Federal lands.

Navigation Tools

Let us now turn to tools that can help those who wish to work on solving wicked problems: science, coping strategies, decision analysis, and adaptive management.

Science

Science is vital in helping stakeholders address wicked problems in at least six ways. Science helps stakeholders:

1. understand and define the problem(s) they are trying to solve;
2. develop objectives relevant to solving the problem(s);
3. design creative yet feasible alternatives to meet those objectives in ways that lead to problem solutions;
4. elucidate the likely consequences (good, bad, and neutral) of those alternatives;
5. characterize and understand uncertainty and risks inherent in each alternative; and
6. design and carry out monitoring, research, and adaptation sufficient to address major uncertainties, reduce risks, and test assumptions made in planning.

The word “helping” is italicized because scientists usually do not conduct these roles in a vacuum and then hand off the products to managers and stakeholders; they interact and work with managers and stakeholders to make sure their work is relevant to the problem(s) and is practical. An exception to this was made for the Northwest Forest Plan, which, by 1993, was judged by political leaders as being at sufficient gridlock to warrant giving Forest Ecosystem Management Assessment Team (FEMAT) scientists the authority to carry out steps 3 through 5 above in isolation, after political authorities had defined steps 1 and 2. Sustainable approaches to solving wicked problems normally require full openness in how steps 1 through 6 above are handled. This was a major reason for the openness of science in the Interior Columbia Basin and Sierra Nevada cases, beginning with science assessments and the Sierra Nevada Ecosystem Project (SNEP) process. Regional assessments, for example, FEMAT, Interior Columbia Basin Ecosystem Management Project) and SNEP, have proven extremely useful in providing a scientific foundation for comprehensive land and resource management planning (Johnson and others 1999).

Very few natural resource decisions are blessed with the quality, comprehensiveness, understanding, and public support of the science that now supports problem-solving efforts for Sierra Nevada Federal lands (Sierra Nevada Ecosystem Project 1996 Sierra Nevada Science Review 1998, Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement 2001). It is truly a most impressive body of knowledge for such a large and complex region. It can and will get better. But better science, by itself, will not lead to better solutions for natural resources problems in the Sierra Nevada if it continues to be used in ways insufficient to solve wicked problems. A new approach is needed.

Coping Strategies

Three alternative coping strategies for dealing with complex problems are the use of authority, competition, and collaboration (Roberts 2001, *fig. 2*). Authoritative strategies try to “tame” problems by putting problem solving into the hands of a few stakeholders who have the authority to define the problem and solve it. In a democracy, authoritative coping strategies work and are sustainable only if all the stakeholders yield power and authority to

the anointed few and agree to abide by their decisions. In other forms of governance, authoritative copying strategies last because those in power force others to accept the solution. Reducing the number and diversity of stakeholders with authority to define and solve the problem decreases complexity. But it has some disadvantages: the authorities can be wrong about the problem and wrong about the solution, and authoritative strategies do not keep the citizenry informed and engaged in the governing process.

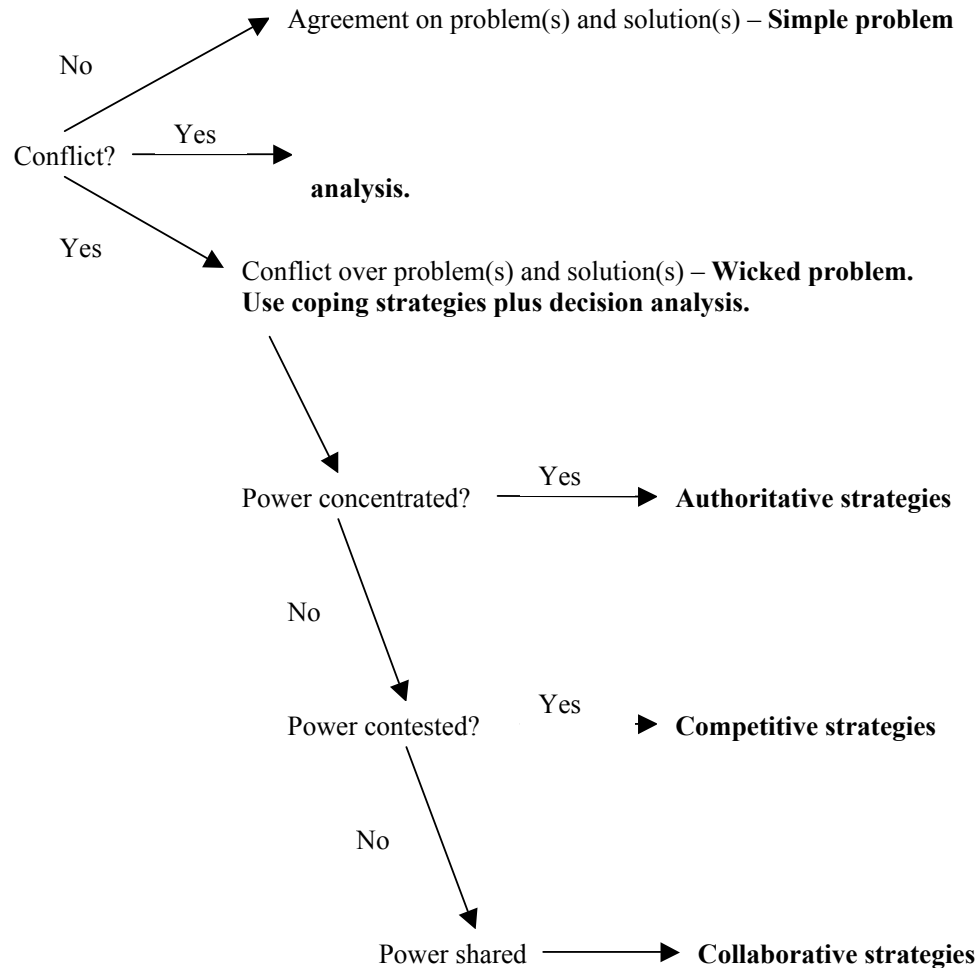


Figure 2— Coping strategies for dealing with wicked problems (adapted from Roberts 2001).

Competitive strategies assume a zero-sum game, and a win-lose attitude permeates the environment. Central to the pursuit of competitive strategies is the quest for power. As more power is acquired and held, it can change the coping strategy from competitive to authoritative. Competition can be an efficient temporary way of solving problems; however, pushed to the extreme, it can lead to violence and warfare. It can also lead to an intermediate situation of gridlock because stakeholders have enough power to block one another, such as

through judicial rulings or political means, but not enough power to actually arrive at a solution or get something done.

Collaboration is the third coping strategy. It occurs when multiple stakeholders who share power work together to jointly define “the problem(s)” and find acceptable and realistic solutions to them. It seeks win-win solutions. The advantages of collaboration are sharing in both the costs and benefits of solutions, strength in numbers, and organizational efficiencies. Disadvantages include the increased transaction costs of adding more stakeholders, more meetings, more time, and the need to learn new interpersonal skills. Collaboration also requires compromise. And it can and does on occasion go awry.

Collaboration is expensive and time consuming and can weary participants beyond their tolerance limits. But, if it works and is linked to continuous improvement processes to learn and make periodic course corrections (in other words, active adaptive management), it may be the only sustainable coping strategy for addressing wicked problems in a democracy. The hope for such an outcome was what led Forest Service executives to design the Sierra Nevada Framework for amending National Forest plans on the basis of principles of collaboration.

Whatever coping strategy is chosen, that strategy is the process wherein the wicked problems get defined, where objectives are set, where alternatives are framed, and where likely consequences are evaluated for how well they are likely to address objectives and solve the problem(s) vis-à-vis scientific, logistical, social, economic, and political criteria. I did not say this is where the problem gets solved. It only gets “solved” through adaptive management. Science can help each coping strategy reach its goals, but it does not drive them; coping strategies are social and political processes, not scientific methods. This is the fundamental reason why natural resources policies and plans are never science based, despite the sloppy use of that term. They are always value based. They are, at best, science informed. They are also, at best, socially, politically, and logistically feasible.

Our current laws, policies, and procedures do not enable collaboration because they do not vest shared power in the collaborators. Power still belongs to those who can prevail in court or Congress or the White House. And this is why we do not yet have sustainable strategies to solve the wicked problems in the Northwest Forest Plan area, the Interior Columbia Basin, or the Sierra Nevada. We do not have the social will or the capacity to make collaborative problem solving work over large areas yet. And agencies still suffer from organizational pain, caught in the crossfire from the gladiators of conflict.

To succeed, collaborators must agree to share power, and the process of collaboration must increase the likelihood that the various stakeholders will have equity in how their concerns and interests are addressed. It must increase the likelihood that critical and creative thinking will occur and that the decision process will lead to higher “buy in” from those affected by the decision. It should go without saying that collaboration cannot occur without full openness and mutual respect in how all aspects of the decision process are handled. Openness means full disclosure and honest and appropriate use and characterization of knowledge, uncertainties, risk, and values. Mutual respect means a commitment to stay within the process and not resort to power plays. Collaboration on complex problems requires a willingness to compromise for the larger, collective good for the greatest public benefit.

As a fundamental goal, collaboration should increase credibility and trust in the solution to the problem, including the adaptive management strategy and the institutions that will carry it out. To reach this goal, collaboration must:

- decrease the potential for the problem or objectives to be incorrectly stated;
- increase creative thinking in designing alternative solutions;

- increase the likelihood that assessments of the alternatives make appropriate use of science *and* the subjective values of the stakeholders; and
- decrease the likelihood for a dysfunctional solution to the stated problem(s).

If collaboration cannot do these four things, it will likely be perceived as not warranting the extra costs. If compromise is unacceptable to stakeholders with sufficient access to power, collaboration will fail. Hence, if power cannot be shared equitably among stakeholders, collaboration should not be used as a coping strategy. To achieve equity in power sharing, the role of the judiciary in natural resource problem solving must be limited to matters of equity and not process or substance of decisions. New governance mechanisms for arbitration or mediation among the collaborators must replace litigation.

Decision Analysis

Regardless of which coping strategy is at work, decision analysis methods can improve the prudence of solutions to complex problems. Decision analysis is likely analysis overkill for simple problems and will probably be most useful for complex problems, those for which people can agree on the problem but need some help finding agreeable solutions.

According to Hammond and others (1999), an effective decision-making process fulfills the following six criteria:

- focuses on what is important;
- is logical and consistent;
- acknowledges both subjective and objective factors and blends analytical with intuitive thinking;
- requires only as much information and analysis as necessary to resolve a particular dilemma;
- encourages and guides the gathering of relevant information and informed opinion; and
- is straightforward, reliable, easy to use, and flexible.

For maximum effectiveness, the decision process must:

Work on the right decision problem(s). This means that, to choose well (make prudent decisions), the decision problem(s) must be stated carefully, acknowledging complexity but avoiding unwarranted assumptions or option-limiting prejudices.

Specify objectives for solving the problem(s). The decision is a means to an end. What are the ends that must be achieved to solve the problem(s)? Which interests, values, concerns, fears, and aspirations are most relevant to achieving the goals?

Create imaginative alternatives. Alternatives are the different possible courses of action to choose from in working toward the objectives. The decision can be no better than the best alternative or the best complementary parts of several alternatives.

Understand the consequences. How well do the alternatives satisfy all the objectives and address the problem(s)?

Grapple with the tradeoffs. Each alternative will fulfill a suite of objectives to different degrees. Choosing intelligently means setting priorities and openly addressing tradeoffs among competing objectives. If the world was certain and everyone had the same tolerance for risk and the same values, this would be the end of the road. But it is not and they do not. So we move on.

Clarify the uncertainties. Effective decision making demands that uncertainties be confronted and the likelihood of different outcomes and possible impacts be assessed.

Think hard about risk tolerances. When decisions involve uncertainties, there is some risk that the desired outcome will not accrue to the course of action taken. How important is this for the various objectives; in other words, what are the costs of being wrong?

Consider linked decisions. What is decided here today may affect outcomes elsewhere or options for decisions in the future.

These eight elements of the decision process provide a framework for making better use of science and coping strategies in decision making. The framework is very similar to how agencies structure their decision making. But agency performance in defining problems, identifying uncertainties and risks, and linking objectives has been weak. Also, this framework must be iterative rather than linear. And it must conclude an approach to implementation that we commonly call active adaptive management (Wildavsky 1995).

There are several barriers to success in applying the above decision-making framework. Reviewing these barriers helps us identify how future Sierra Nevada decisions could be improved.

Barrier: *The problem statement is poorly defined: key factors are minimized or left out, or the wrong priority is assigned.*

The problem statements in the Sierra Nevada Record of Decision appear to be quite fuzzy and poorly focused. They may not be the most useful statements to focus further work. Ideally, the problem statements should have been reviewed thoroughly throughout planning in collaboration with the stakeholders who had authority to share power.

Barrier: *Objectives are either too narrow or too comprehensive.*

As previously noted, the five “problem areas” in the Record of Decision are not the most useful characterization of the multiple objectives that must be addressed to make progress on the problem(s). Not all are necessary, nor are they collectively sufficient to guide further action.

Barrier: *Alternatives are overly constrained by prejudices or weakly reflect science and/or values.*

This is not a weakness of the Sierra Nevada National Forest plan amendment process because stakeholder groups were invited to forge their own alternatives, and these are fully reflected in the EIS. The science consistency check indicated that the science was fully and appropriately used. The evaluation of alternatives in the Record of Decision indicates that all of the action alternatives perform well in regard to the five problem areas; they vary in how well they address each problem area, but all make the future better for all areas.

Barrier: *Assessment of consequences confuses objectivity with subjectivity. Both are necessary to prudent decisions but are not useful when confused.*

Subjectivity in science is inescapable. In the assessment of alternatives in the Sierra Nevada environmental impact statement, scientists were honest and candid about the necessary use of subjectivity: “In summary, there is considerable uncertainty regarding viability” (USDA Forest Service 2001). The explanation of what went into the viability ratings in the FEIS is as comprehensive and sound as can be found to date for such work. But they are still subjective assessments, influenced greatly by both available data and necessary assumptions.

The issue here is not the efficacy of the science *per se* and its necessary use of subjectivity but rather how the science and its attendant subjectivities and uncertainties were used in decisionmaking. When the product of science is stated as a working hypothesis with

uncertainties disclosed, the only viable measure of its veracity is to test it in the real world. That requires actions bold enough to push systems to where errors and learning can occur.

Barrier: *The weighing of science, risk, uncertainty, and values is unclear in the decision-making process.*

The precautionary principle (Wingspread Declaration 1998) is often advocated as the “safest” path to species or ecosystem protection when an effective characterization of comparative risks is lacking, when there is an inability or unwillingness to fully describe the implications of uncertainty, and in the absence of a decision making process that takes these into consideration in a transparent way.

Precaution has long been a basis for taking action to prevent harm. But it has lately gone beyond this to say that, in the absence of full certainty that an action will not do harm, do not take the action (Morris 2000). A weaker and often used form of precaution says that lack of full certainty that a proposed action will or will not cause harm is not a justification for letting that action go forward. These postulates are reflections of a philosophical position regarding risk and uncertainty.

The precautionary principle has several flaws that make it questionable as a guide to decision making (Beckerman 2000). First, if the future is really all that uncertain, then we cannot be confident that action taken or not taken today will not make the future better rather than worse. Second, what constitutes harm is not always clear and could vary over time and space. When the precautionary principle is applied to dynamic ecosystems to constrain actions, such as fuels thinning needed to restore the system’s resilience to fire, it sets up the potential for major long-term harm: harm from inaction could be greater than harm from proposed action. Inaction creates “opportunity benefits,” that is, benefits foregone because action was not taken (Wildavsky 1995).

It is not possible to have full certainty regarding most of the important things in life, and ecosystems are certainly no exception. The standard for burden of proof about certainty in the precautionary principle is infinitely high. And taking no action precludes the opportunity to learn from trial and error. The upshot of applying the precautionary principle is either nothing will ever get done or the preconditions for action are so time consuming and burdensome that action is excessively costly, too timid, or too late. The consequence will be countless unintended harms as a result of inaction. Care, thoughtfulness, and testing of ideas make sense, but extreme precaution is hardly prudent in a dynamic ecosystem, especially one that is vulnerable to uncharacteristic disturbance events. Thus, in situations such as those that confront Sierra Nevada ecosystems, stakeholders, and managers, the precautionary principle sheds no light on prudent choices.

The precautionary principle appears to have greatly influenced how risk or uncertainty about forest management impacts on certain fish and wildlife entered the decision rationale in the 2001 Sierra Nevada Forest Plan Amendment. It appears that uncertainty was assumed to have only negative potential outcomes; however, uncertainty means outcomes or future events are uncertain in both directions. The rationale for how tradeoffs were made warrants open critical thinking and review of what uncertainty implies, what harm is, and how it is judged vis-à-vis other objectives. The 2004 revised Record of Decision handles risk with more boldness, yet even it is insufficient to address the magnitude of risk to late successional forests and their ecological values posed by uncharacteristically intense fires.

Barrier: *Backroom deals and political power plays can pervert the appropriate use of science, nullify investments in structured decision analysis, and scuttle collaboration if that is the coping strategy being openly pursued.*

When Forest Service executives tried to brief a high administration official on the scientific comparison of alternatives in early spring 1999, it was clear that the collaborative strategy and honest use of science to which those executives had publicly committed had been

nullified by stakeholders with enough authority to impose competitive or authoritative power. This also happened to FEMAT's Option 9 as it morphed into the untenable Northwest Forest Plan.

There are paths around these barriers to prudent decisions if people are willing to pursue them. Not surprisingly, they involve recognizing the complex nature of the problem(s) in the first place, and then navigating the barriers to effective solutions.

- Define the problem(s) as clearly and concisely as possible: through collaboration to decrease social fragmentation if possible, or through other means if not. Revisit the problem definition frequently as planning proceeds and fine-tune it as needed. Accept that precise problem definitions are unlikely for wicked problems.
- Frame objectives relevant to the problem(s) in its full dimensions. Help people see what the desired outcomes will be and where the stopping point is for planning and analysis so that action and new learning can begin.
- Create innovative and feasible alternatives—those that can be tried and abandoned or discarded easily if they do not work as intended and that can be objectively evaluated as better or worse.
- Distinguish science from values and treat them accordingly; both are important. Shifting from conventional statistical inference tools to Bayesian inference would help in this task.
- Structure the decision-making process so that science, risk, uncertainty, values, and tradeoffs are clear to all stakeholders.
- Insist on total openness from start to finish, from integrity in commitments made to stakeholders to appropriate use of science.
- Know when to stop planning and start learning through adaptive management.

These may be utopian wishes. But, if the goal is to make prudent, sustainable decisions or more prudent decisions than those we have for complex, dynamic ecosystems, it will take more than just bringing better science to the table or simply doing a better job of science integration. If that is all that gets done, it will be like the common definition of insanity: doing things the same way and expecting different results. Social complexity, rather than lack or misuse of science, is a major barrier to solving complex dynamic natural resource problems. Boggling down in analysis so that action and learning never occur is quite another.

Active Adaptive Management

Numerous times in this paper, active adaptive management has been referred to as key to actual problem solving for complex problems. There is a rich literature on adaptive management (Holling 1978, Walters 1986, Stankey and others 2003). Several points are key to making adaptive management work on Federal lands.

Active adaptive management means that management projects are treated as experiments with sufficient scientific design so that they clearly lie in the interface between research and routine management. It requires that scientists work side-by-side with managers in designing, implementing, and monitoring project work. And, it requires that ecosystems be treated boldly enough to learn where the cause-effect relationship boundaries are between action and response. The Forest Service has experience with such projects, but they have been the exception rather than the rule. To solve wicked problems, active adaptive management must become the rule and routine management the exception. Without major cultural change in both the research and management branches of the agency, adaptive management is a pipe dream.

Large areas were dedicated to adaptive management in the Northwest Forest Plan, and they were determined by the scientists who designed the plan to not be needed for species recovery. Yet these areas were eventually held to the same rules as the rest of the landscape, and little experimentation occurred (Stankey and others 2003). For the Sierra Nevada Forest Plan Amendment to succeed in solving the problems it addresses, active adaptive management should characterize the program of work for every ranger district.

Closing Thoughts

Like many recent National Forest plans, the 2004 Sierra Nevada National Forest Plan Amendment decision contains some very innovative approaches to solving the wicked problems that stakeholders face. Use of science in policy, fuels strategies in the wildland-urban intermix and dense fire-prone forests, the administrative study for California spotted owl responses to habitat alterations, and the tiered approach to ecosystem analysis are all excellent improvements over prior direction for the Sierra Nevada National Forests. But the collaborative coping strategy set in place by SNEP and the Framework process in 1998 floundered in the closing days of decision making in 2001 and again in 2004. Decision analysis was also weak throughout planning, making it very difficult to understand how risks, uncertainties, science, and values were considered and balanced. And our cumulative laws and policies coupled with severe stakeholder polarization have not yet allowed active adaptive management to serve its problem-solving role.

On the basis of the cases mentioned above and my personal experiences, the future for collaboration as a coping strategy for Federal natural resource problems appears cloudy. Success will require changes in laws and processes, changes that powerful interests have signaled they are not about to tolerate. This was clear as recently as 2003 in the compromises necessary to enact the Healthy Forests Restoration Act. If such changes in laws and procedures to assure equity in access to governance are not possible, collaboration will likely work on only the least controversial problems, those that might be complex but are not wicked. This leaves a discomfiting feeling about our societal ability to create sustainable solutions to our toughest Federal natural resource problems.

Even with the uncertain future for collaboration, future natural resources problem solving could benefit from adapting decision analysis and adaptive management learning processes used in other disciplines for complex problems. It is plausible that society could reap greater benefits from National Forests by shifting part of the enormous investments currently made for planning and analysis to investments in active adaptive management and the monitoring and research that support and improve it over time. But we also have a long way to go in making cultural changes in the agency that will be necessary to enable active adaptive management. Yet, these are where the most likely payoffs exist in creating sustainable solutions to wicked problems.

Existing procedural and natural resources laws, judicial precedents, and policies may not allow these innovations to occur. It is also possible that sufficient crisis to effect reform in those laws and policies do not yet exist. Absent such reform, we may well be stuck with the same outcomes we have been getting. But these outcomes are increasingly intolerable to many sectors of society—witness responses to recent catastrophic fire seasons. Thus, we must try something different or we will lose opportunities to learn what we must learn to improve future stewardship of Federal forestlands.

The organizational pain felt so pervasively by the Forest Service these days is caused by fragmentation of direction and mission caused by changes in political leadership, fragmentation of competing stakeholder interests, and strained interpersonal relationships across Federal agencies that must work together on complex and wicked problems. This pain can lead to misdiagnosis of wicked problems as tame problems, leading to delusory notions that those problems can be solved by simply doing more of what has always been

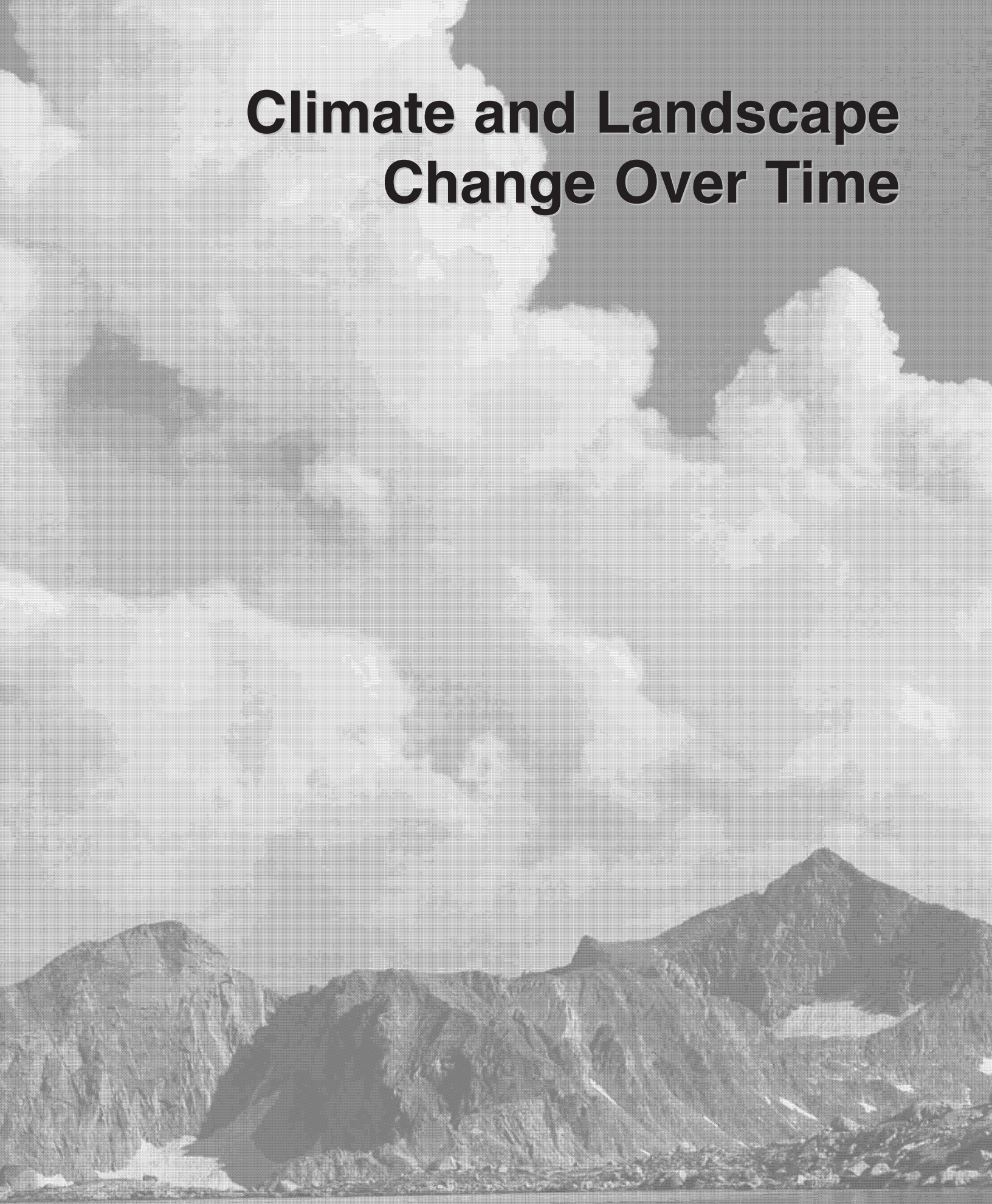
done or just doing it better. The antidote for fragmentation is coherence, shared understanding, and shared commitment, shared meaning for terms and concepts, shared commitment for solutions that are good enough to get on with the real business of learning through action—in other words, willingness to share power and share the benefits of a common cause. Only such a shared commitment to workable solutions and mutual learning will ease the pain and restore health to our Federal forestlands and venerable government institutions for natural resources stewardship.

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Climate and Landscape Change Over Time



Session Overview: Climate and Landscape Change Over Time¹

Constance I. Millar²

In this chapter, we strive for something different. Whereas a goal of the other sessions at the Sierra Nevada Science Symposium was to present new research on familiar themes, our goal in the session “Climate and Landscape Change Over Time” was to introduce a topic that itself is likely unfamiliar to many resource scientists and managers. The limited discourse to date between the fields of climatology and resource ecology is surprising for two reasons. First, in the past two decades, there has been a revolution in research on climatology that has led to dramatic new understanding about the functioning and dynamics of the climate system. Second, these new insights are relevant to the resource sciences—so much so that fuller understanding in our research community could restructure thinking about how ecological systems work and revolutionize strategies for resource management and conservation.

The topic of climate change often invokes images of global warming, greenhouse gas impacts, and 21st century politics. There is a larger context that we must begin to understand and assimilate into resource science thinking—that is, the role of the natural climate system as an ecosystem architect. To understand this larger picture requires looking back in time to analyze historic climate variability and also forward in time to model the interaction of natural climate effects and human influences.

Climate Variability as an Ecosystem Architect: In Perspective

Conceptual views of the natural world influence tactical approaches to conservation, restoration, and management. Advances in ecological sciences during the mid- to late 20th century increased our understanding of succession, disturbance, and spatial variability, causing biologists to view nature as dynamic and process driven rather than static and typological. In turn, conservation and management perspectives matured, shifting emphasis from museum-like nature preservation to the maintenance of variability and natural function. As a result, prescribed fires and managed floods, for instance, became important conservation tools, and emphasis on ecosystem function as well as structure was added to restoration goals.

Important as these changes have been, static concepts still constrain our understanding of natural dynamism and limit our potential for conservation successes. In the same way that resource science embraced fire as a significant natural process, climate variability must be understood as a primary driver of ecological change. Recent advances in climate system sciences characterize recurrent climate change as a central physical force on Earth and a significant agent of physical and ecological change at micro- to macro-scales. Analysis of historic climate change at high resolution with new and precise

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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indicators reveals a picture of oscillating climate that has varied simultaneously, and often abruptly, at nested timescales.

Historically, plants, animals, and landscapes have responded to these climate cycles with dramatic and sometimes rapid changes, including major shifts in species ranges, composition, and structure; in vegetation and ecosystem composition and distribution; in snowpack accumulation, glacial dynamics, and streamflow timing and volume; and with cascading effects on biodiversity and historic human cultures. The picture that emerges is of nature moving an order of change greater than our current ecological perspective embraces; that is, ecological response to climate change becomes a third order of change, or a “variable chasing a variable not a constant” (Jackson 1997). Climate can thus be considered a macro-disturbance element in that it is the background stage of change on which all successional dynamics (including those following disturbance such as fire and flood) play out. Such dynamism has not yet been consistently incorporated into evolutionary and ecological theory nor translated into conservation and management practice. As a result, many management actions, such as evaluation and diagnosis of ecological change, determination of baselines and evaluation of change based on inventory and monitoring, and development of targets for restoration, are at best limited in applicability and at worst wrong.

Sierra Nevada Climate Variability from Past to Future

In this session, the authors introduce basic concepts that describe the mechanisms that regulate climate variability in the Sierra Nevada, document the nature of physical and ecological responses to climate change, and anticipate effects of future climate variability on Sierra Nevada landscapes and implications for resource management. Malcolm Hughes (in these proceedings) sets the context for climate by providing historical perspective. Arguing that the current era, the “Anthropocene,” is human-dominated means we must look to the past for information about how Earth’s natural climate system functions. From the many natural archives available to reconstruct climate, Hughes shows that the 20th century is anything but representative of the kinds of extreme climate combinations and variability possible. Scott Anderson (in these proceedings) echoes this sentiment by summarizing the nature of vegetation change as it responded to climate variability at long to short timescales. The transition from glacial to interglacial 10,000 years ago in the Sierra Nevada was marked by dramatic replacement of community assemblages and major species range shifts. Nonanalog plant communities, that is, plant species growing together that do not now, were present around the Sierra Nevada. By 7,000 years ago, further warming climates triggered advances of pine-dominated forests to high elevations and far greater dominance of shrub communities on both sides of the crest than at present. During the modern period (past 5,000 years), as climates cooled and alternated between wet and dry, modern communities emerged.

Scott Stine (in these proceedings) uses geomorphic evidence from lake- and river-level changes to document that the Sierra Nevada's modern climate is, by the standards of the past four millennia, abnormally wet and warm. Multidecade-scale swings in moisture availability, unlike any seen in modern time, have characterized the Sierra Nevada over the past millennium. Stine emphasizes that more such swings—induced naturally or artificially, or both—must be expected to recur within a time period relevant to land management. Henry Diaz (in these proceedings) further describes changes in physical systems, especially water regimes, as climates change in the modern period. Glaciers are retreating, snowpacks are melting earlier, and runoff is less, leaving the Mediterranean-based Sierra Nevada summers effectively longer and drier. Diaz argues that only with integrated interdisciplinary assessments and studies will we be able to effectively manage for these changes at the resource level. Dave Schimel (in these proceedings) concludes the section by addressing relationships of Sierra Nevada ecosystems to carbon dynamics. Mountains are important contributors to carbon uptake in the western United States as a result of their unique climate within a semi-arid to arid region and because of historical and present-day

management. Fire management strategies must reflect a balance between hazard management, long-term risk management, and preservation of forest health. Any changes to fire regime or fire management practices are likely to have widespread impacts on forest ecosystem function, affecting carbon storage and tightly linked water resources. Although fire suppression has probably led to a larger carbon sink in the West, much of this sink is present in the fine and coarse fuel categories (dead plant material) or in dense stands of small trees and thus contributes to increased risk in drought years. Improved carbon management must consider both the amount of carbon stored and the stability of that storage as climate and fire regimes evolve.

Lessons about Climate Variability and Implications for Conservation and Management

Together the narratives in this chapter and others like them (see references cited section that includes some suggested references for further reading) generalize about the relevance of climate variability to ecosystem science and management. First, climate historically has *oscillated* rather than been dominantly directional or stochastic. Thus, at a coarse scale, climate regimes change but recur over time. As a consequence, distant periods in the past may be more similar to the present than is the recent past. Similarly, past variability may give us better insight into the future than do current conditions. Importantly, although average regimes oscillate (for example, cold: warm, wet: dry), exact climates (combinations of variables) are expressed uniquely over time. Second, climate has varied simultaneously at *multiple and nested scales*, operating at interannual, decadal, centennial, millennial, and multi-millennial scales. Daily and annual weather are the cumulative expression of all mechanisms operating together. Third, transitions between major as well as minor climate phases often occur *abruptly* (over a few years to decades), accompanied by significant changes in climate. Climate states are highly sensitive, catalyzed by threshold events, triggered by stochastic effects, and especially vulnerable during times of high variability (such as the present) (NRC 2002). Fourth, *ecological and physical systems respond to climate change* at each scale and often exist in nonequilibrium state with regard to climate. Plants and animals of the Sierra Nevada have responded to historic climate change with dramatic shifts in population size, distribution, composition, abundance, and ecology.

Management and conservation strategies will be successfully conceived and executed when they are designed with a recognition and understanding of the processes detailed in this chapter. Many management situations will be affected by changes in climate, as the following examples suggest (excerpted from Millar [in press]).

Sustainability as a Guiding Concept in Conservation and Management

Ecological sustainability is a dominant current paradigm routinely used as an implicit or explicit goal in conservation, restoration, and management practice, such as may be found in resource plans of Sierra Nevada National Forests and resource districts, county plans, and the Record of Decision for the Sierra Nevada Framework. Various definitions of sustainability implies the endurance and persistence of species, communities, and ecosystems over time (Lele and Norgaard 1996). Operationally, sustainability has been difficult to describe but is generally accepted to pertain when natural species diversity is maintained, species are well-distributed in their native ranges and occur in historic abundances, community associations are maintained, and natural processes occur at "reference" intervals and conditions (Hunter 1996, Lackey 1995).

The contributions of this chapter emphasize that many conditions we often associate with ecological sustainability did not occur naturally in the history of Sierra Nevada ecosystems. For instance, species diversity changed at timescales of years to decades to centuries.

Similarly, individual species ranges and population abundances shifted, often drastically. Vegetation assemblages changed over time or shifted locations, or both, as individual species followed climate gradients. For example, some vegetation communities sometimes appeared to move “as a whole” when individual species responded to shifts in climate conditions. In other cases, communities changed in composition and dominance relations when species moved individually, following trajectories dictated by their own ecologies. Communities representing assemblages of species that are not found today were common, and population sizes, densities, and productivities fluctuated greatly at multiple scales. Reconstructions of historic fire regimes, snow accumulations, streamflows, and lake levels indicate that physical systems also changed continually over time.

In sum, records suggest that our current, widely used concepts of sustainability, which emphasize the persistence of species and communities within current ranges and in current population relationships and abundances, against a relatively static physical backdrop do not accommodate natural dynamics adequately. If there is any conclusion from the paleorecord, it is that at scales from years to millennia, ecological conditions do not remain stable, and details of structure, composition, or distribution fluctuate rather than persist. The flux is not random, chaotic, or unlimited but is influenced by climate (and other agents of change) and mediated by local environmental and ecological conditions. Resilience, at least in terms of species persistence, occurs through the capacity of plants and animals to track favorable environments as they shift over time and through adjustment in range distribution, habitat, and population and genetic characteristics.

Concepts of Rarity, Population Decline, and Native Range

Rarity in plant and animal species has often been linked to species history (for instance, recent speciation or paleorelictualism) or to direct human impacts. The perspective of climate and species variability, however, illustrates that rarity may also be transient and recurring and may alternate with periods of widespread distribution. Species have adjusted to climate change historically by increasing in abundance in some areas and dying off or migrating from other areas. Thus, climate change must be considered among other factors when evaluating causes for species rarity and population decline (or increase).

A challenging corollary question is, “what is the native range of a species?” Native range is the *sine qua non* of conservation. To define the range of a species forms the basis for a number of standard ecological and conservation benchmarks such as monitoring its “health,” attributing causes of change, understanding favorable habitat, determining restoration targets, and indicting species as exotic. Viewed against historic changes in distribution and natural flux, the native range of a species must be considered a transient and dynamic phenomenon, readily capable of moving in space on the landscape over time. Recognizing that nonequilibrium conditions exist and lags occur means acknowledging that, like Lewis Carroll’s Red Queen, plant and animal populations chase a target (climate) that is itself changing and lag behind current conditions to varying degrees. Distribution ranges may appear stable if climate is in a more stable phase or if the environment of a species offers considerable local heterogeneity (for example, elevation, soil, aspect, hydrology gradients), or both. In these cases, species may track shifts in climate with relatively minor geographic changes. By contrast, in regions that are relatively homogeneous—for instance, broad flat landscapes with little diversity—even small shifts in climate may trigger large changes in population conditions.

Reference Conditions and Restoration Targets: Discerning Natural from Human-Caused Changes

Predisturbance conditions are often used to characterize reference variability and describe desired conditions for restoration in the Sierra Nevada and elsewhere. In western North America, predisturbance conditions are defined as those before Eurasian settlement, in other words, about A.D. 1600–1850. From a climatologist's standpoint, this period is an inappropriate reference for modern conditions in the Sierra Nevada because the Little Ice Age occurred during these centuries, with its coldest period in the 19th century. Many current Sierra Nevada forests were established during this time and thus were influenced in their formative stages by climate conditions that no longer pertain. Vegetation changes that have occurred during the past 150 years are not solely the result of human-caused impacts (for example, fire suppression) but include natural adjustments to changing climate conditions. Misunderstanding of this leads to inaccurate diagnosis of ecological conditions and misprescription of treatment.

Rather than returning species to former conditions (“restoration”), a climate-informed approach might attempt to understand the full niche breadth of a species (from the historic perspective), species' shifts related to climate change in the past, and historic distributions under climates similar to that of the present. Integrating this with knowledge of species responses under less-disturbed modern conditions would give options for restoration (“realignment”) (see Millar 1998 as an example).

Global Warming and Conservation

The specter of global warming raises much concern in conservation communities. As we now understand, this is not a future threat, but a current reality. Warming observed in the past 120 years is partly rebound in the natural climate mechanism and partly anthropogenic (IPCC 2001). Abrupt climate change and ecological responses to it have been common in Earth's history. On the one hand, this is comforting, in that species must be at least somewhat adapted to changes such as are occurring now. Accommodating these changes—if we choose to acknowledge and accept them—will require rethinking our concepts about what and where is native habitat, what are “healthy” population sizes, what are causes of changes in population size, and when is change natural and acceptable. On the other hand, natural as they are, consequences such as population and species declines, minor and major extirpations, shifts in native ranges, or changes in community composition may be undesired socially. If we choose not to accept such consequences, we should know that our management and conservation efforts might run counter to natural processes.

Even more important is the fact that species live now, even in our Sierra Nevadan wildlands, in human-dominated landscapes. If a primary natural mechanism by which species accommodate climate change is movement, anthropogenic constraints, including some of our well-intended plans for conservation, now pose challenging obstacles for many species. Human activities—from fragmentation to land conversion, from atmospheric pollution to invasion by introduced species, and even conservation attitudes about where species ought to be (native ranges) and policies that set static land designations—limit the potential of species to move as they naturally would. Adapted as they may be to natural climate change, the current human imprint on the landscape may severely limit natural adaptive responses, unless we reevaluate our actions.

From the societal standpoint, ecosystems services provided by the Sierra Nevada, especially water and hydropower, will also change in the future as a result of climate change. In contrast to most Sierra Nevadan ecosystems, social systems have proven to be rigid and inelastic to abrupt changes in availability of resource goods. The infrastructures and demands of California's urban areas especially create a dependency on Sierra Nevadan resources that will be significantly challenged in the future.

We are just beginning to integrate climate science into resource management and conservation planning for the Sierra Nevada. Our attempts at understanding its implications for specific plans and actions are rudimentary. It will take the concerted efforts of Sierra Nevadan scientists, managers, planners, and conservationists to integrate concepts of temporal dynamism fully into our practice and to develop robust and enlightened approaches to protecting and maintaining natural biodiversity. A potential forum for such analysis would be a collaborative, interdisciplinary assessment of climate change for the Sierra Nevada. Such a project, similar in nature to the Sierra Nevada Ecosystem Project, would provide a crucial opportunity to evaluate the implications of climate variability and future uncertainties for current planning efforts in the Sierra Nevada.

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Interannual-scale to Century-scale Climate Variability in Western North America¹

Malcolm K. Hughes²

“All our direct observations are from a ‘treatment’ of the system.”

Nobel prizewinner Paul Crutzen argues that the Holocene period of Earth history has ended, within the past century or so, and that we are now at the beginning of the “Anthropocene,” the period in which the face of the Earth and the composition of its atmosphere has been altered by our species. One indicator of this is the concentration of carbon dioxide in the Earth’s atmosphere, which started to climb in the 19th century and has now reached higher levels than for millions of years. This has implications for global climate and also for the functioning of both terrestrial and aquatic ecosystems in all regions. These implications may be serious for mountainous regions, which may be particularly vulnerable to climatic and other atmospheric change. These global changes have important implications for our understanding of how the Sierra Nevada systems work, because all our scientific observations, including those made by John Muir, were made on an altered system. If we are to have a “control” for this global unplanned experiment, we must look back to the centuries and millennia immediately before the Industrial Revolution.

The Climatic Theater and the Ecological Play

(with apologies to G. Evelyn Hutchinson)

It is not unusual to think anecdotally of the consequences of extremes of weather or climate. So, for example, it may not seem too provocative to link the death of many sugar pine trees to the 1988 drought in the Sierra Nevada although a forest entomologist or pathologist might well feel that the anecdote needs elaboration. There are many good reasons for adopting a more systematic approach to the analysis of the effects of climate variability on ecosystems and resource systems. The one I emphasize here is that it is a mistake to think of climate variability as random. There is temporal structure in climate variability: there have been periods of several decades when events like the 1988 drought have been consistently either more or less frequent.

The species composition and age structure of many forests in the western United States have been strongly influenced by two episodes, a severe drought in the late 16th century and two decades or more of remarkably wet conditions in the early 17th century. Those episodes were apparently caused by shifting climatic “regimes” over the whole Pacific Basin in both hemispheres and represent patterns which may well recur naturally. Thus, it is not valid to assume that climate variability is random and may be ignored in models (whether conceptual or numerical) of ecological processes. In order to understand the dynamics of ecosystems, we must know their climate history.

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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The Texture of Climate Variability in the Sierra Nevada

Natural archives of climate variability, such as tree rings and geomorphic features, show that the 20th century was not a representative sample of climate variability in the Sierra Nevada in recent millennia. Climate has varied on interannual to century timescales long before the addition of excess greenhouse gases to the atmosphere, and it will continue to vary although probably in modified forms. Certain general conclusions may be drawn on the basis of current information. First, in several respects, the Sierra Nevada region's 20th-century climate was unusually benign. Droughts were less severe and less persistent than in earlier times, for example, in the period before A.D. 1500 (*fig. 1*). Several sources indicate that multidecadal extreme droughts, unlike any in the past few centuries, occurred between A.D. 400 and 1500 in the central and southern Sierra Nevada. Single-year droughts like that of 1977 occurred four times as frequently in some centuries than in the 20th century. Some of these, for example, the drought in 1580, were markedly more severe than the 1977 drought. There is evidence that the sustained but less extreme drought of the late 1980s and early 1990s was weaker than hundreds of other droughts in the past 8,000 years. Secondly, this variability is neither completely random in time nor strongly cyclical, but it does have considerable temporal structure. Some of the most severe multidecadal droughts in the central Sierra Nevada (for example, in the 10th–14th centuries) probably coincided with wetter-than-average periods in Oregon and northern California.

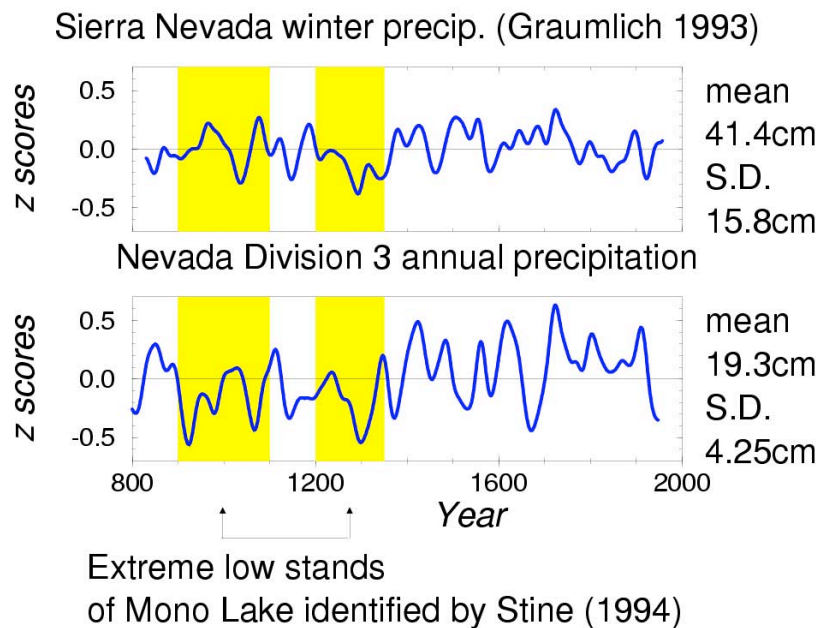


Figure 1— Two smoothed records of past precipitation derived from tree rings. The upper panel shows a record for the central Sierra Nevada published by Graumlich (1993) and the lower a record from the White Mountains (Hughes and Funkhouser 1998), just to the east of the central Sierra. Note that both records show greater wetness in the past 500 years than before and that severe multidecadal droughts coincide with the sustained extreme low stands of Mono Lake described by Stine (1994) for the period between A.D. 900 and 1350.

Conclusions and a Caution

All our direct observations were made on a changed planet.

Even apart from this, the 20th century is an inadequate example of climatic variations—much more extreme fluctuations have occurred in recent millennia. For example, the 20th century was relatively drought free.

The climate record relevant to the Sierra Nevada is textured on several time scales, so it should not be thought of as varying randomly. Basing future expectations on a recent 30-year mean or standard deviation could be misleading and perhaps even wrong in the absence of consideration of global warming.

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Regional Changes and Global Connections: Monitoring Climate Variability and Change in the Western United States¹

Henry F. Diaz²

Mountain ecosystems of the Western United States are complex and include cold desert biomes, such as those found in Nevada; subpolar biomes found in the upper treeline zone; and tundra ecosystems, occurring above timberline. Many studies (for example, Thompson 2000) suggest that high-elevation environments, comprising glaciers, snow, permafrost, water, and the uppermost limits of vegetation and other complex life forms, are among the most sensitive to climatic changes occurring on a global scale. The stratified, elevationally controlled vegetation belts found on mountain slopes represent an analog to the different latitudinally controlled climatic zones, but these condensed vertical gradients are capable of producing unique hotspots of biodiversity, such as those that serve as habitat for a variety of species ranging from butterflies, frogs, and toads to birds, trout, and salmon. High relief and concomitant environmental gradients make mountain ecosystems very vulnerable to slight changes of temperatures and extreme precipitation events.

Likewise, the role of mountain regions in providing life-sustaining water for communities in the western United States means that climatic and other environmental changes in these mountains will have a large impact not only on the region but in many other areas as well. In essence, mountain regions represent a discrete quantifiable domain where relatively small perturbations in global processes can have cascading effects on most or all of the myriad interdependent mountain systems, from hydrological cycles to complex fauna and flora distributions and abundances, to the people that depend on those resources.

What will changes in global climate mean at the regional scale? Are we monitoring the right things? Is the observing system adequate for the task? Can we find some critical systems at risk—"canaries in the mine"—that will alert us to imminent and perhaps irreversible changes starting in our mountain ecosystems?

Monitoring Climate Processes in the Western United States

As in any complex geophysical system, questions about the past, present, and future status of mountain environments in the western United States must be addressed through focused efforts to monitor and anticipate any ongoing changes and provide historical context for the measurements. Information on fundamental processes and patterns of local and regional change can be used to assess impacts of climate variability and mountain ecosystem vulnerability to change. This information is vital for optimal management of mountain ecosystems, conservation of their biodiversity, sustainable use of mountain resources and ecosystems, and preservation of the social and economic well-being of mountain communities in the western United States.

Meeting the challenges of observing, understanding, and predicting changes in our mountain environment requires sustained and stable funding and institutional support for long-term

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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multidisciplinary, multi-institutional efforts. Climate monitoring in mountain regions can be a difficult undertaking; developing the long baseline of observations needed to properly assess environmental changes on multiple time scales requires a long-term commitment to quality and stability. Climate-related signals can be subtle and are sometimes obscured by short-term variability; hence, changes in variability arising from changes in the measuring system can obstruct efforts to detect climate change.

Figure 1 illustrates the present coverage of weather-observation stations in the western United States (area west of the 100th meridian) as a function of elevation. I have conservatively assumed that each station is representative of a 100-km² area. The curve depicts the proportion of area that is occupied by the equivalent topography, in 1000-foot increments, using a high-resolution digital elevation model (DEM) of the western United States. This is simply the relative proportion of stations grouped by 1000-foot (approximately 300-meter) intervals. Of course, although the relative proportion of stations is similar to that of the topography, the actual physical coverage of those stations is rather meager. A sample area of 100 km² is perhaps overly restrictive with respect to surface temperature, which tends to be correlated to a relative radius. In regions of complex topography, however, typical decorrelation scales are often less than 100 km. *Figure 1* shows clearly that the alpine regions of western United States are grossly undersampled, and there is an obvious need for the development of a comprehensive climate monitoring program that would complement other long-term observation programs, such as for example, the Long-Term Ecological Research program.

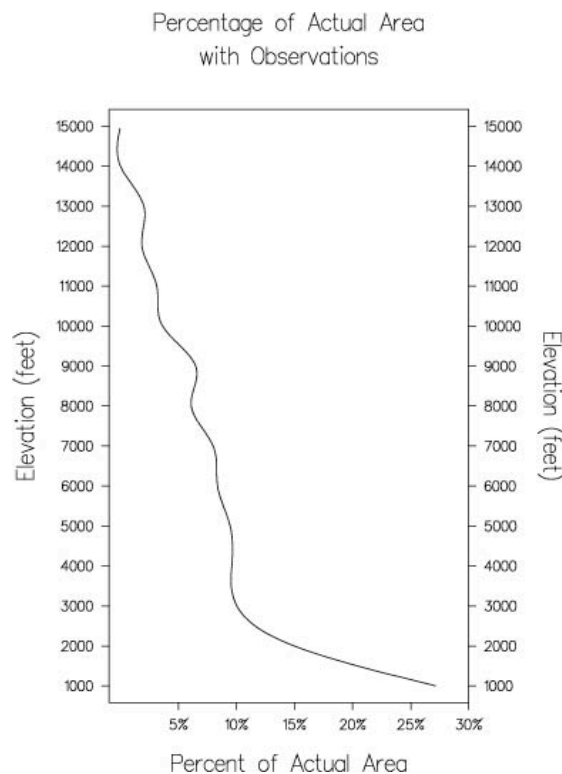


Figure 1— A conservative estimate of the percentage of actual area coverage with observations in the western United States. Values calculated assuming that each station is representative of a 100-km² area. Corresponding area is based on a high-resolution digital elevation model of western United States topography.

We have calculated 50-year surface temperature trends for the western United States based on the available long-term (stations with period-of-record ≥ 30 years) observation network, which contains 2,092 stations. The results are illustrated in *figure 2*. The statistical significances of the trends (not shown) vary from better than 10 percent (that is, $p < .10$) below 7,000 feet (approximately 2135 m) to not significant above that (possibly because of so few stations at higher elevations). Temperature increases fairly uniformly with elevation, averaging about 1°C per century over the entire region. The increases in mean minimum temperature are even slightly larger, amounting to about 1.5°C per century over the entire region (*fig. 3*). These changes have significant implications for the management of ecosystems and water resources management in the West.

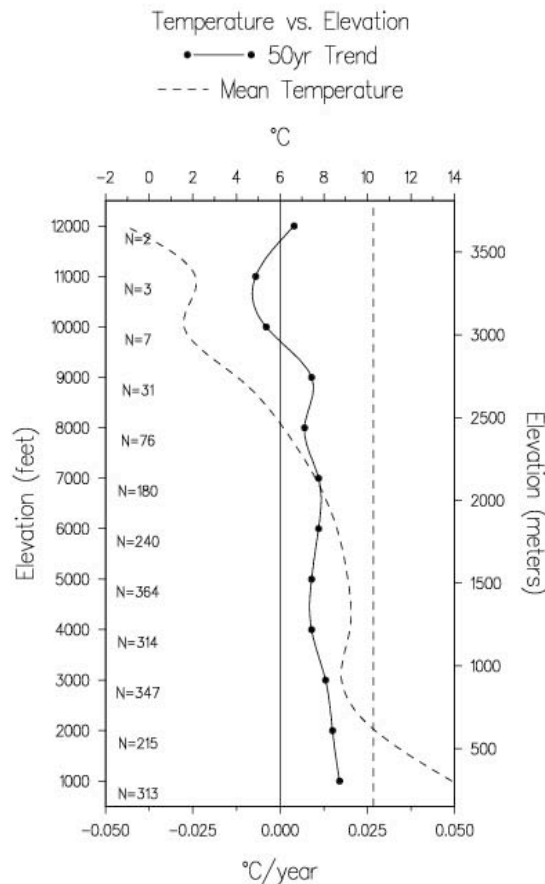


Figure 2— Median 50-year trends (1950–2000) of annual average surface temperature. Values are shown as a function of elevation for 2,092 stations in the western United States (west of 100°W) and are plotted in 1,000-foot (approximately 300-m) increments and smoothed using a rigid spline. The trend values are plotted against the annual mean temperature of the stations (dashed curve), averaged for each vertical segment, and based on the number of stations shown on the left side of the graph.

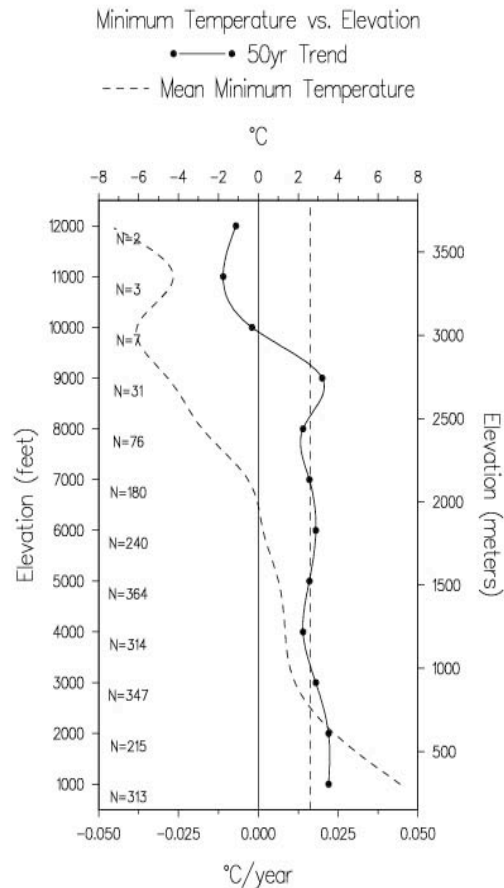


Figure 3— Median 50-year trends (1950–2000) of average annual minimum temperature. Values are shown as a function of elevation for 2,092 stations in the western United States (west of 100°W) and are plotted in 1,000-foot (approximately 300-m) increments and smoothed using a rigid spline. The trend values are plotted against the average annual minimum temperature of the stations (dashed curve), averaged for each vertical segment, and based on the number of stations shown on the left side of the graph.

An analysis of changes in the number of days with mean temperature below freezing in the Sierra Nevada region (using a set of 88 stations located above 3,000-foot elevation; not shown) indicates a reduction of approximately 10 percent over the past 50 years in the number of such days. This is consistent with the results of other studies (Cayan and others 2001) that documented the advance of spring flowering of several western shrub species in the West during the past several decades.

A United States program to develop a long-term climate reference network for the purposes of climate-change monitoring and detection may provide an opportunity to incorporate into the reference network some of the mountain sites where currently active research programs utilize multidisciplinary data sets of high quality. The integration of measurement programs at these mountain research sites will ensure that the data are state-of-the-art and continue to meet research requirements for studies of climate variability and change.

Changes in the alpine cryosphere (the portions of the Earth's surface where water is in a solid form) may represent some of the earliest signs of large-scale climate change. The

cryospheric variables (glaciers, ice flows, snowfields, etc.) not only serve as indicators of change but also initiate powerful feedback loops through changes in albedo. Timely and detailed knowledge of the ongoing changes, coupled with modeling of the effects, will allow managers and policy makers to plan for the impacts arising from such changes. At present, there is great uncertainty regarding the amplitude of recent climatic changes and their future course at high elevations of the American Cordillera. Observation and modeling studies of the alpine regions of the western United States will help researchers quantify and understand the impacts of global climate change in our mountain regions.

Lack of water-flow and water-quality data in critical climate-sensitive areas, such as the mountain regions of the West, impairs our ability to understand and model hydrologic processes governing climatic land-atmosphere-ocean interactions. The information is needed to make reliable projections and assess the impacts of variability and change in climate and water resources. Streamflow observations are inadequate, and stations are being discontinued. Areas where data are particularly lacking include discharge of freshwater to the oceans and precipitation, snowmelt, and runoff in high mountain basins, which contribute disproportionately to the flow of many rivers.

Insufficient resources often limit efforts to make regular, long-term observations in high mountains, where sites are remote and often difficult to access. However, some well-established technical means are available, and various innovative technologies either are already available or in need of only minor development and field-testing before application. In order to monitor adequately the changes in the natural environment that may be occurring as a result of global climate change, it will be necessary to establish *in situ* streamflow gauging stations, ground-water observation wells, and water-quality measurement sites in selected climatically sensitive basins in the West. The payoff will be improved definition of surface and subsurface flows and transports of water-quality constituents, which will enhance understanding of hydrologic processes and how they might respond to global climate changes in the future.

Studies have shown that since 1950, the snowmelt season in some watersheds of the western United States has advanced by about a month. This change to an earlier melting of the snowpack has been noted at mid-elevation watersheds of the Sierra Nevada in California (Dettinger and Cayan 1995, Dettinger and Diaz 2000). Global change projections indicate that Western snowpacks will diminish markedly over the next century and this crucial spring-summer portion of the runoff will be sharply reduced. Besides having direct economic impact, this change in mountain hydroclimate would presumably affect ecosystems, both up- and downstream. A better multi-faceted observational system is needed to monitor and understand these changes as they occur.

Continued support of paleoclimate studies is needed to help establish a scale for what can be considered normal variation by looking back at climatic variations in the recent past. Results from paleoclimate studies have shown that during the past 2000 years climate variation has resulted in both warming and cooling events, the Medieval Warm Period, at around 1000 A.D., and the Little Ice Age at around 1500 to 1800 A.D. Both were accompanied by significant elevational shifts in lake levels and alpine treelines, as well as temperature and rainfall. Studies that produce high-resolution paleorecords of these relatively recent events would clarify the surface spatial distribution of climatic effects and possibly allow us to infer the past atmospheric driving forces.

It is not clear yet whether climate changes in high-elevation regions will represent an amplification of the global warming signal. It behooves the scientific community to address this important question definitively. To do that, however, a variety of high-quality records will be needed. The current sampling network of climate monitoring in the mountainous regions of the western United States provides inadequate spatial coverage to answer that question.

Implications for Mountain Resources Management

Because of the fundamental complexity of mountain regions, progress in understanding the response of both natural and human ecosystems to climatic variation and change will require the integration of various disciplines into a more cohesive intellectual framework. In the mountainous western United States, there is a need to develop a more holistic view of the processes affecting the physical and biological systems comprising the region. The problems must be tackled in an interconnected manner, reflecting the operation of the real system.

To meet the major water resources challenges facing the West, as a result of its rapid population growth (see Diaz and Anderson 1995), it will be necessary to develop an adequate monitoring system for the alpine regions that provide most Western communities with their water. This implies the development and maintenance of improved networks to sample, both spatially and temporally, all the critical elements needed to define the state of the region's climate and understand its past, present, and future behavior.

The climate-observing system should be linked to ongoing research across the region, should be able to support the needs of other users, and should accommodate a broad range of uses of the data. It should also have the ability to adapt to the use of new technologies as they become available at lower costs, add new variables as needed, etc. Finally, the climate-observing system must adhere to the principles for climate monitoring, as outlined in a U.S. National Research Council report (NRC 1999), and to the management guidelines that are required to implement them. Adequate monitoring of critical environmental variables and processes forms the foundation for understanding global climate change and variability and provides an adequate temporal context for extreme events. Efficient access to comprehensive data derived from observations, paleoenvironmental records, and models is also required.

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Recent Projections of 21st-Century Climate Change and Watershed Responses in the Sierra Nevada¹

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In the near future, the Sierra Nevada's climate is projected to experience a new form of climate change due to increasing concentrations of greenhouse gases in the global atmosphere from the burning of fossil fuels and other human activities. If the changes occur, they presumably will be added to the large interannual and longer-term climate variations in the recent and distant past that have been described in this chapter. The projected changes include much-discussed warming trends as well as important changes in precipitation, extreme weather, and other climatic conditions, all of which may be expected to affect Sierra Nevada rivers, watersheds, landscapes, and ecosystems.

Simulated temperatures in climate-model grid cells over Northern California began to warm notably by about the 1970s in response to acceleration in the rate of greenhouse-gas buildup in the atmosphere then and are projected to warm by about +3 °C during the 21st century (*fig. 1a*). The temperatures shown were simulated by the coupled global atmosphere-ocean-ice-land Parallel Climate Model (PCM) in response to historical and projected "business-as-usual" (BAU) future concentrations of greenhouse gases and sulfate aerosols in the atmosphere. The model, part of the Department of Energy-funded Accelerated Climate Prediction Initiative Pilot Study, yields global-warming projections that are near the cooler end of the spectrum of projections made by modern climate models and thus represent changes that are relatively minor. Projections of precipitation change over Northern California are small in this model, amounting in the simulation shown (*fig. 1b*) to no more than about a 10 percent increase. Notably, though, other projections by the same model with only slightly different initial conditions yield small decreases rather than increases. Thus we interpret the precipitation change in the projection examined here as "small," without placing much confidence in the direction of the change. Even more generally, there is essentially no consensus among current climate models as to how precipitation might change over California in response to global warming. In light of these precipitation-change uncertainties, we focus below on the watershed responses that depend least upon the eventual precipitation changes.

River-basin responses to climate variations and trends in the Sierra Nevada have been analyzed by simulating streamflow, snowpack, soil moisture, and water-balance responses to the daily climate variations spanning a 200-year period from the PCM's historical and 21st century BAU simulations. Watershed responses were simulated with spatially detailed,

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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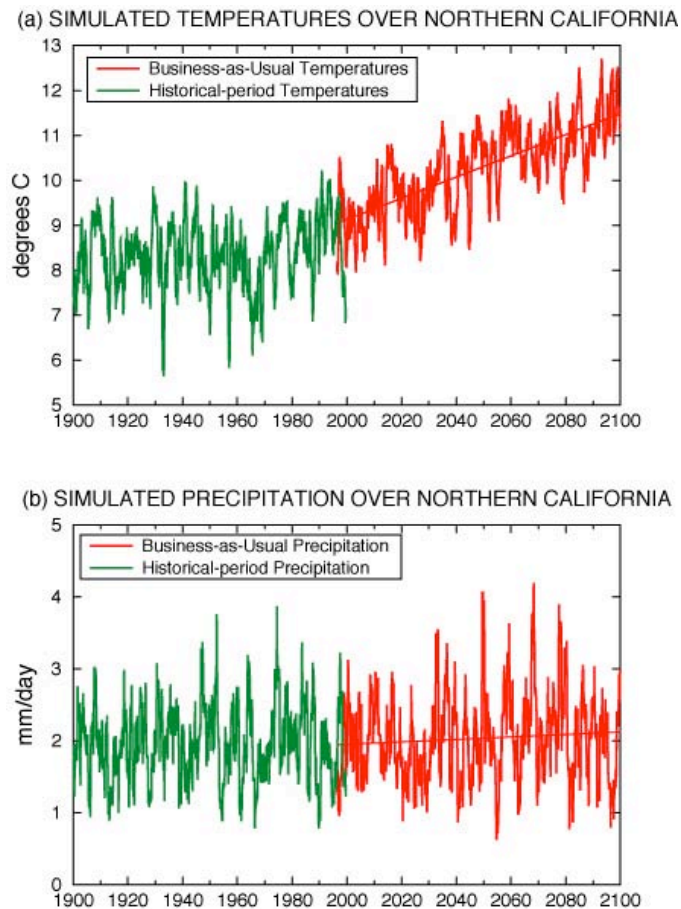


Figure 1— Simulated annual mean temperatures (a) and precipitation (b) in Parallel-Climate Model grid cells over Northern California, from 1900 to 2100, where the historical simulation is forced with observed historical radiative forcings and the business-as-usual future simulation is forced with greenhouse-gas increases that are extensions of historical growth rates. Straight lines are linear-regression fits.

physically based watershed models of several Sierra Nevada river basins but are discussed here in terms of results from a model of the Merced River above Happy Isles Bridge at the head of Yosemite Valley. The historical simulations yielded stationary climate and hydrologic variations until the 1970s when temperatures begin to warm noticeably. This warming resulted in a greater fraction of Sierra Nevada precipitation falling as rain rather than snow (*fig. 2*), earlier snowmelt (*fig. 3*), and earlier streamflow peaks. The projected future climate variations continue those trends through the 21st century with a hastening of snowmelt and streamflow within the seasonal cycle by almost a month. By the end of the century, 30 percent less water arrives in important reservoirs during the critical April–July snowmelt-runoff season (*fig. 4*). These reductions in snowpack are projected to occur in response to the warming climate under most climate scenarios unless substantially more (order of two times or more) winter precipitation falls; even in that case, although enough additional snowpack could form to yield a healthy spring snowmelt, the snow-covered areas still would be substantially reduced. In any event, the earlier runoff comes partly in the form of increased winter floods so that the changes would pose challenges to reservoir managers and could result in significant geomorphic and ecologic responses along Sierra Nevada rivers. With snowmelt and runoff occurring earlier in the year, soil moisture reservoirs dry

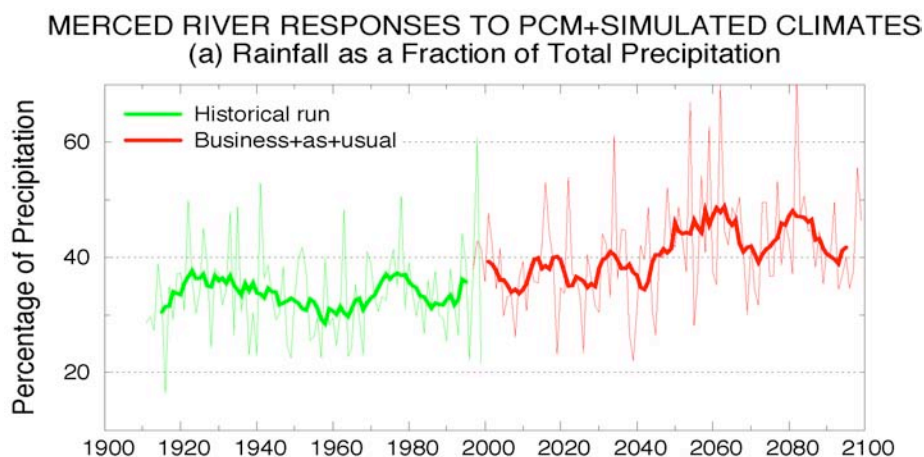


Figure 2— Water-year fractions of total precipitation as rainfall in the Merced River basin in response to PCM-simulated climates. Heavy curves are 9-year moving averages.

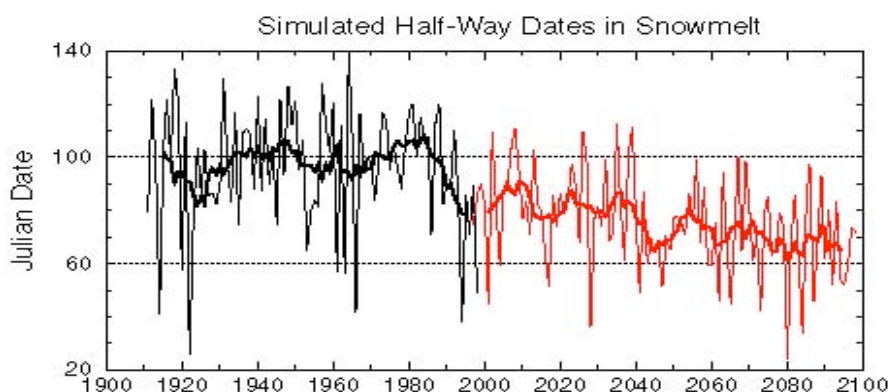


Figure 3— Water-year fractions of total precipitation as water-year centroids of daily snowmelt rates in the Merced River basin in response to PCM-simulated climates. Heavy curves are 9-year moving averages.

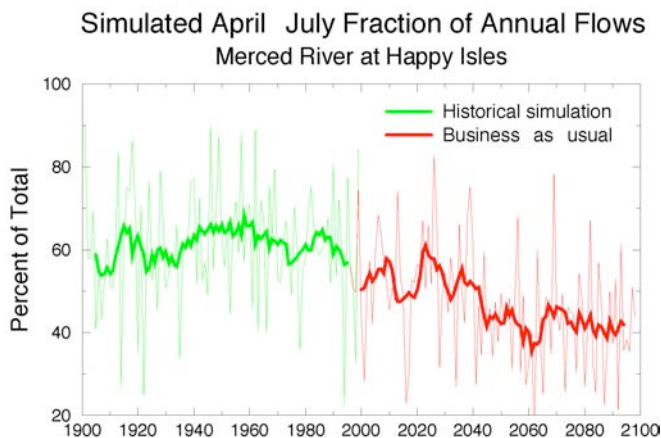


Figure 4— Fractions of each water year's simulated total streamflow that occur during April–July in the Merced River at Happy Isles in response to PCM-simulated climates. Heavy curves are 9-yr moving averages.

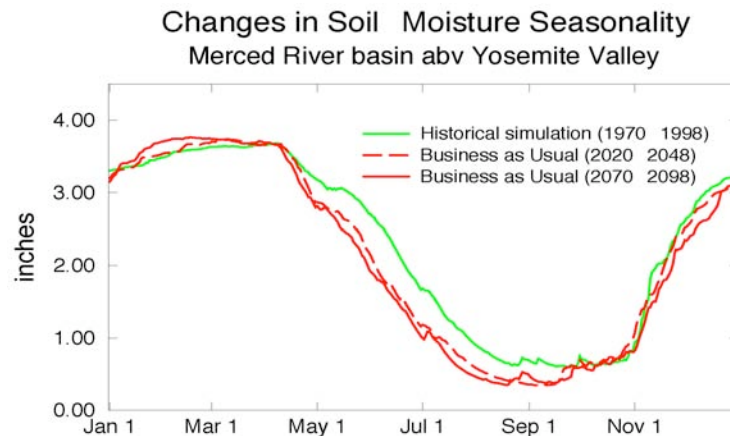


Figure 5— Simulated seasonal cycles of basin-average soil-moisture contents in Merced River above Happy Isles in response to PCM-simulated climates during selected interdecadal intervals.

out earlier and by summer are more severely depleted (*fig. 5*). By about 2030, the projected hydrologic simulations of other river basins, hydrologic simulations at the scale of the entire Sierra Nevada, and projections of wildfire-start statistics under the resulting hydroclimatic conditions indicate that the results from the simulations of the Merced River basin considered here are representative of the kinds of hydrologic changes that will be widespread in the range. Thus, it appears likely that climate change would affect hazards and ecosystems significantly and throughout the range. The riverine, ecological, fire, and geomorphic consequences are far from understood but are likely to be of considerable management concern. Considerations for resource managers confronting 21st-century landscape issues in the Sierra Nevada include:

- Climate projections by current climate models are fairly unanimous in calling for warming of at least a few degrees over the Sierra Nevada, and this warming may be increased over the range by orographic effects (that is, effects resulting from the presence of mountains).
- Projections of future precipitation are much less consistent so that we do not yet know if the Sierra Nevada will be wetter or drier.
- Even the modest climate changes projected by the PCM (with a conservative value for warming and small precipitation changes) would probably be enough to change the rivers, landscape, and ecology of the Sierra Nevada, yielding: (1) substantial changes in extreme temperature episodes, for example, fewer frosts and more heat waves; (2) substantial reductions in spring snowpack (unless large increases in precipitation are experienced), earlier snowmelt, and more runoff in winter with less in spring and summer; (3) more winter flooding; and (4) drier summer soils (and vegetation) with more opportunities for wildfire.
- The projections used here suggest that global warming at the accelerated pace that will characterize the 21st century is already about 30 years old; thus, changes in the recent past must also be considered in light of global change. For example, changes in streamflow timing are already known to be widespread across most of the Western states.
- The consequences of climate change are likely to be significant, but in light of current uncertainties about their nature, policies that promote flexibility and resilience seem most prudent.

Response of Sierra Nevada Vegetation and Fire Regimes to Past Climate Changes¹

R. Scott Anderson²

The study of changing vegetation patterns within forested communities of the Sierra Nevada has had a long history, initiated by the great naturalist John Muir. More recently, paleoecologists, who study ecosystems of the past, have analyzed fossil plant remains recovered from lake and meadow sediments to understand the regional biogeography and disturbance history of Sierra Nevadan forests. This research on paleo-historical vegetation associations has increasingly attracted the attention of land managers and others for several reasons, including the potential that future climate changes will cause rapid and substantial changes in vegetation composition, fire occurrence, and insect infestation.

Plant communities are continuously stressed by environmental change, such as natural disturbance, climatic perturbations, and human activities, and exhibit variation in structure and species composition on several time scales. Some agents of change such as humans, fire, and insects operate over time cycles of years to decades. Records of their effects are often gleaned from historical accounts, matching photographs and individual trees. At the other end of the time scale are extremely long-term changes—those caused by movements of the Earth's crust, such as the rise of the Sierra Nevada itself, occurring on the order of millions of years. But changes in vegetation linked to climatic perturbations occur on the order of hundreds to thousands of years. Evidence accumulating over the past several decades makes it clear that on this intermediate timescale, climatic change is the primary driver for major vegetation changes. Although it is easier to refer to forests as assemblages of plant species, each species actually responds individually to varying climatic parameters. When viewed over intermediate timescales, then, vegetation associations appear to be merely temporary aggregations of species.

Former forested ecosystems can be reconstructed by using a combination of paleoecological “tools.” The most useful are pollen and plant macrofossil remains from the species that formerly grew in a particular area. Analysis of these plant remains allows identification of the important forest species at different times in the past. Analysis of charcoal particles allows reconstruction of former forest fire regimes. Plant remains and charcoal particles are concentrated from lakes, meadows, and wetlands by extracting sediment cores from those deposits. Several types of sediment corers have been used in the Sierra Nevada, including stationary piston corers, such as the Livingstone corer.

The Sierra Nevada is, arguably, the most studied mountain range of its size in the Western Hemisphere. Presently, information on former vegetation has been gathered at more than 70 sites (Anderson and Smith 1997). More sites are on the western side of the crest than on the east, owing to its gentler topography and larger number of sedimentary basins.

The balance of this paper concentrates on three time periods of substantial past vegetation change for the Sierra Nevada. The history of forest disturbance, primarily fire, during these

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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time periods is also briefly described. The time periods include (1) the late glacial, with anomalous plant assemblages compared to today; (2) the early Holocene, which was dominated by pines; and (3) the middle to late Holocene which saw the development of the modern forests of today.

The late glacial time period, defined here as occurring from approximately 18,000 to 11,000 radiocarbon years ago was a time of active redistribution of plant species in nearly all regions of the world. The great ice sheets of the Northern Hemisphere reached their maximum extent and had begun to melt. Their influence on climatic patterns, along with ongoing changes in Earth's orbital parameters, caused climatic conditions that were very different than those of today. One presumably representative location in the Sierra Nevada that has provided a rich record of past vegetation for this time period is Swamp Lake in Yosemite National Park (Smith and Anderson 1992). Although today the site is surrounded by species characteristic of the lower montane forests (conifers and hardwoods), during the late glacial period, the forest around the lake contained a wider variety of trees characteristic of today's montane, upper montane, and subalpine forests. Of particular interest is the former occurrence around the lake of mountain hemlock (*Tsuga mertensiana*) and incense-cedar (*Calocedrus decurrens*), which rarely occur together today and occupy very different climate space at present (Thompson and others 2000).

In general, the elevational ranges of most forest species in the late glacial period were depressed by about 1000 meters in the Sierra Nevada relative to today (Cole 1983). On the west side of the crest, subalpine conifers probably grew with sagebrush in forest openings at approximately 2000-m elevation, while xerophytic and mesic conifers grew at approximately 1000-m elevation. Giant sequoia may have grown along watercourses at lower elevations. Modern Great Basin species grew in the San Joaquin Valley, suggesting that the biogeographic boundary between the Sierra Nevada and the Great Basin (today found at the Sierra Nevada crest) occurred at least 100 km further west (Davis 1999).

By the Early Holocene, defined as approximately 9,000 to 7,000 radiocarbon years ago, much of the Sierra Nevada ice cap had melted, and most common tree species in the Sierra Nevada had migrated to higher elevations than their ranges during the glacial period. Higher-elevation forests during this time period were primarily dominated by different pine species, with montane chaparral shrubs in forest openings.

A particularly good record exists for lodgepole pine (*Pinus contorta* var. *murrayana*) (Anderson 1996). The species was widely established within its modern elevational range between 9,000 and 10,500 years ago. During the early Holocene, lodgepole pine remained a key component of montane forest assemblages below its present range. The species disappeared from most lower-elevation sites between 6,750 and 9,000 years ago. The Sierra Nevada forests were more open than today, as suggested by a greater occurrence of sagebrush (*Artemisia*) and many montane chaparral shrubs, such as bush chinquapin (*Chrysolepis sempervirens*) (Anderson and Smith 1994). Giant sequoia moved upslope and may have even grown above its present elevational range (Davis and Moratto 1988). The lower montane forest may have been partly dominated by oaks (*Quercus*) (Anderson and Smith 1994).

The record of vegetation for the middle to late Holocene, from approximately 6,000 radiocarbon years to the present reveals differentiation and development of the vegetation associations we see today. Four conifer species have provided us with an excellent record, demonstrating vegetation and climate change during this time. Pollen of white and red fir (*Abies concolor* and *A. magnifica*) and mountain hemlock suggests that during the early Holocene these species were only minor components of the Sierra Nevada forests. However, by approximately 6,000 years ago, each of these species increased in abundance, perhaps largely in response to changing climate and higher soil moisture levels (Anderson and Smith 1994). Similarly, after approximately 4,500 radiocarbon years ago, the range of giant sequoia (*Sequoiadendron giganteum*) expanded (Anderson 1994). The abundance of

montane chaparral shrubs declined in Sierra Nevada conifer forests as the forest canopy closed (Anderson 1990).

What would account for the gradual but important changes that occurred in Sierra Nevada forests during this period? Because each of the tree species that increased during the late Holocene depends upon readily available soil moisture during the summer growing season, it has been suggested elsewhere (Anderson 1990) that either a reduction in the length of the summer dry season, an increase in precipitation during the winter months (as snow, lasting longer into the spring), a reduction in temperature causing reduced evaporation, or some combination of these processes would have favored the above-mentioned conifers.

Several studies have provided evidence that explains the changes in biota seen in the fossil record for the past 18,000 years. First, the occurrence of massive North American ice sheets influenced the broadscale climate patterns in several ways. The Laurentide Ice Sheet, occurring up to 3 km thick in some places, diverted the Jet Stream to a more southerly position, bringing colder and mostly wetter conditions to the Sierra Nevada and the Southwest compared to today (COHMAP Members 1988, Thompson and others 1993). As the ice sheets melted, their influence diminished, and the average position of the Jet Stream migrated northward to its present position. Second, the Earth's orbital parameters have varied singly and in conjunction over time, changing the seasonal distribution of solar radiation for the Northern Hemisphere and affecting temperatures. Compared to today, summer insolation was 8 percent greater and winter insolation 8 percent lower during the transition from the glacial to early Holocene periods (Kutzbach and Guetter 1986). The net result was warmer summers and cooler winters than today, a situation that allowed a variety of conifers to grow in proximity to each other during that time. Later in the early Holocene, high levels of summer insolation led to warmer conditions during summer, causing progressive drying of soils and perhaps an intensification of Mediterranean conditions. During the middle and late Holocene, however, the difference between summer and winter insolation lessened, leading to a cooling during the growing season, a potential increase in winter precipitation and a reduction in evaporation. Groundwater tables rose (Anderson and Smith 1994), and these conditions favored species that require high levels of soil moisture.

What is the relationship between vegetation and climate change and the long-term history of forest fire in the Sierra Nevada? Recent work by Brunelle and Anderson (2003) at a site in the upper montane zone of Yosemite National Park shows highly variable occurrences of large-magnitude fires through time. The greatest fire activity occurred in the early Holocene, when climate was drier than today. However, another period of high fire activity occurred during the Medieval Warm Period approximately 850 to 575 calendar years ago in the Sierra Nevada (Graumlich 1993). Similarly, studies by Anderson and Smith (1997) for the mixed conifer forest showed very widespread fires in the Sierra Nevada about 700 calendar years ago, which probably corresponds to widespread fire at the end of the 13th century as deduced by tree-ring fire scar analysis (Swetnam 1993).

If, as we assume, fire occurrence depends on effective moisture and can be used as a proxy for climate, then the severe droughts that occurred during the Medieval Warm Interval are small when compared with those during the warmer early Holocene. If the atmospheric warming trends documented for the 20th century continue into the 21st century as projected, the record of vegetation and fire from these earlier time periods becomes an important record that informs us about the future of fire and vegetation change in the Sierra Nevada.

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Climate Change in Wildland Management: Taking the Long View¹

Scott Stine²

Climate constitutes one of the great determinants of all natural environments. As such, it goes a long way in accounting for the distributions of the plant and animal species that inhabit the Sierra Nevada today. Most land managers are well aware that climate has changed over geologic time—indeed, one needs to look no farther than the polished rock of high Sierra Nevadan canyons to see evidence that a climate conducive to large-scale glaciations existed in the past. And most land managers accept that these past climate changes must have brought about shifts in distributions of the biota. But many still tend to view modern climate (defined, for present purposes, as that of the past 120 years) as being both long established and “normal.” In this view, climates of the pre-modern period are treated as long gone (and thus largely irrelevant to land management) and as mere deviations from “normality.”

Two primary factors contribute to this tendency. First, many scientists lack an appreciation for time scales that exceed a few human generations in length, considering 1,000 years ago as the distant past. Second, many assume that the pre-instrumental past cannot be well known or understood and that the inferences drawn from proxy records, such as pollen records in lake sediment cores, therefore constitute an insufficient basis for high-stakes management decisions.

Proxy records of Sierra Nevadan climate spanning the past millennium suggest that these views are flawed in ways that have consequences for management and mismanagement of the land. Specifically, proxy records indicate that

- the Sierra Nevada's modern climate is, by the standards of the past millennium (or the past 2, 3, or 4 millennia, for that matter), abnormally wet and warm;
- wide, multi-decade-scale fluctuations in moisture availability, unlike any seen in modern time, have characterized the Sierra Nevada over the past millennium; and
- many such swings—naturally or artificially induced, or both—must be expected to recur within a time period relevant to current land management practices and decisions.

This paper summarizes some of the multi-decade to century-scale records, examining first the Sierra Nevadan climate of late Medieval time (from roughly A.D. 900 to 1350) and then the climate of the Little Ice Age (from roughly A.D. 1350 to 1880). The final section considers some of the management implications of the records.

The Sierra Nevada Droughts of Medieval Time

Radiocarbon-dated evidence from an increasing number of localities in and adjacent to the Sierra Nevada indicate that on two occasions—the first encompassing the roughly 200 years

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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before about 1100 A.D. and the second spanning the century-and-a-half before approximately 1350 A.D.—the Sierra Nevada was, by modern standards, remarkably dry. Hydrographically closed lakes of the western Great Basin, which receive the bulk of their inflow from Sierra Nevadan runoff, fell to levels far below those that would exist today under natural conditions. Hydrographically open lakes of the Sierra Nevada's middle and high elevations fell to and were maintained at levels as much as 70 feet below their spillways; Sierra Nevadan rivers were greatly diminished in size and presently existing marshes desiccated.

Many types of evidence reveal these hydrologic and hydrographic responses to Sierra Nevadan drought. Most conspicuous, perhaps, are the stumps of shrubs and trees, rooted in growth positions, at sites that are today too wet (in many places, too aquatic) to support woody vegetation. Thus, the stumps of trees and shrubs that grew during the earliest of the two droughts (hereafter the Generation 1, or “G-1” stumps) and those that grew during the second drought (hereafter the “G-2” stumps) can today be found rooted on the artificially exposed shorelands of Mono Lake at sites that would, given natural conditions, be under more than 50 feet of water. Tree stumps of G-1 can be seen rooted on the artificially exposed Walker Lake shorelands at elevations that would today, under natural conditions, be covered with as much as 140 feet of water. And shrub stumps of G-1 are found rooted near the lowest elevations on the (now artificially exposed) Owens Playa, indicating that Owens Lake must have desiccated, or nearly desiccated, during G-1 time.

The upright trunks of trees protruding from the depths of Sierra Nevadan lakes tell a similar story. At Tenaya Lake, both G-1 and G-2 trunks stand in as much as 70 feet of water; at Fallen Leaf Lake G-1 trunks are rooted in tens of feet of water; so too are G-2 trunks at Independence Lake. Because all three of these water bodies have stable spillpoints, drought-induced drawdown is the most likely explanation for the presence of the relict trees. Such drawdown would also best explain the presence of G-1 conifer stumps rooted in what is today a virtually conifer-free marshland—Osgood Swamp between Echo Summit and Lake Tahoe.

Rooted on the bed of the West Walker River, between its junction with the Little Walker and the lower end of Chris Flat, are more than 100 stumps and trunks of trees. The 30 individuals that have thus far been radiometrically assayed all date from one or the other of the two Medieval droughts. This reach of the river runs through the very narrow West Walker River Canyon—a defile in which the stream has little room to move laterally over time. Today's river is far too large to permit trees to grow on the lowest areas of the canyon floor. The presence of the rooted paleo-trunks thus seems to indicate that the stream was considerably smaller than those in modern times during two periods of the Medieval past—the same two periods that would be inferred from the stump- and trunk-studded water bodies noted above.

Evidence for these Sierra Nevadan droughts is not limited to derelict shrubs and trees. Both sedimentary and geomorphic records confirm that lakes were drawn to abnormally low levels during the Middle Ages (Stine 1990a, 1994b). Moreover, tree-ring records highlight the severity of the Medieval droughts. Graumlich's (1993) dendroclimatic reconstructions from foxtail pines (*P. balfouriana*) and western junipers (*Juniperus occidentalis*) of the southern Sierra Nevada indicate that the two driest 50-year intervals in the past 1,000 years (from A.D. 1250 to 1299, and from A.D. 1315 to 1364) occurred during the second of the two Medieval droughts and that the third-driest 50-year interval of her records (A.D. 1021–1070) occurred during the first of the two droughts. LaMarche's (1974) work on the bristlecone pines of the nearby White Mountains likewise identifies these two periods as anomalously dry. Like Graumlich, LaMarche characterizes the first of the droughts as being cool relative to the modern climate and the second as being warmer than modern (though note that his “modern” did not include the very warm 1980s and 1990s).

The Little Ice Age in the Sierra Nevada

The term “Little Ice Age,” now applied in many mountain regions of the world (Grove 1988), was conceived in the Sierra Nevada. As originally used by Matthes (1939), it referred to the past 4,000 years, during which, he believed, Sierra Nevadan glaciers advanced because of a general cooling trend that followed a putative mid-Holocene thermal maximum. The more recent convention (Porter and Denton, 1967) is to lump the world's mountain glaciations of the past 4,000 (or 5,000, 6,000, or 7,000) years into a “Neoglacial Period,” with “the Little Ice Age” being restricted to the few centuries preceding the mid- to late 1800s. The phrase Little Ice Age is used here in this more limited sense.

That small glaciers exist high in cirques of the Sierra Nevada was recognized early on by Muir (1875) and Russell (1885, 1889). Matthes (1939) established that the moraines of these glaciers overlie deposits of talus (as opposed to bedrock), thus demonstrating that the birth of the small ice bodies had been preceded by a thorough deglaciation. In recognition of that and other contributions, Birman (1964) named the ice advance the “Matthes glaciation”—a colloquialism for Little Ice Age glacier activity in the Sierra Nevada.

Dating this activity has been at best imprecise. Wood (1977) observed that, unlike the surrounding lands, the Matthes-age moraines lack a cover of volcanic ash from the Mono-Inyo Craters and Domes—the volcanic chain that rises just east of the central Sierra Nevada. He reasoned that the Matthes glaciation must therefore be younger than the most recent west-blowing eruption of that chain—an event that he (1977; corrected by Wood and Brooks [1979]), and Sieh and Bursick (1986) dated to about 1,300 years ago. On the basis of a number of nonglacial proxy indicators of past climate, Konrad and Clark (1998) argued convincingly that the Matthes advance commenced sometime within the past 700 years. Lichenometric dates on stabilized (thus, post-advance) Matthes-age moraines indicate that the glaciers likely withdrew from their maximum positions sometime within the past 200 years (Konrad and Clark 1998). Photos taken in the early 1880s by Russell (1885) show that the glacier fronts had receded only a few hundred feet or less, at that time. Since then (thus, throughout “modern time” as defined here) wastage of the ice has been proceeding at an accelerating pace (for some of the documentation of this recession, see Matthes 1939, 1942a, 1942b; Stine 1996; and photo comparison by Stine [Bradley 2000]).

Given that modern climate is not conducive to the maintenance of glaciers in the Sierra Nevada, the conditions that caused them to form and advance during Matthes’ time must have been, by comparison, wetter (that is, snowier) or less ablative (the latter likely due to relatively low melt-season temperatures), or both. Some investigators have stressed wetness as the overriding driver of glaciation, but this overlooks important lessons from other proxy records. Thus, the hydrographically closed lakes of the eastern Sierra Nevada, which fluctuated substantially during Matthes’ time (Stine 1990a, 1990b, 1994a, 1994b), spent centuries of that interval dropping to levels that, by modern-natural standards, must be considered low (though not as low as during the Medieval time). Indeed, during the first half of the 19th century, when the Sierra Nevadan glaciers were near their maximum Neoglacial extent, Mono, Owens, and Pyramid lakes were lower than their lowest natural level of modern time, and much lower than they would be today but for diversions of their influent streams (Stine 1996). This coincidence of large glacier size and low lake levels is best explained by a combination of (by modern standards) relatively cold, relatively dry conditions. However, climate was not consistently dry throughout Matthes’ time—indeed, on two occasions during that interval, the surface of Mono Lake reached elevations higher (in one case, more than 25 feet higher) than any level attained in the modern period. Rather, precipitation in the Sierra Nevada was well below the modern average for several extended intervals of the past 500 years.

The tree-ring record confirms the lake-level evidence. Graumlich (1993), for example, found that temperatures remained below the modern mean (defined as A.D. 1928–1988) for nearly the entire period from A.D. 1450 to 1850. Although some intervals of this period were wet (for

example, the late 15th and early 16th centuries and the early to mid-18th century), others were remarkably dry (including A.D. 1834–1883, which was the fifth-driest 50-year period of the past millennium). Other evidence for a cold, episodically dry Little Ice Age in the Sierra Nevada is summarized by Stine (1996).

Implications for Management of Wildlands

The proxy records discussed above highlight the peculiarity of the warm, wet climate that has characterized the Sierra Nevada during the past 120 years. Equally importantly, they demonstrate that substantial fluctuations in relative wetness, on scales from multiple decades to centuries, have occurred on numerous occasions over the past millennium. For several reasons, these findings point to the need for resource managers to take a multi-decade- to centuries-scale view of wildlands—one that bases long-term planning on an understanding of the long-term past and treats the landscape as a perpetually changing entity, rather than as one that might change someday.

First, shifts in Sierra Nevadan climate will occur in the future, just as they have in the past under natural conditions; however, unlike the shifts of our natural past, those of the future will be (and likely have already been) also influenced by anthropogenic forcing.

Second, given the recency of the latest shift in climate (it commenced around A.D. 1880), it is likely that much of the Sierra Nevada's vegetation has not yet come into distributional equilibrium with the new warmth and wetness. In fact, if the frequency and magnitude of the past millennium's climatic swings are any indication, it seems probable that distributional equilibrium in the Sierra Nevada is never reached or even closely approached. Thus, in a long-term view of the Sierra Nevada that acknowledges climate change, it is not static distributions of plants and animals that must be managed but rather distributions that are constantly in flux and transition, moving up, down, or laterally along complex and variable temperature and moisture gradients.

Third, because of the above-noted flux and transition, long-term management schemes must not constrain wildlands within “hard boundaries” (those along which wildlands are bounded by thoroughly altered landscapes), because such boundaries restrict the ability of species to shift their distributions in response to climate change. Thus, “soft boundaries” and corridors must be part of any realistic long-term management plan for wildlands.

Fourth, while it seems likely that climate will continue to warm in the coming decades, it is impossible to predict whether the next shift in wetness will be toward drier, or even wetter, conditions. But this uncertainty does not preclude the formation of sound management plans. The goal of such a plan cannot be to accommodate just one type of climate change; rather, the goal must be to accommodate change in general, no matter what its direction or severity.

Finally, the paleodroughts of the past millennium undoubtedly inflicted much stress on the high-moisture-dependent biota of the Sierra Nevada and surrounding regions. Aquatic, amphibious, and riparian species probably suffered the most, as lakes and streams shrank, marshes and wet meadows desiccated, and spring sites diminished in size and number. Clearly, the indigenous species that we see today in the Sierra Nevada survived these past droughts and ultimately may have been genetically invigorated by them. But could these same plants and animals, now so stressed and so constricted and fragmented in distribution, survive epic drought again? Only if land managers take the long view, conserving during what may currently be the best of times but preparing for the worst of times ahead.

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Mountains, Fire, Fire Suppression, and the Carbon Cycle in the Western United States¹

David Schimel²

Most mountain regions in the western United States are covered by forests, which are for the most part recovering from historical harvesting and have been experiencing active fire suppression over approximately the past 100 years (Tilman and others 2000). Whereas many western landscapes are currently perceived as pristine natural systems, the Rockies, Sierra Nevada, and Cascades were essentially deforested between 1860 and the end of the 20th century, during the era of mining, railroad building, and settlement. Currently, the fraction of old-growth forest remaining in the West is variously estimated at 5 to 15 percent; however, these numbers must be interpreted with caution. In some regions, high-elevation forests of limited current economic value are excluded from the analysis. In other cases, young, naturally disturbed stands are included in the disturbed category, even in forests with normally short disturbance cycles. Forest harvest has generally occurred preferentially in areas of relatively high productivity and standing biomass, so much of the regrowth is occurring in regions with relatively high carbon accumulation potential. Also, in some areas of active fire suppression adjacent to urban corridors, particularly at lower elevations with relatively productive conditions of soil, moisture and light, forests are becoming denser. Although the proportion of total forest land is probably higher than that quoted (taking into account regional variation, high-elevation forests), it remains that a very considerable fraction of the more productive forest lands have experienced some degree of historical disturbance.

Fire exclusion tends to increase carbon accumulation in soils and dead plant material. Since the initial harvesting of Western forests, fire suppression has been actively and for the most part successfully implemented. The average annual area burned in the Sierra Nevada in the 1990s was approximately 15 percent of the area burned annually in the pre-settlement period. Fire suppression does not favor healthy long-term carbon storage in large mature trees, but it does create ecosystems with large quantities of carbon stored in litter, dead wood, and small trees. Thus, the carbon budget of the western United States and the health of Western forests are best understood in terms of:

- climate, with favorable water balance permitting productivity at higher elevations;
- historical land use, with past forest disturbance setting the stage for widespread forest regrowth, especially in the more productive areas; and
- current land use, with fire suppression favoring high carbon storage but creating at-risk ecosystems.

Wildfire suppression in regrowing stands is thought to have a significant effect on carbon sequestration in western U.S. forests. Pacala and others (2001) estimate significant sinks as a

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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result of fire suppression in Western pine forests. Schimel and others (2000) also showed significant sinks in mountain biomes. The fire regime before the European settlement of the western United States was dominated by frequent low-intensity fires and sporadic stand-replacing fires (Pyne 1982). These fires occurred mainly in dry seasons because of lightning strikes and land management practices of the indigenous peoples. As a result of ground fires, forests were broadly maintained in healthy, but relatively low-carbon states (Tilman and others 2000). Current fire-suppression efforts have reduced the annual area burned to 10 to 15 percent of pre-settlement levels (Pyne 1982, Tilman and others 2000). Incorporation of fire-suppression activity into predictive models suggests massive consequences for carbon storage in Western landscapes (Houghton and others 1999, Pacala and others 2000). In the most comprehensive effort to date to reconstruct national carbon budgets, Pacala and others (2000) concluded that about 25 percent of annual U.S. carbon uptake (0.12 gigatons of carbon per year) could be due to fire suppression in Western coniferous forests.

Fire suppression is not the only factor responsible for carbon uptake in mountain environments. In the United States and Europe, as recreational, watershed, and other nonconsumptive land uses have increased in the mountains, forest harvest and pasture maintenance practices have decreased. In Europe, the abandonment of high pastures, formerly used for livestock husbandry, is allowing significant expansion of high- and mid-elevation forests, creating significant carbon sinks. In temperate Asia, where large populations impose a high demand for agricultural land, remaining forests are largely in mountainous areas. The largest global sink of carbon is found in the mid-latitudes of the Northern Hemisphere, and much of this sink is located in mountainous or hilly terrain (*fig. 1*).

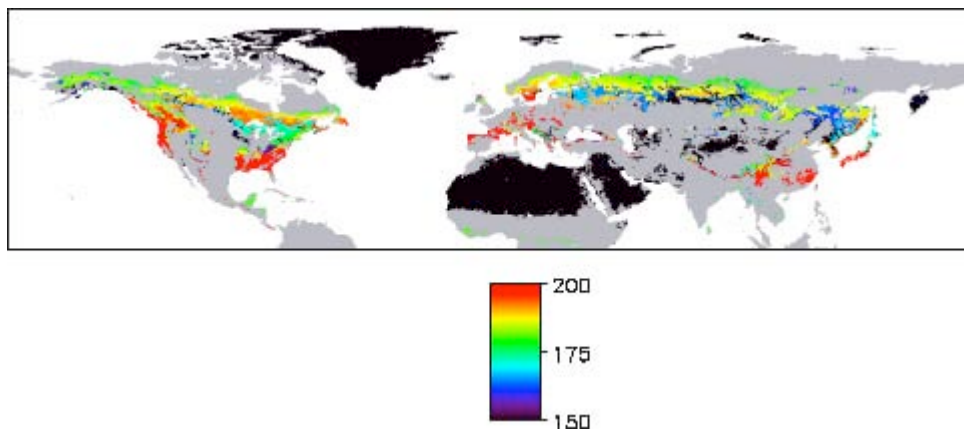


Figure 1— Regions of high carbon storage for the Northern Hemisphere, indicating that in Europe, North America, and China most of the mid-latitude “hot spots” are in mountain ranges. Exceptions to this are found in the boreal (which contributed relatively little globally to carbon uptake) and in parts of the southeastern United States.

The carbon budget of the United States has been the focus of recent scientific debate (Fan and others 1999, Pacala and others 2001). Most researchers suggest that U.S. ecosystems take up a large amount of carbon (Houghton and others 1999, Pacala and others 2001, Schimel and others 2000). Substantial research is being planned to quantify carbon uptake and understand the processes and mechanisms (Wofsy and Harris 2002). The strategy relies on atmospheric measurements from ground-based micrometeorological techniques, concentration networks and airborne sampling to quantify carbon fluxes, complemented by remote sensing, process studies, and operational inventories (Wofsy and Harris 2002). However, because a significant fraction of U.S. carbon uptake is in complex and mountainous terrain, existing atmospheric measurement techniques cannot be used directly. To achieve the goals of the North American Carbon Program

in mountain landscapes, meteorological, hydrological, and biogeochemical approaches must be tightly integrated.

Quantifying carbon sequestration in the mountains will require extensive model-data integration: using measurements to calibrate and constrain models and using models to interpolate observations. Effective measurement approaches will allow the development of accurately calibrated models and algorithms for extrapolating carbon fluxes over complex terrain. As we develop confidence in simulated carbon budgets of mountain ecosystems, we will be able to explore issues such as the effects of climate variability and change, fire management alternatives, pest outbreaks, and timber harvesting on carbon sequestration.

Mountain environments have rarely been addressed specifically in studies of terrestrial carbon dynamics. The International Geosphere Biosphere Program report on mountain ecosystems makes no mention of a key role for mountainous regions in the Earth's carbon cycle (Becker and Bugmann 2001). Although it was first suggested that the U.S. sink was localized in eastern U.S. forests (Fan and others 1998), more recent studies that partition the U.S. sink into specific regions suggest that a significant fraction is in the western United States (Pacala and others 2001, Schimel and others 2000).

In the semi-arid western United States, a large fraction of the carbon uptake occurs in complex terrain and montane environments. Most low-elevation areas are dry and dominated by low-carbon density ecosystems, and historical harvest and fire management regimes favor net carbon accumulation in today's Western mountains. Imperatives to preserve forests for watershed management, natural area preservation, and hillslope stabilization actually make mountainous regions a good prospect for long-term carbon sequestration, emphasizing the need for a solid scientific understanding of mountain biogeochemistry. However, our ability to measure carbon exchange is currently limited in the mountains.

Modeling and Remote Sensing of Mountain Biogeochemistry

Using Biome-BGC and Century biogeochemistry models, we explored potential carbon uptake patterns in the United States (*fig. 2*). The results are drawn from the Vegetation and Ecosystem Modeling and Analysis Project (VEMAP) (Schimel and others 2000). These model experiments were driven by historical climate, reconstructed from 1895 to 1993 using more than 8000 long- and short-term weather stations, as well as about 700 high-elevation stations from the SNOTEL network. Short-term stations were linked geostatistically to long-term stations to create a complete pseudo-network of 98-year-long records, which were then gridded to obtain a spatially distributed climate record. In the gridding procedure, temperature and precipitation were statistically corrected for elevation, aspect, and mountain valley inversions. The ecosystem models were “spun up” and then run from 1895 to 1993. The models also included the effect of increasing atmospheric carbon dioxide. Vegetation definitions were fixed and based on reconstructed actual vegetation. Agriculture was treated explicitly, using USDA county-level information (Schimel and others 2000) and 18 crop-management combinations simulated using Century. Century agricultural results were blended on an area coverage basis into both the Century and Biome BGC results. The VEMAP results have been independently compared to observations for validation and agree reasonably well with data.

Our results indicate that 70 percent of the Western U.S. carbon sink occurs at elevations above 750 meters (*fig. 2*), an elevation range dominated by hilly or mountainous topography (50 to 85 percent complex terrain: *fig. 2*). This comprises 20 to 40 percent of total uptake for the lower 48 states. The pattern is striking in the semi-arid western United States, in which most low-elevation ecosystems are dry and dominated by biomes with low carbon density (*fig. 2*); foci of high carbon uptake are found in the Sierra Nevada and Rocky Mountains.

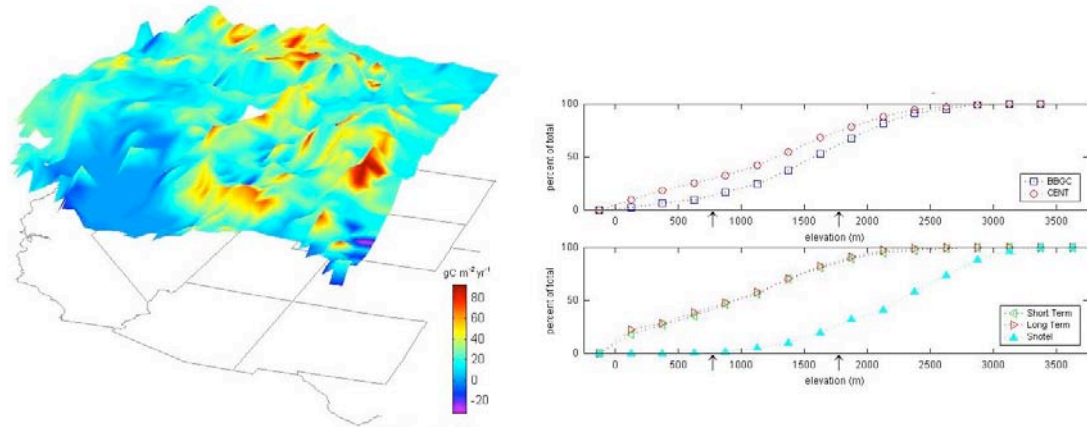


Figure 2— *Left:* Mapped net ecosystem exchange in the western United States, draped over topography (1980–1989 simulations: Schimel and others 2000) is mainly in the mountains (see draped map of modeled Net Ecosystem Exchange [NEE] Biome-BGC). Fluxes in the Pacific Northwest and California are depressed for this decade because of drought. *Right:* Models agree on the basic distribution with elevation (upper line graph) with 75 percent in complex high-elevation topography. Arrows indicate approximately 50 and 85 percent complex terrain at 750- and 1750-m elevations, respectively. A flat high-elevation flux site would represent only 15 percent of the topographic landscape. Meteorological data (lower line graph) used in developing the VEMAP data sets are shown plotted against elevation. Note that data from long-term (10+ years of records) are sparse in the elevations of maximum NEE, and only a small number of SNOWTEL (approximately 700) sites provide high-elevation coverage.

The VEMAP results are probably at least qualitatively correct. These simulations were run without detailed disturbance and management regimes, however. The Western mountains have been intensively managed over the past century. Despite the impression visitors receive of vast wilderness areas, most of the mid- and low-elevation montane forests have been logged or otherwise disturbed, beginning in the pioneer mining era with intensive harvesting during the railroad era. After the early period of forest utilization for construction and fuelwood, industrial harvesting began and continues to this day (Veblen and Lorenz 1991). In the VEMAP simulation illustrated, only a very simple land use and natural disturbance history was applied, consistent with broad-scale statistics but likely wrong in many details. Model results thus do not take into account all of the factors acting to modify spatial patterns of carbon exchange in the western United States.

Remote sensing provides wall-to-wall coverage of ecosystems but does not provide direct estimates of NEE, a measure of the net exchange of carbon between ecosystems and the atmosphere. However, a new operational satellite product provides regular estimates of fractional intercepted photosynthetically active radiation (FPAR) from the MODerate Resolution Imaging Spectroradiometer instrument on NASA's TERRA and AQUA spacecraft. FPAR has been shown to be highly correlated with Gross Primary Productivity (GPP), the gross flux of carbon into the biosphere via photosynthesis and Net Primary Productivity (NPP), the balance of carbon uptake and respiration in vegetation and provides an additional check on our model simulations. The GPP image from MODIS (*fig. 3*) shows a pattern clearly corresponding to the model results shown in *figure 3* and supports the argument that most highly productive and high-carbon-storage potential systems in the western United States are in montane forests and complex topography. High rates of GPP can support significant amounts of carbon storage although much of the annual GPP is respired or burned each year.

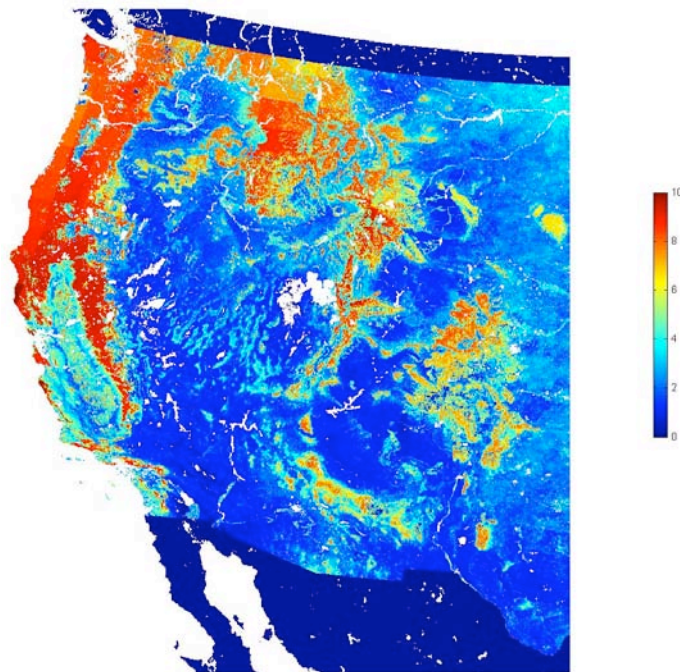


Figure 3— Mapped GPP for the United States, from the MODIS instrument aboard the NASA TERRA satellite for growing season 2001.

Conclusions

Mountains are important contributors to carbon uptake in the Western United States as a result of their unique climate within a semi-arid to arid region and historic and current management emphasis on fire suppression.

Fire management strategies must reflect a balance between hazard management, long-term risk management, and preservation of forest health. Any changes to fire regime or fire management practices are likely to have widespread impacts on forest ecosystem function, affecting carbon storage and tightly linked water resources.

Whereas fire suppression has probably led to a larger carbon sink in the West, much of this sink is present in the fine and coarse fuel categories (dead plant material) or in dense stands of small trees and thus contributes to increased wildfire risk in drought years. Improved carbon management must consider both the amount of carbon stored and the stability of that storage as climate and fire regimes evolve.

Carbon storage in the mountains is largely fed by snowpack moisture, and improved understanding of snowpack and high-elevation water dynamics will be important for forecasting anticipated future ecological conditions in montane forests.

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Fire and Physical Processes



Fire in the Sierra Nevada¹

Carl N. Skinner² and Scott L. Stephens³

Fire has been described as both a major ecological force necessary for long-term functioning of Sierra Nevada ecosystems and as one of the greatest threats to human and natural resources (SNEP 1996a). Fire has shaped the terrestrial ecosystems of the Sierra Nevada for millennia. Before the mid-1800s, fires generally were frequent and mostly of low to moderate intensity, from lower-elevation blue oak woodlands through upper-montane red fir forests (Skinner and Chang 1996). Modern fire regimes are highly altered from their historical character because of the combined effects of fire exclusion, logging, grazing, forest clearing, urbanization, and climate change. These highly altered fire regimes have fostered changing ecosystems, including commonly discussed increases in vegetation density and accumulation of detritus (fuel for fires) that support more high-intensity fires than occurred under historical conditions (Chang 1996; McKelvey and Busse 1996; McKelvey and others 1996; Skinner and Chang 1996).

The changing fire environment, along with increasing urbanization and human use of the Sierra Nevada, have created conditions where human life and property, as well as key ecosystem components, are at increasing risk from the effects of high-intensity wildfires (Biswell 1989, California Spotted Owl Federal Advisory Committee 1997, SNEP 1996a). There is significant Congressional interest in finding a way to reverse the trend toward increasing funding necessary for fire suppression (GAO 1999, Schuster and others 1997). As a result, national emphasis has been placed on increasing fuels treatments, especially thinning of dense stands in the western United States (National Fire Plan <http://www.fireplan.gov/content/home/>). Though information exists on the effectiveness of different fuel treatments in reducing potential fire behavior in the Sierra Nevada (van Wagtendonk 1996; Stephens 1998), considerable debate surrounds nearly any strategy suggested to address forest and fuels conditions.

To help inform the debate on how to manage fire-prone ecosystems in the Sierra Nevada, five leading scientists in this field were asked to address important topics related to fire management. The topics that follow include: (1) fire history and climate interactions, (2) fire and landscape patterns and processes, (3) historic and current smoke potential, (4) evidence of the effectiveness of thinning and prescribed fire for reducing fire behavior, and (5) the National Fire and Fire Surrogates Study. Each presentation was developed independently by its author(s) with knowledge of the topics to be addressed by the other authors and the vision of the overall session theme.

T. W. Swetnam set the stage by reviewing his recently published work (Swetnam and Baisan 2003) that describes broad-scale climatic influences on both long-term and short-term fire regimes of the Sierra Nevada and southwestern United States. Because the article is not

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included in this volume and only a brief synopsis is provided here, readers are urged to peruse the complete article.

Swetnam and Baisan (2003) describe how broad, regional synchrony of fires in extensive networks of tree-ring records is related to global-scale climatic processes, such as the El Niño-Southern Oscillation. Decadal scale variations (10 to 100 years) in historical fire frequency and extent were related to trends in temperature and moisture as reconstructed from tree rings. Generally, the influence of climate on fire regimes is through temperature trends affecting fire frequency and precipitation affecting fire extent (Chang 1999, Swetnam 1993, Swetnam and Baisan 2003). Tree-ring evidence (Swetnam 1993, Swetnam and Baisan 2003) and modeling (Chang 1999) suggest that fire seasons lengthen with increasing temperature, thus increasing the probability of fire in a given year. The same evidence suggests that precipitation is related to the growth of vegetation (fuels) so that periods of higher precipitation lead to more extensive fires in the inevitable, occasional dry years.

As climate has warmed considerably since the mid-1800s (Graumlich 1993, Jacoby and D'Arrigo 1989, Stine 1996, Taylor 1995, Wiles and others 1996) and was accompanied by relatively high precipitation through much of the 20th century (Earle 1993, Graumlich 1987, Graumlich 1993, Hughes and Brown 1992), Stine (1996) speculated that in the absence of fire suppression, fire regimes of the 20th century would likely have been characterized by increased fire frequency and increased fire extent—the opposite of what actually happened. Current projections of warming climates (see papers in the climate session of these proceedings) portend a greater opportunity for fire ignitions due to longer fire seasons. A higher probability of fire starts coupled with the changes in forest fuel conditions that have occurred over the past century lead many to predict that large, generally more intense fires will become more likely than occurred historically (McKelvey and others 1996, SNEP 1996a).

Scientists have only recently begun to understand the long-term influence of fire on the dynamics of landscape patterns in forests historically characterized by frequent fires of mostly low to moderate intensity (Beaty and Taylor 2001, Heyerdahl and others 2001, Taylor and Skinner 1998, Taylor and Skinner 2003). Yet, knowledge of the long-term influence of fire in landscape dynamics is crucial to improving models of the spatial pattern of fuel treatments in efforts to help managers better achieve goals of sustainable habitat conditions while providing for the reduced likelihood of large, high-intensity fires (Skinner and Chang 1996, Taylor and Skinner 1998, Weatherspoon and Skinner 1996). Drawing on the experience of three decades of wildland fire use in Yosemite National Park, van Wagtendonk (these proceedings) furthers this knowledge by discussing the spatial and temporal interactions of ignitions, fuels, weather, and topography that are necessary for fire to influence long-term landscape patterns.

At present, the most significant contribution to detrimental air quality in the Sierra Nevada comes from air pollutants originating from outside the range (Cahill and others 1996). Yet, if fire is to be reintroduced as a major process in forest management (SNEP 1996a), there is likely to be an increased contribution of smoke to deleterious air quality (Cahill and others 1996). Little is known about how historical fire regimes and vegetation patterns influenced past air quality or indeed what “pristine” conditions would be (Skinner and Chang 1996). Ottmar and Alvarado (in these proceedings) present results of modeling work that was designed to better understand how vegetation composition and structure (fuels) under both historical fire and modern management regimes influence fire vulnerability and resultant smoke production. Their work describes the tradeoffs involved in managing forests for different structural and compositional conditions with and without the use of fire.

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A critical finding of the Sierra Nevada Ecosystem Project (SNEP 1996b) identified the need for a study of the effects of using alternative treatment methods to achieve fire hazard reduction and ecological restoration (Weatherspoon and Skinner 2002). To help fill this void in knowledge, a large study is under way—“A National Study of the Consequences of Fire and Fire Surrogate Treatments (FFS)” funded by the USDA/USDI Joint Fire Science Program (http://www.nifc.gov/joint_fire_sci). Knapp and others (these proceedings) describe the objectives of the FFS, the national network of FFS sites, and the two FFS sites in the Sierra Nevada.

Opinions differ widely over alternative approaches to fire management in the Sierra Nevada. Regardless of management strategy, fire is a fundamental, undeniable process that significantly affects ecosystems in this bioregion. This session attempts to inform the debate through a synthesis of current research on important aspects of fire ecology and fuels management.

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Fire and Landscapes: Patterns and Processes¹

Jan W. van Wagtendonk²

Fire has been a pervasive influence on the Sierra Nevada landscape for millennia. Lake sediments containing charcoal and pollen indicate that fires have occurred for at least the past 13,000 years. Brunelle and Anderson (2003) found that charcoal accumulation varied with vegetation and temperature, increasing during warm periods dominated by oaks (*Quercus* spp.) and sagebrush (*Artemisia tridentata*) and decreasing during cool periods dominated by subalpine species, such as mountain hemlock (*Tsuga mertensiana*). They concluded that the lake sediment record was consistent with other long-term records of climate and vegetation in the Sierra Nevada and with records of fire and climate for the past 1,000 years as determined from tree-ring studies (Graumlich 1993). Although it is not possible to determine whether the frequency of lightning strikes varied during the period covered by the sediment record, the number of ignition sources was obviously sufficient to produce fires across the landscape.

Predictions of increased temperatures with global warming indicate that fire could become even more prevalent in the future than it is today (Knox 1992). Higher temperatures might double the frequency of lightning strikes (Price and Lind 1994). As fuels accumulate because of fire exclusion and as more and more new homes are built in wildlands, the situation becomes even more severe. In order to reduce fire hazards and risks, land managers and private landowners must take into account the natural role of fire. This paper discusses the conditions essential for fire to be a component of the landscape and the patterns and processes that occur as these conditions interact. The evolution of the current hazardous situation in the Sierra Nevada is described, and a management program is suggested that would encompass the natural role of fire and allow humans to live harmoniously in a fire-adapted environment.

Conditions Essential for Fires

For fire to play an ecological role on a landscape, three conditions must occur simultaneously and frequently during the evolution of that landscape. First, a source of ignitions must be present, for example, lightning or anthropogenic activities. Second, the ignitions must encounter a receptive fuel bed with sufficient fuel to burn. Finally, the weather conditions must be conducive for fire spread. These conditions are all met frequently in the Sierra Nevada, and fires occur annually throughout the range. Since the early 1900s, nearly 5,000 fires have burned more than 20,000 km² in the 67,000-km² region (*fig. 1*).

Ignition Sources

Without an ignition source, fire cannot be a factor in an ecosystem. Lightning and ignitions by Native Americans were the principal sources of fires in the past. Although it is difficult to

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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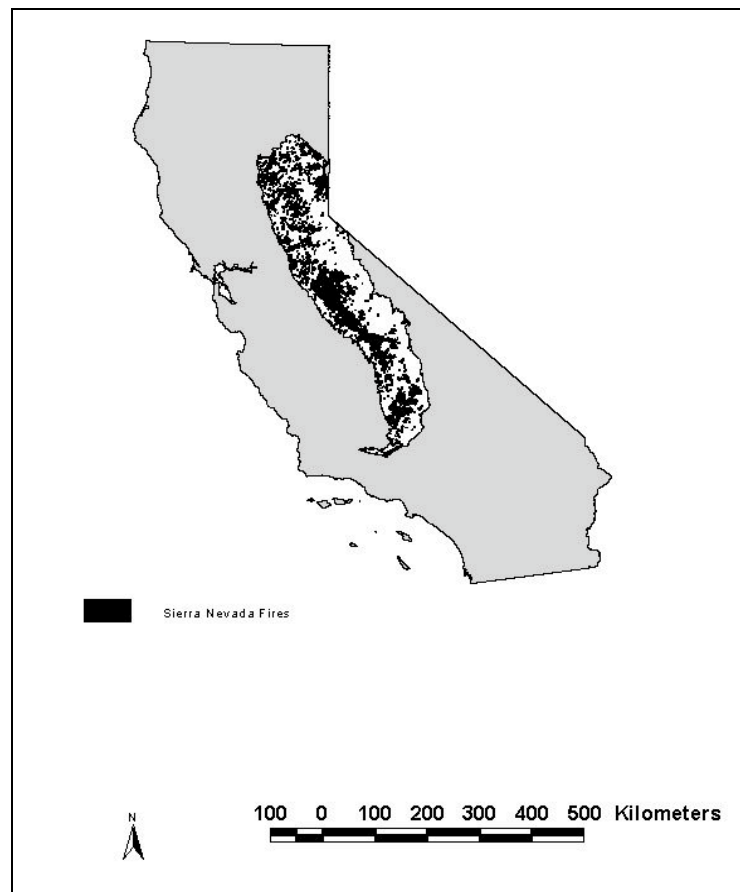


Figure 1— Fires from all causes in the Sierra Nevada bioregion, 1908–2001.

quantify the extent of burning by native people, ethnographers believe their use of fire was extensive (Anderson 1994). Regardless of the contribution of Native Americans to the number of ignitions, lightning is so prevalent that it alone can account for the evolution of fire regimes in the Sierra Nevada (Vale 1998). With the advent of automated lightning detection systems, information regarding the location, date, and time of each strike can be recorded. *Figure 2* shows the annual variation in number of strikes in the Sierra Nevada from 1985 through 2000. Not all of these strikes resulted in a fire because many of them did not land in receptive fuels or during adequate burning conditions. Moreover, it is estimated that less than 70 percent of the strikes exhibited long-continuing currents associated with ignitions (Anderson 2003). In a study of lightning strikes and fires in Yosemite National Park, van Wagtendonk (1994) found that an average of 1,208 strikes per year started only 42 fires per year.

The role fire plays is also affected by the location of the lightning relative to the landscape. *Figure 3* shows the geographic distribution of lightning strikes per year per 100 km² in the Sierra Nevada from 1985 through 2000. The density of strikes increases from west to east, reaching a maximum of just under 50 strikes per year per 100 km² just east of the crest. Elevation accounts for much of this increase. *Figure 4* shows the number of strikes occurring in 1999 for the Sierra Nevada per 500-ft contour interval. The strike density reached a maximum between 8,500 and 9,000 feet on both sides of the crest and was lowest in the foothills.

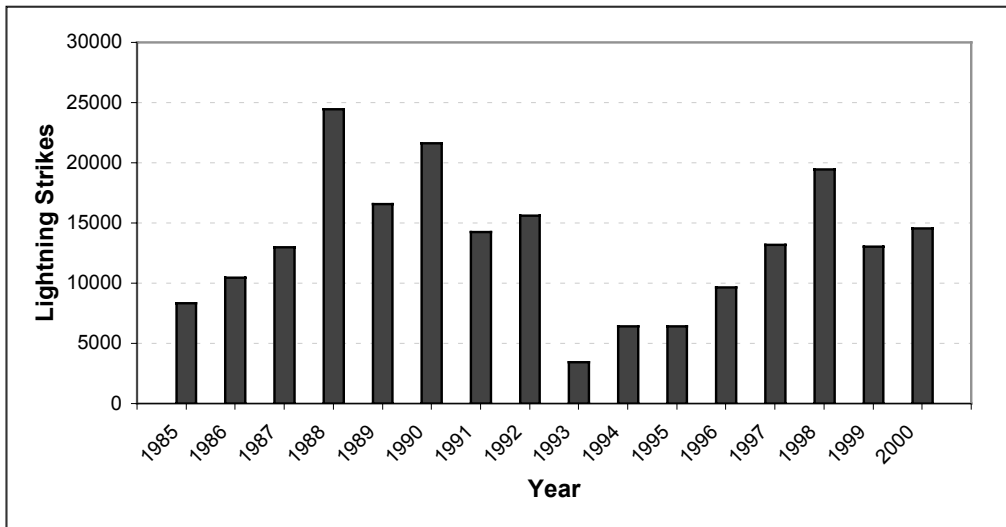


Figure 2— Number of lightning strikes per year from 1985 through 2000 in the Sierra Nevada bioregion.

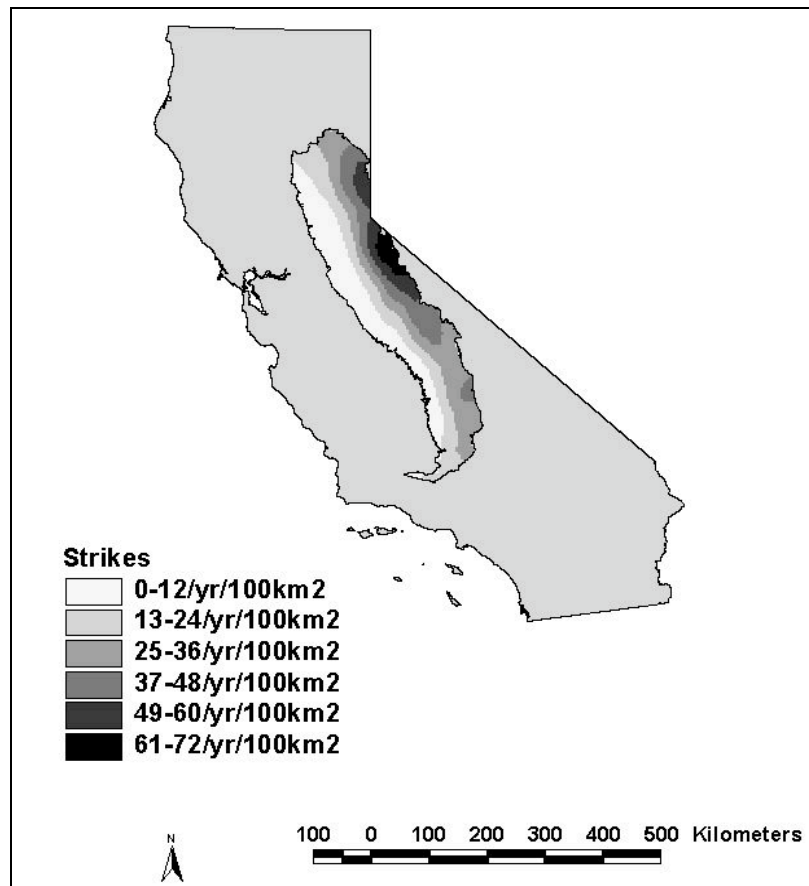


Figure 3— Number of lightning strikes per year per 100 km² in the Sierra Nevada bioregion, 1985–2000.

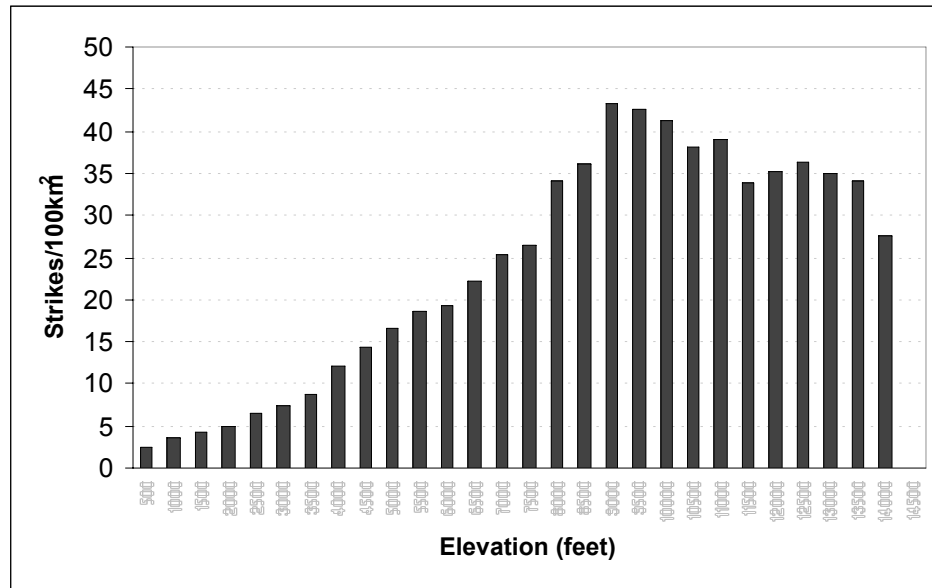


Figure 4— Number of lightning strikes per 100 km² by 500-ft contour intervals in the Sierra Nevada bioregion, 1999.

Fuels

Fuels vary in amount, type, and distribution over space and time. For example, van Wagtendonk and others (1998) found that the weight of woody surface fuels of Sierra Nevada conifers ranged from 0.22 kg m⁻² for foothill pine (*Pinus sabiniana*) to 2.34 kg m⁻² for giant sequoia (*Sequoiadendron giganteum*) and increased as trees grew older and larger. Fuelbed bulk density ranged from 12.41 kg m⁻³ for foothill pine to 40.21 kg m⁻³ for limber pine (*Pinus flexilis*). These variations in fuel characteristics result in dramatic differences in fire behavior under similar weather and topographic conditions. Similar variation can be found in crown fuels. Although no data are available for the Sierra Nevada, Brown (1978) found that crown bulk densities in the Rocky Mountains ranged from 0.6 kg m⁻³ for western red cedar (*Thuja plicata*), a species similar in crown structure to incense cedar (*Calocedrus decurrens*), to 2.24 kg m⁻³ for whitebark pine (*Pinus albicaulis*).

Fuel maps based on satellite imagery show that the spatial distribution of fuels is very heterogeneous (van Wagtendonk 1998). The Sierra Nevada landscape is a mix of fuel types interspersed with water and barren areas. This pattern is influenced by the response of vegetation to the available water and also reflects climate, elevation, aspect, and soil properties. Fires burning over this landscape exhibit a similar degree of spatial heterogeneity.

Weather

Weather patterns in the Sierra Nevada are influenced by its topography and geographic position relative to the Central Valley, the Coast Ranges, and the Pacific Ocean. The primary sources of precipitation are winter storms that move from the north Pacific and cross the Coast Ranges and Central Valley before reaching the Sierra Nevada. As the air masses move up the gentle western slope, precipitation increases and, at the higher elevations, falls as snow. Once across the crest, most of the moisture has been driven from the air mass and precipitation decreases sharply. Precipitation also decreases from north to south, with nearly twice as much falling in the northern Sierra Nevada as in the southern region. Sierra Nevadan temperatures are generally hot in the summer and cold in the winter. Temperatures

decrease as latitude and elevation increase. Wind speeds are variable, averaging up to 10 km hr^{-1} , but speeds of more than 100 km hr^{-1} have been recorded out of the north during October.

The burning index for a given area is calculated by combining data on fire weather (temperature, relative humidity, cloudiness, and wind speed) with information about topography and fuels, to provide an indicator of fire behavior conditions. *Figure 5* shows the variation in the average maximum burning index across an elevational transect through the Yosemite region from the foothills to the Great Basin. At Buck Meadows, located at the upper edge of the foothills at 917 m, the 10-year average maximum burning index reaches 82. As elevation increases, the average maximum burning index decreases, reaching 68 at Crane Flat at 2,023 m and falling to only 21 at Tuolumne Meadows at 2,614 m. Across the crest of the Sierra Nevada at Crestview (2,310 m), the burning index rises to an average maximum of 41.

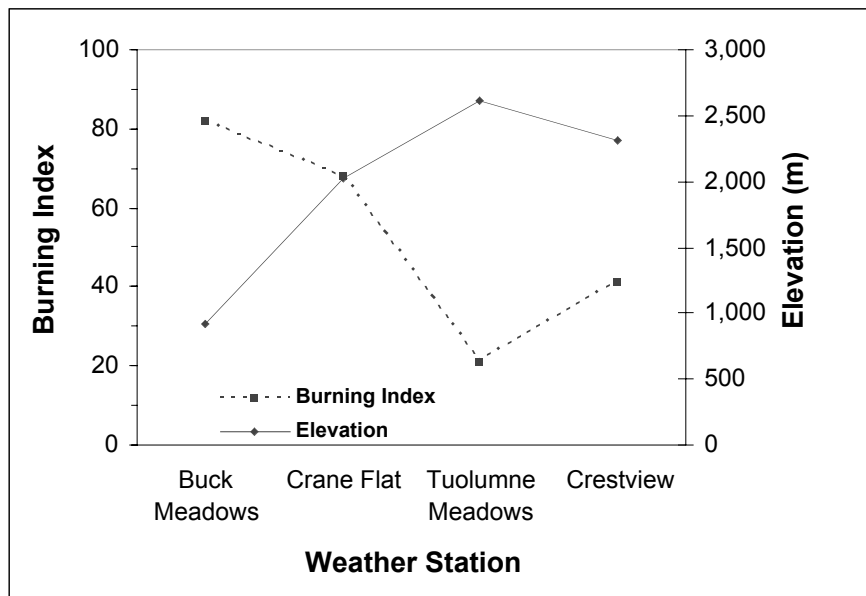


Figure 5— Average maximum burning index at sites of weather stations along an elevational transect of the Sierra Nevada, 1993–2002.

Landscape Mosaic

A very complex landscape mosaic results from fires burning under variable conditions of ignition, fuels, and weather. In the absence of anthropogenic influences, the simultaneous occurrence of lightning strikes, flammable fuels, and weather conducive for burning determines the frequency, size, and intensity of a fire. The resulting variation in fire effects (including fire severity) influences subsequent vegetation succession and fire behavior. Interrupting this burning cycle by excluding fire leads to homogenization of the landscape, resulting in large continuous forest stands with tangled understory vegetation and accumulated dead woody debris.

Fire and Landscape Interactions: The Illilouette Basin Example

To understand how primeval forests developed with the influence of fire, it is instructive to look at an area where fires have been allowed to burn with minimal interference. For the past three decades, Yosemite National Park has had a program of wildland fire use, which prescribes the conditions necessary for allowing lightning-caused fires to run their course. The U.S. Army suppressed all fires in the park between 1890 and 1916, at which point the

National Park Service was established. The Park Service continued to suppress all fires until 1973 when it began implementing the wildland fire use program.

The Illilouette Creek Basin, just south of Yosemite Valley, is an ideal place to examine patterns that emerge from fires freely interacting on a landscape (*fig. 6*). From 1930 (when fire records were first kept) through 1972, only 26.7 ha were burned by 100 fires. Between 1973 and 1979, the area burned increased by 1,885.7 ha, with 1,467.9 ha burned in the 1974 Starr King Fire. An additional 1,941.1 ha burned between 1980 and 1986. The 1981 Fat Head Fire burned up to the Starr King Fire area before going out.

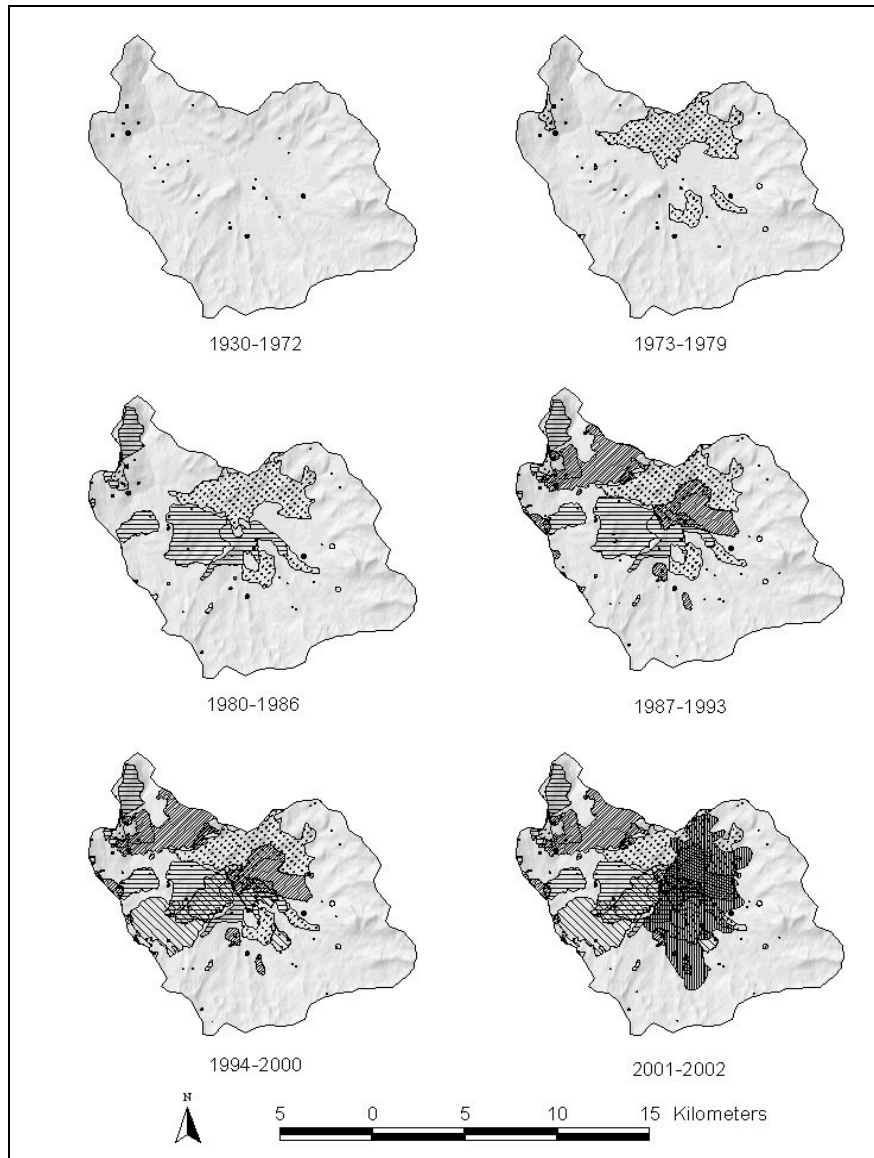


Figure 6— Fires in the Illilouette Creek Basin before and after the wildland fire use program was initiated in 1973, Yosemite National Park, 1930–2002.

Not until the period between 1987 and 1993 did reburning occur: in 1988 when the Alaska Fire burned into portions of the Starr King Fire and the 1980 Buena Vista Fire. In both cases, fire intensity was greatly reduced in the reburned areas. Out of the total of 1,996.5 ha that burned during this period, 759.7 ha burned in the Alaska Fire and 791.2 ha in the 1991 Ill Fire. Interestingly, the Ill Fire did not reburn the Starr King fire because the fires were separated by several granite domes. The next period (from 1994 through 2000) saw extensive reburning during the 1994 Horizon Fire before it was suppressed when prescribed conditions were exceeded. The Horizon Fire burned 1,316.6 ha out of the 2,007.3 ha that burned during this period. By 2001, enough fuel had accumulated on the older fires for the 2,135.1-ha Hoover Fire to reburn large areas. However, very little reburning occurred on the 6-year-old Horizon Fire. The Ottoway Fire burned an additional 25.3 ha in 2002.

Reburns are only part of the process that creates diverse landscapes. Fine-scale patterns of fire severity within a fire perimeter add to the heterogeneity already exhibited at landscape level. Recalculating the perimeter of the Hoover Fire based on a severity analysis excludes many areas thought to be burned. *Figure 7* shows fire severity levels within the new perimeter of the Hoover Fire. The unburned areas were either barren, previously burned (as recently as 1994), or were too moist to burn. As severity data become more widely available, it will be possible to examine the intricacies of fire interactions and develop a more detailed understanding of landscape patterns.

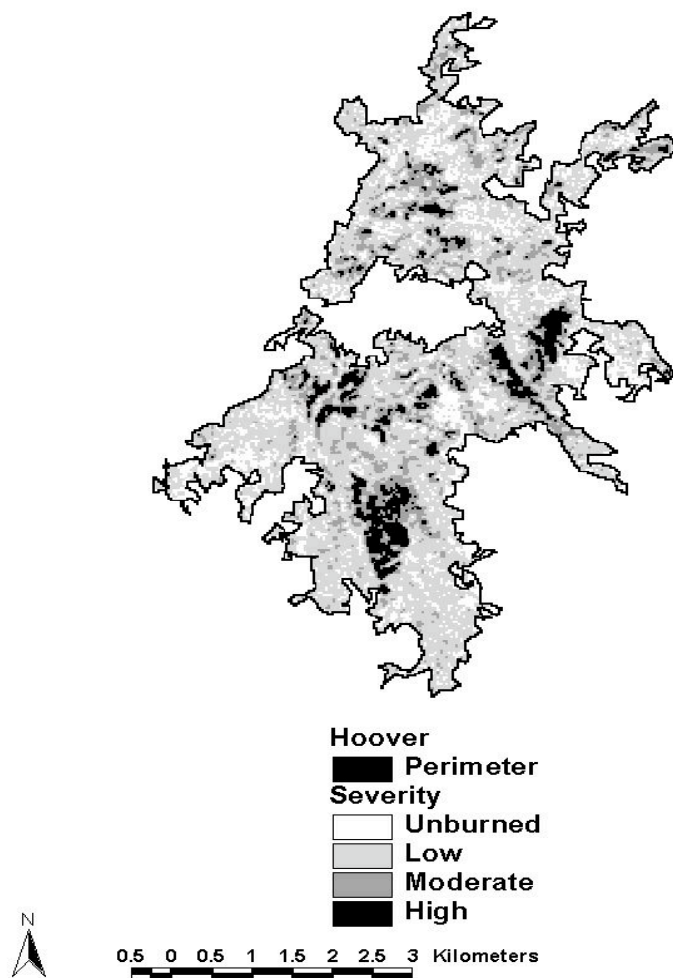


Figure 7— Fire severity on the Hoover Fire, Yosemite National Park, 2001.

Sierra Nevada Landscapes Today

Years of resource-extraction activities and fire exclusion have disrupted ecological patterns and processes on the landscape (McKelvey and others 1996). Accumulations of dead woody debris and dense stands of shade-tolerant understory trees and shrubs have made the fuel and vegetation complex nearly homogeneous. The inevitable fire that cannot be suppressed becomes larger and burns more intensely than would have occurred without this history of fire exclusion. Some believe these conditions are a result of natural succession: even without human intervention, Sierra Nevada forests would have become denser and fuels would have increased. Others believe that environmental groups have contributed to the problem because they have sued to prevent activities that might reduce fuels, such as prescribed burning and thinning. The environmental community, in turn, blames the timber industry for removing the larger trees and leaving the small, unmerchantable debris. The truth is probably somewhere in between these contrasting viewpoints, and, rather than placing blame, the key is to take action to solve the problem.

A Landscape-Level Fire Management Program

To allow fire to play a more natural ecological role, management must take a landscape-level approach. Such an approach requires large blocks of land with single ownership, or multiple owners with compatible objectives. Examples of a single-owner program can be found in large national parks. In Yosemite National Park, an integrated fire management program includes fire suppression, prescribed fire, and wildland fire use. The program is based on analysis of natural fire return intervals—the number of years between naturally occurring fires—and the magnitude of departures from these for each vegetation type (van Wagtendonk and others 2001). Areas where departures are generally two or fewer have been categorized as wildland fire use zones. In these areas, lightning fires that meet specific prescriptions are allowed to burn to meet land management objectives. Human-caused fires are extinguished immediately using the appropriate management response. Approximately 85 percent of the park is in this zone. Areas where fire return intervals are three or more times greater than normal are managed to reduce fuel hazards and restore natural conditions. Prescribed fires and mechanical treatments are used for this purpose. Mechanical treatments are restricted to areas immediately surrounding structures or other developments requiring protection from fire.

The 2002 fire season illustrates the results achieved with this program. A total of 53 fires burned 2,722.1 ha (*fig. 8*). Thirty-two of the fires were caused by humans or exceeded the prescription, and these fires were suppressed. The largest two of these fires burned 49.0 ha out of the total of 62.0 ha burned by this type of fire. Thirteen lightning-caused fires were allowed to burn 1,124.1 ha under prescribed conditions. The Wolf Fire burned 725.6 ha between July and October around the development at White Wolf. Eight prescribed fires, the largest of which was the Gin Flat Fire at 1,350.8 ha, treated 1,536.0 ha. In addition to the burning program, 124.2 ha were mechanically treated. Our results to date confirm that landscape-level fire management objectives can be met through a program that combines aggressive suppression, active prescription burning, and wildland fire use.

Conclusion

The patterns and processes of landscape-level fire are a product of the interactions between ignitions, fuels, weather, and topography. Interruption of these processes results in changes to the patterns and, subsequently, the behavior of future fires. Attempts to ameliorate the negative results of past practices will be most successful if they mimic the natural role of fire. Hazard reduction methods must focus on modifying the amount and continuity of surface fuels to reflect the conditions of the pre-suppression era. In order to restore the natural role of fire, fire itself must be one of the tools used. Fire cannot be reintroduced without fire.

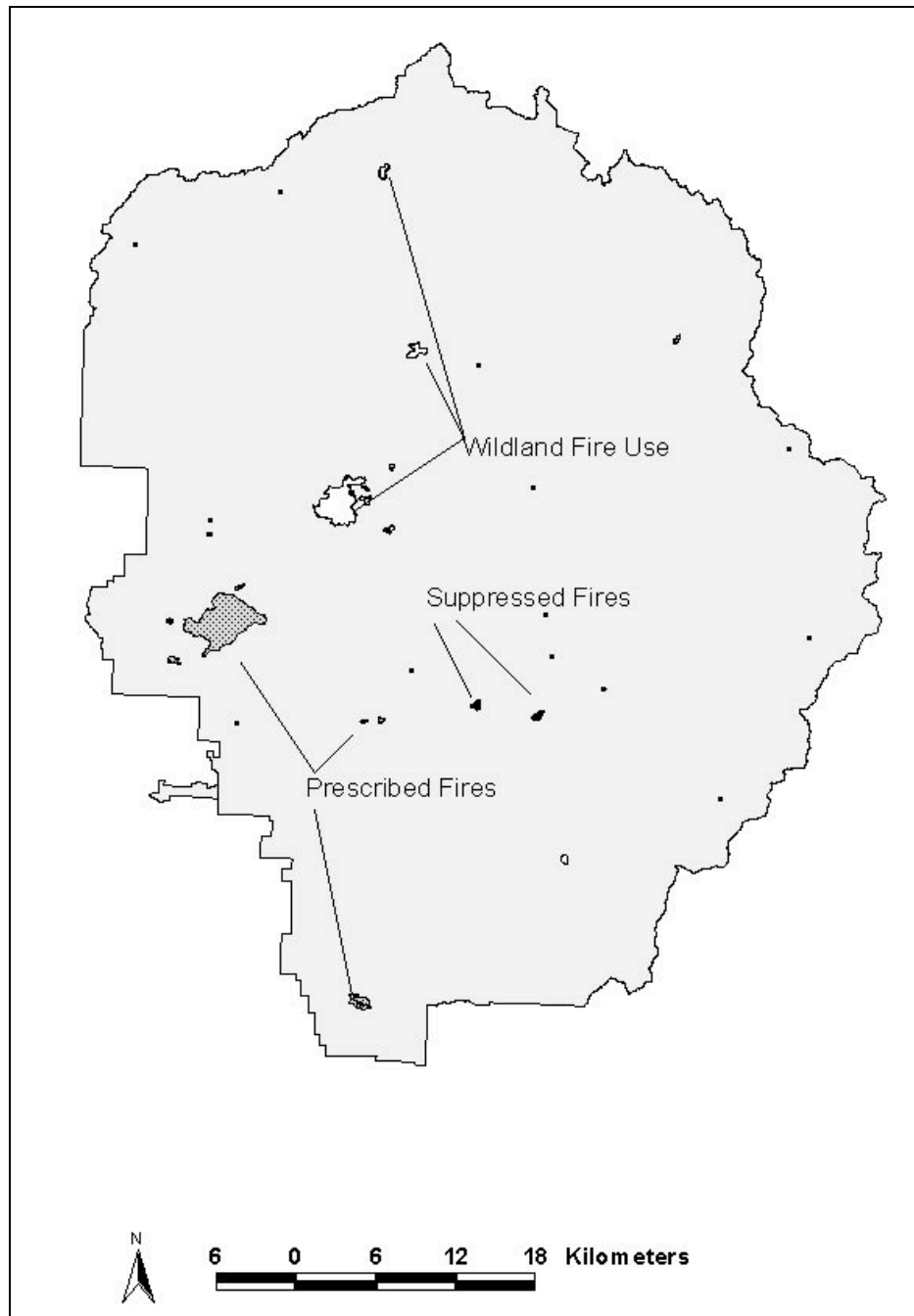


Figure 8— Landscape level fires in Yosemite National Park, 2002.

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Fire and Fire Surrogate Study in the Sierra Nevada: Evaluating Restoration Treatments at Blodgett Forest and Sequoia National Park¹

Eric E. Knapp,² Scott L. Stephens,³ James D. Mclver,⁴
Jason J. Moghaddas,³ and Jon E. Keeley²

Management practices have altered both the structure and function of forests throughout the United States. Some of the most dramatic changes have resulted from fire exclusion, especially in forests that historically experienced relatively frequent, low- to moderate-intensity fire regimes. In the Sierra Nevada, fire exclusion is believed to have resulted in widespread vegetation changes, including greater density and cover of white fir (*Abies concolor*) and reduction in the area occupied by hardwoods and shrubs (Parsons and DeBenedetti 1979, Vankat and Major 1978). Fire exclusion has allowed both live and dead woody fuels to accumulate, increasing the probability of large, high-severity, stand-replacing fires (Stephens 1998, van Wagtendonk 1985).

Fire is an important ecological process in Sierra Nevada mixed conifer forests (Kilgore 1973). Many tree and shrub species depend on fire to expose mineral soil and create gaps for establishment. In the Sierra Nevada, the use of prescribed fire to restore these natural ecological processes began in the late 1960s in Sequoia and Kings Canyon National Parks. Today, Yosemite and Sequoia and Kings Canyon National Parks have active prescribed burning programs. Outside of the national parks, prescribed burning is conducted; however, its use is more variable and generally less widely implemented.

As human populations living in and adjacent to forested areas of the Sierra Nevada have increased, property losses due to wildfires have correspondingly increased, highlighting the need to address high-fire hazards in these forests. Concerns about potential escape risks of prescribed fires, perceived conflicts between meeting restoration goals with prescribed fire and growing trees for harvest, and concerns about smoke-dispersal impacts make it unlikely that prescribed fire will be the sole tool for reducing hazardous fuels and meeting ecosystem restoration goals. Mechanical thinning has been and will likely continue to be a widely applied alternative to fire. As resource managers and the scientific community grapple with the problem and try to devise strategies for managing fire and fuels in the Sierra Nevada, important gaps in the knowledge base remain. These include the following questions:

Can mechanical thinning be used as a surrogate for prescribed fire?

Historical structures and compositions of mixed conifer forests under a regime of relatively frequent, low- to moderate-intensity fire can be approximated using mechanical thinning. However, knowledge is limited about which of fire's ecological functions can be emulated by mechanical means and which cannot. The long-term ecosystem consequences of replacing one

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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type of disturbance with another require investigation. For example, some understory shrubs and herbs require the direct effects of fire (heat and/or smoke) to stimulate germination. In addition, nutrient cycling following fire may be very different than nutrient cycling following mechanical thinning.

Can fuel reduction using prescribed fire be conducted without killing or injuring large numbers of overstory trees?

Exclusion of fire over the past century in Sierra Nevada mixed conifer forests has allowed fuels to accumulate to unnatural levels and become more spatially continuous, factors that might cause fire to have unnatural ecosystem impacts (Bonnicksen and Stone 1982). There are concerns that prescribed fires could lead to high mortality of large trees because of cambium and fine-root damage during combustion. In addition, prescribed fires could be of uniformly high intensity, erasing the character of the original forest mosaic.

What are the ecological impacts of prescribed burning in alternate seasons when smoke dispersal impacts are not as severe?

The majority of prescribed burning in the Sierra Nevada is currently conducted during early fall, which coincides with or occurs after the period of maximum historical fire activity, as determined from tree fire scar records (Caprio and Swetnam 1995). Fall burning also coincides with the period of poorest air quality in adjacent populated areas of the Central Valley. Air quality concerns during this time of year often severely limit the number of days when prescribed burning can be conducted, particularly in the southern Sierra Nevada. Air quality is typically better during the spring or early summer, owing to greater atmospheric instability. However, early-season prescribed burning has the potential to affect trees, shrubs, and other forest species in different ways than late-season prescribed burning (Kauffman and Martin 1990). In addition, concern exists about the potential impact of early-season fire on animal species that may be more active during this time of year.

Fire and Fire Surrogate Study

The above questions are being addressed through a large national research effort, known as the Fire and Fire Surrogate (FFS) Study (<http://ffs.fs.fed.us>) (McIver and others 2001). The FFS study, funded by the Joint Fire Science Program, USDA Competitive Grants, and the National Fire Plan, consists of a network of 13 sites located in forested ecosystems across the United States, each characterized by a historical regime of frequent, low- to moderate-intensity fire. The objective of the national study is to evaluate the economics and ecological effects of alternative fuel-reduction methods. Each treatment is designed to produce a forest structure that would result in survival of 80 percent of the dominant and co-dominant trees if the treated area were to experience a wildfire at 80th percentile weather conditions.

Two FFS study sites are located in the Sierra Nevada, one at Blodgett Forest in the northern/central Sierra Nevada and another in Sequoia National Park in the southern Sierra Nevada. At the Blodgett Forest site, the consequences of four management options are being assessed: (1) mechanical treatment alone, (2) prescribed fire alone (early season or late season), (3) mechanical treatment and prescribed fire, and (4) untreated control. Treatments at the Sequoia National Park site include early-season prescribed fire, late-season prescribed fire, and untreated control. No mechanical treatments are being used at the Sequoia National Park site because mechanical thinning is not currently a landscape-scale management option on most national park lands in the Sierra Nevada. Treatments at Blodgett Forest are similar to those being studied at 11 other sites nationwide. All sites in the network, including Blodgett Forest and Sequoia National Park, will be used to evaluate the same ecological and economic components, which include overstory and understory vegetation, fuel and fire behavior, soils and the forest floor, wildlife, entomology, pathology, treatment costs, and utilization economics.

A common research design will facilitate meta-analyses at the site and national levels and broaden the scope of data being collected at the two Sierra Nevada sites. Results from Blodgett Forest and Sequoia National Park thus will be directly comparable to treatments applied at other sites, including the southern Cascades in California, Hungry Bob in northeastern Oregon, Lubrecht Forest in western Montana, Southwest Plateau in Arizona, and Jemez Mountains in New Mexico. In addition, seasonal prescribed fire data collected at Sequoia National Park will be comparable to data collected at the Hungry Bob and the Lubrecht Forest sites, where prescribed burns have been applied in fall and spring, respectively.

Methods

Blodgett Forest

The University of California's Blodgett Forest Research Station is located approximately 20 kilometers east of Georgetown, California. Study plots are in mixed conifer forest stands at elevations ranging from 1,100 to 1,410 meters (m) above sea level. Forest stands in this area are composed of sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), incense-cedar (*Calocedrus decurrens*), Douglas-fir (*Pseudotsuga menziesii*), and California black oak (*Quercus kelloggii*). The presettlement fire return interval for the study site ranged from 4 to 9 years on a 15-hectare (ha) scale; however, the last large fire in the Blodgett Forest area occurred nearly a century ago.

Twelve 15-ha study plots (three prescribed fire only, three mechanical treatment only, three mechanical treatment and prescribed fire, and three controls) were established in 2000. Mechanical treatments included a commercial thinning from below followed by mastication of 85 percent of the submerchantable trees and small snags (less than 15 centimeters diameter at breast height [dbh]). The small material was masticated using a track-mounted rotary masticator, and the resulting fuels were shredded into pieces less than 1 m in length. Desired forest conditions were estimated using computer models with parameters set to meet the 80:80 criteria described below in *table 1*. Prescribed burning was conducted during fall 2002 before the first significant rainfall. Most of the burning occurred at night when relative humidity, temperature, wind, and fuel moistures were within prescription.

Table 1. Desired conditions within the Blodgett Forest fire and fire surrogate units.

	Percent overstory cover	Percent overstory crowns touching	Percent of stand with two layers	Height to live crown base (m)	Snags/ha over 30 cm dbh	Large woody debris/ha > 30 cm	Surface fuel load (tonnes/ha)	Percent soil covered by duff
Maximum	60	20	15	n.a.	5	7.5	60	75
Minimum	35	0	0	1	0	0	25	50
Average	45	15	10	3	2.5	5	49	40

Sequoia National Park

The Sequoia National Park study site lies within the Marble Fork watershed of the Kaweah River. Study plots are located on 15- to 25-degree slopes and west- and northwest-facing aspects at elevations ranging from 1,900 to 2,150 m above sea level. Forests in this area are old-growth, and tree species composition, in order of abundance, is as follows: white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), incense-cedar (*Calocedrus decurrens*), red fir (*A. magnifica* ssp. *shastensis*), Jeffrey pine (*P. jeffreyi*), ponderosa pine (*P. ponderosa*), dogwood (*Cornus nuttallii*), and California black oak (*Quercus kelloggii*). Estimates of the presettlement fire return interval range from 20 to 40 years (communication) for forests and

aspects of the type found at the study site. However, before the start of this project, study plots had not experienced fire for at least the past 110 years.

Nine 15-ha study plots (three early-season prescribed fire, three late-season prescribed fire, and three control) were established at the Sequoia National Park study site in 2000. Late-season prescribed burns were conducted in fall 2001, and early-season prescribed burns were conducted during late spring and early summer of 2002. Moisture content of fuels at the time of ignition was determined by weighing collected samples before and after oven drying.

Both Study Sites

Vegetation variables were measured in subplots within each experimental unit (10 0.1-ha subplots in Sequoia National Park experimental units and 25 0.04-ha subplots in Blodgett Forest units) before treatment application. Each tree was labeled; its dbh measured; and species, status (alive or dead), and health noted. Similar data were collected for saplings, defined as individuals with a height greater than 1.37 m and dbh less than 10 cm. Fuels were evaluated using methods described by Brown (1974). Litter, duff, and 1-, 10-, 100-, and 1,000-hour fuel loads were calculated using equations described by van Wagtendonk and Sydoriak (1998) and van Wagtendonk and others (1996). Area burned at Sequoia National Park study plots was estimated by mapping burned and unburned segments along fuel transects.

Early Results and Discussion

Research at the Blodgett Forest and Sequoia National Park FFS sites is still in the early stages, and most post-treatment data will not be collected until 2003 and 2004. Post-treatment results from Blodgett Forest are available only for the period after thinning and before burning. Post-treatment data from both sites should be considered preliminary.

Mechanical thinning and mastication reduced total fuel loads from 150.0 tonnes/ha to 101.9 tonnes/ha (*table 2*). Much of this reduction can be attributed to a loss of litter, duff, and 1,000-hour (greater than 7.62 cm) fuels. Litter and duff (combined) and 1,000-hour (sound plus rotten) fuels decreased by 37.3 and 12.8 tonnes/ha, respectively. Losses in litter and duff may be explained by the ubiquitous disturbance resulting from harvest and mastication treatments. Litter and duff were completely removed from many of the main skid trails throughout treatment units. Loss of 1,000-hour material was observed to be primarily in large rotten fuels. These fuels may have been redistributed or otherwise broken up during harvest and mastication treatments.

Thinning and mastication increased the fuel load in small-diameter woody fuel classes and also increased the fuel depth (*table 2*). These increases in activity fuels may in turn affect rate of spread and flame length of surface fires. Whether these effects are significant is still pending further data collection and analysis. Although total fuel load was somewhat reduced by thinning and mastication alone, the desired condition (*table 1*) was not met. [Since the Sierra Science Symposium was held, prescribed burns have been completed within these units. The prescribed burns removed much of the remaining ground fuels. Final fuel reduction estimates will be available at a later date.]

Fuel loading was very high before the prescribed burns, averaging 192.8 tonnes/ha across all plots. More than half this fuel was found in the litter and duff layers (*table 2*). The early- and late-season burns consumed 66 and 79 percent of the fuels, respectively. This difference was statistically significant ($P = 0.015$). Lower fuel consumption during the early season was likely due to higher fuel moisture levels. Moisture in 1,000-hour and duff fuels averaged 24 and 38 percent, respectively, at the time of the early-season burns; moisture in these fuels averaged 10 and 12 percent, respectively, at the time of the late-season burns.

Table 2— Preliminary results from fuel transects measured in the three mechanical plus fire treatment units at Blodgett Forest and in all treatment units at Sequoia National Park. Post- burn data are not yet available at Blodgett Forest. For fuel size classes, 1 hour is 0–0.64 cm, 10 hour is 0.64–2.54 cm, 100 hour is 2.54–7.62 cm, and 1,000 hour is greater than 7.62 cm.

Site	Treatment phase	Litter & duff	Small woody (1, 10, 100 hr)	Large woody (1000 hr)	Total fuel load	Fuel depth
		tonnes/ha			cm	
Blodgett	Pretreatment ¹	103.5	12.7	33.8	150.0	9.9
Blodgett	Post-harvest ²	65.5	12.9	29.0	107.4	13.1
Blodgett	Post-mastication ³	66.2	14.6	21.0	101.9	16.1
Blodgett	Post-burn	-	-	-	-	-
Sequoia	Pretreatment (All plots) ¹	105.6	8.4	78.7	192.8	10.6
Sequoia	Post treatment (Early burn) ⁴	26.1	2.6	33.9	62.7	4.0
Sequoia	Post treatment (Late burn) ⁴	16.4	2.1	19.9	38.4	4.1

¹Pre-treatment data were taken in summer 2001.

²Post-harvest data were taken after harvest was complete (spring/summer 2002) and before mastication.

³Post-mastication data were taken after mastication of understory nonmerchantable material was completed (summer/fall 2002).

⁴Post-burn data taken during summer 2002.

Initial (first post-fire season) mortality of trees smaller than 50 cm dbh was significantly less within early-season burn units compared with late-season burn units (*fig. 1*). Mortality of trees larger than 50 cm dbh did not differ between units burned in different seasons. Overall mortality among these larger trees was very low, averaging 4.8 percent across all burning treatments. Initial mortality of trees was primarily due to crown scorch. Additional mortality is expected due to secondary causes (bole damage, bark beetles, and so forth). Before the burns, density of trees and saplings averaged 717/ha across all plots. Density remaining in the first season after the burns was 510/ha in the early-season burn units and 305/ha in the late-season burn units. The latter value falls within Sequoia and Kings Canyon National Parks' post-fire structural target of 60 to 325 trees/ha. If substantial secondary tree mortality does not occur in the early-season treatment units, at least one additional burn will be required to reach this structural goal in these units.

Mortality patterns were extremely heterogeneous within and among both the early-season and late-season burn units. Some areas burned intensely, leading to relatively high tree mortality, whereas other areas burned at low intensity, inflicting minimal visible damage to trees. The hypothesis that heavy fuel loads and greater continuity of fuels would lead to a uniformly intense fire was not supported within this mixed conifer vegetation type. Despite the long period of fire exclusion preceding the prescribed fire treatments, sufficient heterogeneity in fuels, vegetation type, and local weather conditions existed at the time of burning to create a highly variable post-burn landscape. Multiple regression analyses indicate that variation in percentage of basal area composed of pine trees and variation in total tree density explain at least some of the heterogeneity in burn pattern for the late-seaso

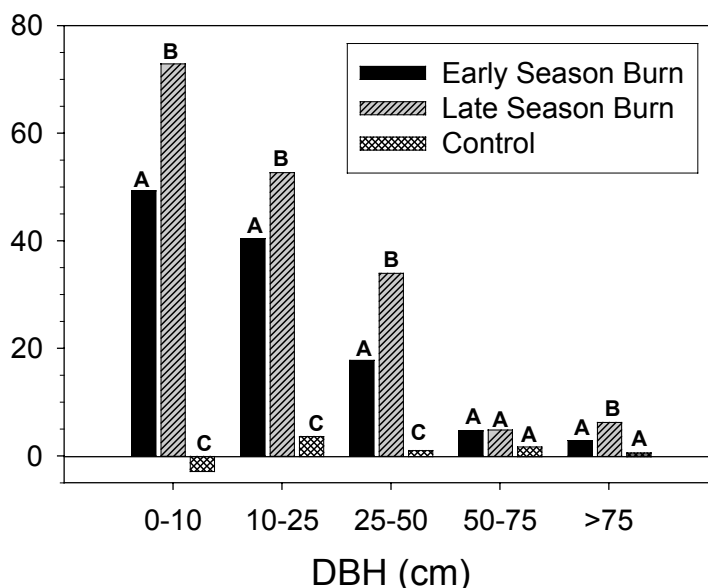


Figure 1— Initial tree mortality (from 2001 to 2002) in different size classes following early- and late-season prescribed burns at the Sequoia FFS site. Bars within DBH categories topped by different letters denote treatments that were significantly different by the chi square statistic, run on the tree number data.

treatment. Flame lengths were lower, and probability of burning was less in areas dominated by fir trees. This was likely due to the more compact nature of the short-needle ground fuels (Agee and others 1977, Stephens 2001). Differences in firing pattern may have also played a role.

The early-season burns were significantly patchier than late-season burns. Within the early-season units, 71 percent of the plot area was estimated to have burned, whereas late-season units had an estimated 85 percent of the plot area burned ($P = 0.023$). Islands of unburned habitat may be important for post-fire recolonization by some plant and animal species. Lower fuel consumption and reduced initial mortality of trees in the early-season burns demonstrate the potential value of this treatment, especially employed as an initial restoration burn where high fuel loading requires special care to avoid ecosystem damage. However, burning-season effects on herbaceous understory, small mammals, and birds have not yet been determined. Data collected in the coming years will help managers evaluate burning season as another tool for achieving desired ecological and fuels-reduction goals.

Acknowledgments

The authors thank Andrew Corer, Danny Fry, and the staff of Blodgett Forest for field assistance; and Liz Ballenger, Jeffrey Kane, and the rest of the U.S. Geological Survey summer field crew, as well as Jeff Manley, Tony Caprio, and MaryBeth Keifer of Sequoia National Park for technical assistance, and Sequoia National Park Fire Management (Bill Kaage, Fire Management Officer) for conducting the prescribed burns. The authors also thank reviewers within the National Park Service, U.S. Geological Survey, and USDA Forest Service for constructive comments. This is Contribution Number 21 of the National Fire and Fire Surrogate Project (FFS), funded by the U.S. Joint Fire Science Program.

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Effectiveness of Thinning and Prescribed Fire in Reducing Wildfire Severity¹

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The severity of recent fire seasons in the United States has provided dramatic evidence of the increasing complexity of wildfire problems. A wide variety of indicators suggest worsening dilemmas: extent of area burned, ecosystems at risk, funds expended, homes destroyed or evacuated, and human fatalities and injuries; all seem to be on the increase or have peaked in recent years. The National Fire Plan (and ongoing initiatives by the USDA Forest Service and Department of Interior) and President Bush's Healthy Forest Initiative in response to the 2002 fire season have stimulated heightened interest in fuel treatments.

This paper describes the scope of fuel management practices by providing an ecological, socioeconomic, and spatial/temporal context to the practice of fuel treatments. The state of science, which focuses on findings from two successive studies of treatment effectiveness to reduce wildfire severity, is described next. The first study (supported by the Intermountain Fire Sciences Laboratory) looked at fuel treatments following the 1994 fire season. The Joint Fire Science Program sponsored the second study, which started in 1999. Together, these two studies provide the most extensive database available on fuel treatment effectiveness in long-needle pines. This paper concludes with comments on how the current body of science is informing management and policy and a recommended agenda for future scientific work.

Scope

Fuel treatment has traditionally focused on biomass reduction to reduce wildfire hazards. More recently, emphasis has broadened to include treatments designed to reduce fuels, not only to reduce hazards but also to restore the role of fire in native ecosystems. Earlier, most fuel treatments were carried out as part of fuelbreak construction and maintenance activities. Most evidence for fuel treatment effectiveness (or ineffectiveness) is anecdotal, not relying on systematic comparisons between treated versus untreated areas, nor providing statistical analysis of results.

By contrast, the study described here focuses on the severity of wildfires that have burned through areas subjected to precommercial or "waste" (in other words, small-diameter) thinnings, in some cases with subsequent application of prescribed fire, as compared to untreated control plots of similar aspect and elevation. All of the areas in the study were burned by wildfires that spread into stands that were treated recently (less than 10 years before wildfire outbreak) to reduce fuel hazards.

Ecological Context

Fire exclusion has resulted in unsustainable forest conditions, including increased density of shade-tolerant trees, dead fuel accumulations, and live fuel canopy closures. Drought has exacerbated the situation, leading to unprecedented, extreme fire behavior—especially in

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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frequent, low-severity fire regimes characterized by long-needle pines (for example, *Pinus ponderosa*). This situation extends into the drier, mixed conifer zones populated by fire-adapted species (for example, *Sequoia gigantea*) as well. Higher-elevation subalpine systems characterized by infrequent, severe, or mixed severity regimes have been less affected by fire exclusion in terms of fuel accumulations although effects of fire suppression may be unknown.

Socioeconomic Context

The expansion in urban interface areas has compounded the likelihood that fires will destroy or damage homes and disrupt commerce or people's livelihoods. Reservoirs, power lines, and transportation corridors (ground and air) are also at risk. High wildfire costs and losses have stimulated public interest but also raised questions about proposed remedies, such as expanded mechanical thinning and prescribed fire programs. Some view the proposed expansion in thinning activities as a veil to allow private industry greater access to logging large trees and old-growth on National Forests (through increases in the diameter of trees considered for removal) and in relatively remote areas. Related concerns include proposed relaxation of environmental protection processes, including public input and legal appeals. Concerns extend to issues regarding roads and endangered species protection.

Public concerns with prescribed fire include risk of escape and smoke. Interestingly, debates about prescribed fire seem less contentious than those about thinning. Fuel mitigation costs are also of concern, as well as the scant information on the effectiveness of thinning as an ecosystem restoration tool.

Fire interacts with many disciplines, including ecosystem science, wildlife and fish biology, and political and social sciences. Other discussion topics at this conference that influence or are affected by fire incidence include climate and landscape change over time, forestry and watershed management (including the fire-flood sequence and biogeochemical cycling), and biological complexity concerns (including invasive plants).

Spatial and Temporal Context in the Sierra Nevada

Fuel treatments are of concern throughout the Sierra Nevada and southern Cascades owing to the presence of flammable vegetation types, including ponderosa pine, mixed conifer, and Jeffrey pine (*P. jeffreyi*) forest types as well as montane chaparral communities. Lower- to mid-elevation systems characterized by frequent, low-severity fire regimes have been most affected by fire exclusion and simultaneously present some of the greatest urban interface challenges because of population ingrowth. Fuel treatments to reduce fuel hazards are more acceptable in these areas. The need for fuel treatments at higher elevations is debatable, with the possible exception of fire restoration efforts using managed lightning and intentional ignitions.

The scope of the proposed expanded treatments is controversial throughout the Sierra Nevada bioregion although there is general agreement that something needs to be done. President Bush's Healthy Forests Initiative follows on the heels of numerous earlier efforts to counter the growing risk of wildfires. Previous initiatives include the 2000 National Fire Plan, the Sierra Nevada Ecosystem Project, Quincy Library Group, and fire restoration efforts in the southern Sierras since the 1970s. In fact, fuel treatments have been practiced in the Sierra Nevada since the early 20th century, including the so-called light-burning controversy (Carle 2002; Pyne 1982) and Ponderosa Way fuelbreak in the 1930s. As early as 1929, E.B. Show had proposed the 650-mile Ponderosa Way and Truck Trail to span the length of the Sierra Nevada, creating a foothills buffer between montane chaparral and timbered areas. Installed with Civilian Conservation Corps labor in the 1930s, the 100- to 300-foot wide fuelbreak fell into disrepair by the 1950s but was largely resurrected by the

early 1970s (Pyne 1982). More recently, experiments with prescribed fire and lightning ignitions in higher elevations have been conducted in national parks (Yosemite and Sequoia-Kings Canyon) and Calaveras State Park, following pioneering research by Dr. Harold Biswell during the 1960s.

State of the Science

Most research to date on fuel treatments, particularly prescribed fire, has taken place in frequent, low-severity regimes, such as ponderosa pine and lower mixed conifer, for example, Giant sequoia and white fir (*Abies concolor*). An overview of this research is presented by McKelvey and others (1996). Higher-elevation red fir (*A. magnifica*) systems also have been studied, with emphasis on national parks (Kilgore 1973). Thinning prescriptions are fairly well-established for meeting timber stand-improvement objectives but not for fuel hazard reduction or ecological restoration objectives. Thinning provides more exact control over the trees removed and retained in a stand but does not replicate burning processes (soil albedo, nutrient cycling, patchy mosaic, and removal of fine fuels).

Forest structural influences on wildland and prescribed fires are described by Agee (1996). Prescriptions for burning in low-severity regimes are fairly well-established (for example, van Wagtenonk 1974). Fuel treatments have been associated with reductions in wildfire severity in ponderosa pine (*fig. 1*), though the degree of effectiveness is variable (Omi and Martinson 2002, Pollet and Omi 2002). Residual tree diameters and historic fire regimes appear to be particularly important for distinguishing stand damage in untreated stands compared with treated stands. The most effective treatments will likely be those that complement ecological restoration objectives. Relatively little data are available from the Sierra Nevada although the findings presented here should be broadly applicable to long-needle pine and drier mixed conifer types.

Results of Statistical Comparisons				
Fire	Crown Scorch	Stand Damage	Ground Char	
Hi Meadow, CO		*		
Megram, CA	**	***	***	
Webb, MT	***	*		
Cerro Grande, NM	***	**	**	
Tyee, WA	****	***	***	
Cottonwood, CA	****	****	n/a	
Hochderffer, AZ	*****	*****	n/a	
Fontainebleau, MS	*****	*****	**	
*	**	***	****	*****
p<0.1	p<0.05	p<0.01	p<0.001	p<0.0001

Figure 1— Summary of differences in crown scorch, stand damage, and ground char in untreated versus treated stands in eight wildfires occurring during 1994–2000.

Fire and fire surrogate studies (McIver, these proceedings) should provide additional insight. But inferences from fuel treatment projects applied at the stand level may not extend to landscape-scale fire disturbances. Similarly, fuelbreak (also called “defensible fuel profile zone”) effectiveness is controversial and has not been established at the landscape scale. Still, fuelbreaks provide options for managing wildfires, anchor points for prescribed fires, and safer access and egress for firefighters (Agee and others 2000).

Uncertainty about fuel-treatment effectiveness is highest in higher-elevation systems, such as lodgepole pine (*Pinus contorta*), and subalpine systems, characterized by mixed or high-severity fire regimes, or both. Extrapolating results from lower-elevation, frequent, low-severity regimes is inappropriate for these systems.

Treatments are effective if they improve options for managing wildfires, but firefighting crews must be able to access and exit a treated area safely in order to make a stand against oncoming fire or to take advantage of airtanker retardant drops. Otherwise, the fire would be expected to spread through the treated area, although with reduced-fire severity, before spreading through the untreated areas.

Drought conditions may obscure changes in fire behavior because of fuel treatments; however, fuel treatments are not intended to stop wildfires. Fire severity may be reduced, for example, when a crown fire drops to the surface once it encounters an area where surface and ladder fuels have been reduced. This effect may be obscured when a wildfire encounters a treated area during a drought. Also, increased solar insolation from the opening of an overstory canopy can result in higher biomass of fine fuels (for example, grasses) that can increase fire spread rates.

During drought, risks and hazards may be high for frequent, low-severity and dry mixed regimes (ponderosa pine and giant sequoia, respectively) throughout the Sierra Nevada. Historically and currently, these areas have the greatest number of ignitions (lightning- and human-caused), and the biological integrity of these systems have been compromised the most by fire exclusion and urban incursions. The 2002 drought demonstrated that fire size and severity may exceed historic ranges of variability in these low-severity regimes. When this occurs, ponderosa pine seed sources may be scarce or nonexistent in extensively burned areas. Furthermore, as witnessed this year, these fires can spread with high severity and threaten lower mixed conifer zones, including valued giant sequoia groves. In the Sierra Nevada as elsewhere, numerous jurisdictions are affected because fire respects no administrative boundaries, including National Forests, national and state parks, and private lands.

How Current Knowledge Informs Management and Policy

The extent to which current knowledge is informing management and policy is difficult to assess. Policy makers and vocal detractors often rely more on political motivations than available science, which can be limited in many instances. Information and tools are probably adequately used, although improvements are always possible. Policy statements tend to deal with the real world in terms of absolute, black and white distinctions, whereas scientific knowledge includes understanding of the inherent variability of natural systems and management interventions. Given this disparity, there is mutual benefit to be derived from improved communications among managers, policy makers, scientists, and the lay public.

Conference proceedings should inform future management decisions. Current interest is high with regard to thinning standards (threshold tree diameters and types of thinning—low, canopy, and so forth), effects on wildfire severity, and treatment and suppression cost reductions.

Future Management Challenges and the Role of Science

The greatest challenges will be the creation and maintenance of sustainable (fire-safe) forests and willingness to accept the adaptive management paradigm. Other challenges relate to optimal strategies for managing higher-elevation systems and translation of results from stands and projects to the landscape scale. The role of science can have the greatest impact in pointing out historical precedents; understanding current ecosystem dynamics; identifying future desired conditions based on historical regimes; identifying tradeoffs, knowledge gaps, and areas of uncertainty associated with various alternatives; assisting in developing defensible positions; monitoring; and evaluation. The public must understand that there will be no quick fixes or magic bullets—undoing the effects of a century of fire exclusion will require patience, cooperation, and tolerance for mistakes. In 1980, the late Dr. Harold Biswell noted, “We cannot expect to undo the failures of the past ...in a short time. That is, neglecting to understand nature and [work] in harmony with it. We must exercise great patience and persistence, too” (Carle 2002, p. 7).

Policy makers and the public need to realize that fuel treatments should always be viewed as work in progress in a changing environment. Once installed, a treated area will require maintenance and tuning. Also, a constantly changing environment may result in a revised perspective toward treatments and their maintenance. Examples of a changing environment include future wildfires, human population incursions, episodic drought, warming and cooling trends, and insect and pest outbreaks. Maintenance questions might revolve around desired species and age distributions, changing tree densities in treated areas, and needs for tree removal, planting, or both.

Recommended Agenda for Future Research

Future research is needed in all aspects of fuels treatment and ecological restoration activities. Possible topics include: (1) effectiveness of fuels treatment and ecological restoration efforts across a spectrum of vegetation and topographic gradients; (2) off-site impacts (including sedimentation in streams) from wildfire and fuels treatments; (3) scale of treatments (including subsequent maintenance) required to manage fire effectively at the landscape level; (4) wildfire and treatment effects on threatened and endangered species, invasive plants, and riparian zones; and (5) social impacts.

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Linking Vegetation Patterns to Potential Smoke Production and Fire Hazard¹

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During the past 80 years, various disturbances (such as wildfire and wind events) and management actions (including fire exclusion, logging, and domestic livestock grazing) have significantly modified the composition and structure of forests and ranges across the western United States. The resulting fuel loadings directly influence potential smoke production from wildland and prescribed fires and affect the vulnerability of landscapes to extreme fire behavior and crown fires. Assessments of potential smoke production and tradeoffs in air quality and fire hazard relative to managed fire and wildfire during large landscape assessments are essential to inform stakeholders involved in landscape-level decision making.

Little information is available on how shifts in forest and range composition and structure over time have changed fuel accumulation on landscapes or affected the associated fire vulnerability and smoke production. The analysis of current and recent (historical) aerial photographs for the *Eastside Forest Health Assessment* (Huff and others 1995) represented an initial attempt to compare potential fire behavior and smoke production in historical and current time periods, based on the comparison of vegetative conditions in 49 watersheds in eastern Oregon and Washington. However, this methodology was designed for forested landscapes and had limited application to other types of landscapes in the West.

We developed a more general method to compare fuel loading, modeled fuel consumption, smoke production, fire behavior, and susceptibility to crown fire in recent historical versus current time periods, on the basis of attributes of vegetation at a variety of spatial scales. Vegetation cover, structure, and management disturbance features were delineated from recent historical and current aerial photography. These features were matched to one of 192 fuel characteristic classes and assigned fuel loadings (Ottmar and others 2001, Schaaf 1996). The fuel loadings were then coupled with typical wildfire and prescribed fire fuel moisture scenarios and entered into fuel consumption models Consume 2.1 (Ottmar and others 2001) and FOFEM 4.0 (Reinhardt and others 1997) to predict fuel consumption and smoke emissions. Finally, the surface fire behavior and crown fire susceptibility of each vegetation patch was modeled using various fire models, such as NFDRS (Deeming and others 1977), other published hazard models (Fahnestock 1970, Rothermel 1972), fuel characteristics, and weather scenarios typical of wildfire and crown fire situations. The changes in area and connectivity of fuel loading, smoke production, and fire hazard could then be quantitatively assessed over time (McGarigal and Marks 1995).

This method was used for the mid-scale assessment of the Interior Columbia River Basin Ecosystem Management Project. The study compared fuel loadings, modeled fuel

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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consumption, smoke production, fire behavior, and crown fire potential in historical and current time periods, based on vegetative attributes of 337 subwatersheds (average size: 9,500 ha [23,475 acres]) distributed in 43 sampled subbasins (average size: 404,000 ha [998,324 acres] average size) selected by random draw from all public and private ownerships within the interior Columbia River drainage and portions of the Klamath and Great Basins. Vegetation cover, structure, and management disturbance features were delineated from historical (1930s to 1960s) and current (1985 through 1993) aerial photography of the sampled subwatersheds. Results of the statistical change analysis were reported at four scales, including the entire Interior Columbia River Basin, the 13 province-scale ecological reporting units (ERUs), subbasins, and selected subwatersheds.

The Interior Columbia River Basin as a whole showed a small but significant increase in fuel loading, wildfire fuel consumption, smoke production of particulate matter less than 10 microns in diameter (PM_{10}), fire line intensity, rate of spread, flame length, and crown fire potential during the past 80 years. Fuel loading increased over the sample period in 8 of the 13 ERUs. In general, an increase in fuel loading was positively correlated with forest vegetation composition shifts from open patches of mid-seral species such as ponderosa pine and western larch to dense patches of mixed coniferous forests. Increased fuel loading was responsible for increases in smoke production, fire behavior parameters, and vulnerability to crown fires. Decreased fuel loading was positively correlated with the occurrence of recent wildfires or harvest activities that had been followed by fuels treatment. Decreases in fuel loading were generally responsible for declines in wildfire smoke, fire behavior parameters, and vulnerability to crown fires. Under current conditions, potential PM_{10} smoke production from a wildfire was two to four times the amount from a prescribed fire.

At the smaller scale, individual subwatersheds generally displayed much greater changes over time than were apparent at the much larger ERU scale. Change at the subwatershed scale was typically related to disturbances such as wildfires or management actions. For example, the Upper Coeur d'Alene #0501 Subwatershed displayed a large increase in fuel loading over time, with a correspondingly large increase in modeled smoke production, fire behavior, and crown fire vulnerability. Major wildfires in 1910 burned a majority of this subwatershed, and as a result, stands of grand fir and Douglas-fir were initiated during the 1920s and 1930s. Under a fire exclusion policy, forests matured into predominantly understory reinitiation structures, resulting in the noted fuel loading increases (*figs. 1–4*).

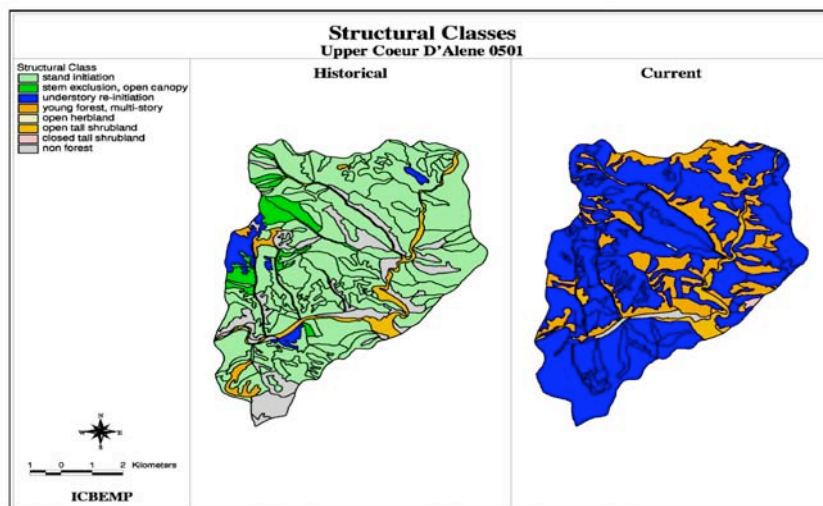


Figure 1— Historical and current structural classes for the Upper Coeur D'Alene #0501 Subwatershed in the mid-scale assessment of the Interior Columbia River Basin.

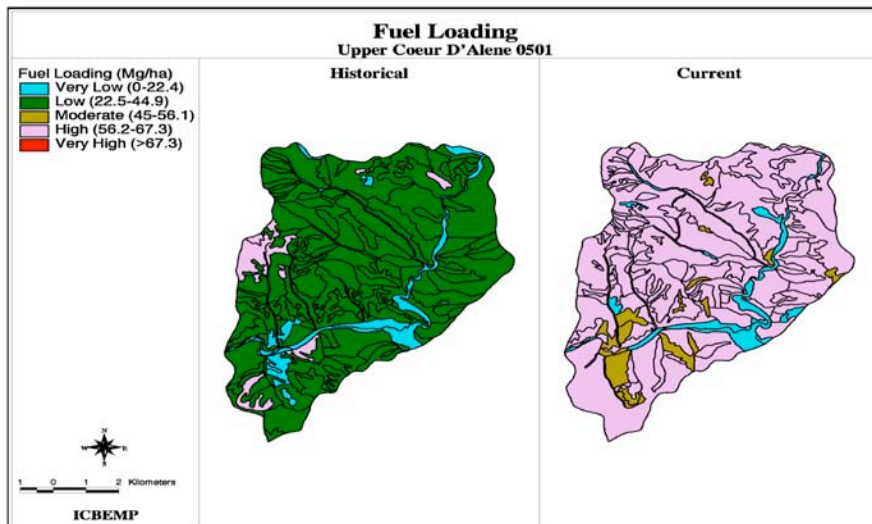


Figure 2— Historical and current fuel loading classes for the Upper Coeur D'Alene #0501 Subwatershed in the mid-scale assessment of the Interior Columbia River Basin.

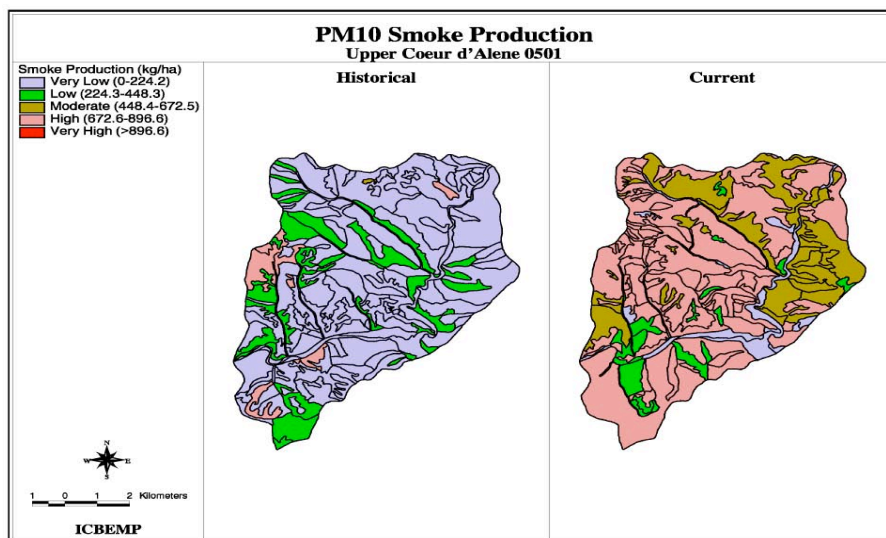


Figure 3— Historical and current potential PM₁₀ smoke production classes for the Upper Coeur D'Alene #0501 Subwatershed in the mid-scale assessment of the Interior Columbia River Basin.

Our general landscape pattern analysis also indicated that changes in fuels, smoke, and potential fire behavior had occurred between the two time periods we examined. Overall, there was an increase in the size and continuity of areas with higher fuel loading, fire line intensity, crown fire susceptibility, rate of spread, and flame length, indicating a higher potential on current landscapes for large, continuous wildfires that produce substantial amounts of smoke.

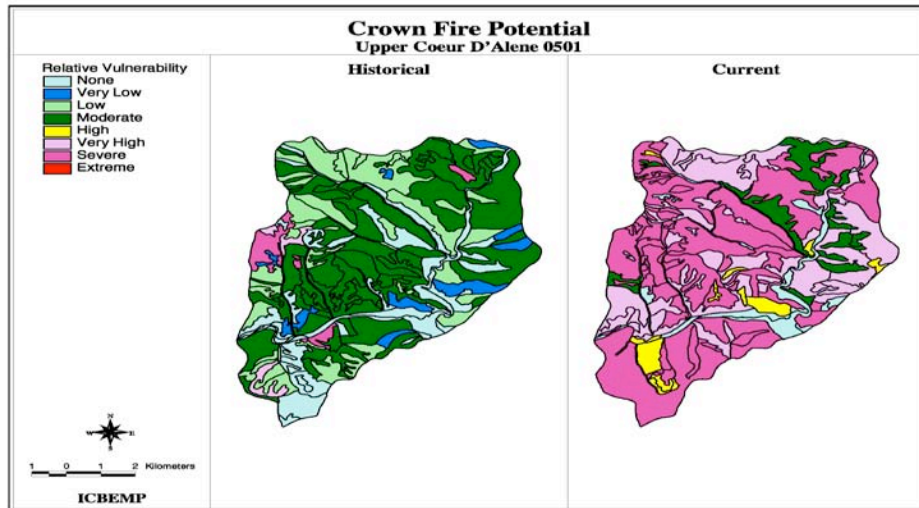
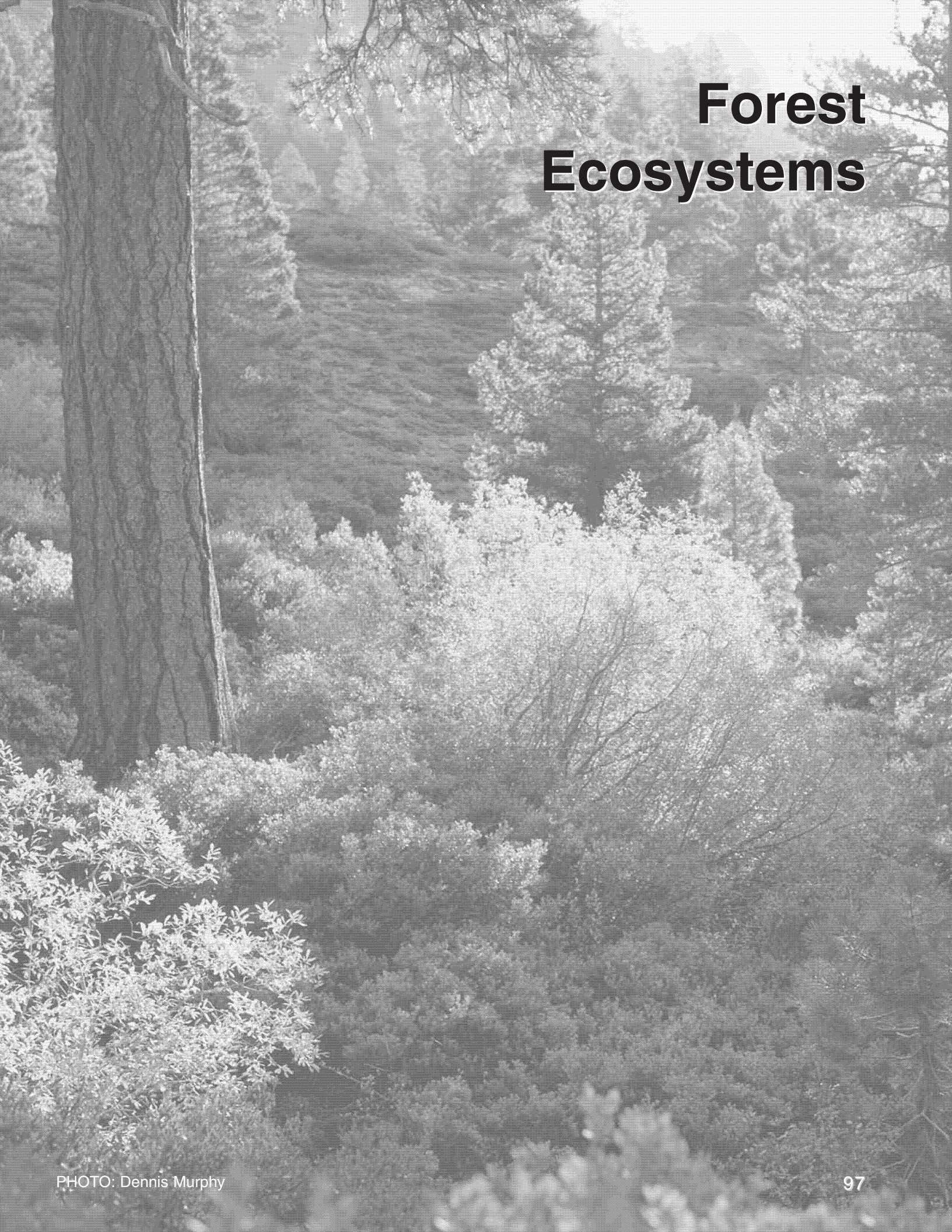


Figure 4— Historical and current crown fire potential classes for the Upper Coeur D'Alene #0501 Subwatershed in the mid-scale assessment of the Interior Columbia River Basin.

Since the early 1900s, human activities such as logging and fire exclusion policies, along with natural disturbances, have significantly changed the spatial distribution and composition of forests and rangelands of the western United States. Understanding changes in vegetation patterns and how these changes will affect the likelihood and outcomes of further natural disturbances and human activities will inform managers and policy makers addressing fire-related problems and decisions.

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Forest Ecosystems

Session Overview: Forest Ecosystems¹

John J. Battles² and Robert C. Heald³

The core assumption of this symposium is that science can provide insight to management. Nowhere is this link more formally established than in regard to the science and management of forest ecosystems. The basic questions addressed are integral to our understanding of nature; the applications of this understanding are crucial to effective stewardship of natural resources (Carpenter and Turner 1998, Christensen and others 1996). For example, the challenge of managing Sierra Nevada forests motivated an unprecedented ecosystem assessment of the entire bioregion with the explicit goal of generating management options (SNEP 1996). Yet despite the attraction of “the ecosystem approach” as both a fundamental ecological concept (Pickett and Cadenasso 2002) and a philosophical management paradigm (Rauscher 1999), the complexity of ecosystems perplexes scientists and managers. Ecosystems by definition are multidimensional (Pickett and Cadenasso 2002). They cross spatial and temporal scales, ignore political borders, and transcend the expertise of any one discipline. At the same time, ecosystems are real places where boundaries are defined, services are expected, and managers are held responsible.

The contributors in this session confront this multidimensionality head-on. On display are new insights about the linkages between the biotic and abiotic components of the Sierra Nevada ecosystem. The fundamental role of human impacts and interventions figures prominently in every presentation.

Allen Goldstein highlights recent findings from his work on biosphere-atmosphere interactions. He shows how emissions of nitrogen oxides from the Sacramento urban area contribute to upwind ozone pollution in forests of the Sierra Nevada. He also presents novel results that suggest forest operations may affect regional air quality. Goldstein and his colleagues found that precommercial thinning of a pine plantation dramatically increased biogenic hydrocarbon emissions from the stand. Such hydrocarbons are essential precursors of ozone and aerosol formation.

Dean Urban’s work in the southern Sierra Nevada focuses on the interactions between climate, forest process, and fire. He addresses the challenge inherent in the ecosystem approach: how to extrapolate information across spatial scales. He provides a compelling framework for a model-data dialogue designed to make tractable investigations of large and complex landscapes.

Dale Johnson examines the biogeochemistry of forested watersheds on the east side of the Sierra Nevada. In particular, he describes the annual patterns of nutrient flux associated with snowfall and snowmelt as well as the impact of a wildfire on carbon and nitrogen pools. In terms of snowmelt biogeochemistry, the function of east-side watersheds cannot be simply extrapolated from results derived from better-studied sites on the west side of the Sierra Nevada. Johnson and his colleagues (in these proceedings) also quantified losses and recovery of nutrient capital associated with wildfire. For example, the magnitude of nitrogen

¹This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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loss at a site affected by a wildfire and subsequent salvage logging dwarfed the nitrogen fluxes associated with atmospheric deposition and leaching.

Barbara Allen-Diaz summarizes findings from her research on meadow and wetland ecosystems embedded within Sierra Nevadan forests and woodlands. She notes that these grass-dominated communities exist within a context of historical grazing. Allen-Diaz demonstrates how grazing studies can enhance our understanding of ecosystem function and improve the management of these important ecosystems. As an example, she presents results from her studies of spring-fed wetlands nestled within blue oak woodlands. She and her colleagues convincingly show how light grazing in these wetlands can increase species diversity with no measurable impacts on water quality. Alternatively, heavy grazing or ill-timed grazing can degrade the health of these key wetlands.

Kevin O'Hara asks how forest management can be modified to fall more in line with the natural temporal-spatial dynamics of disturbances in the Sierra Nevada. He characterizes forest stand dynamics as a multidimensional, chaotic process and notes that past land uses in the Sierra Nevada have created a complex array of stand structures. O'Hara makes a compelling case that modern silviculture can not only accommodate this complexity but also exploit it. He and his colleague have demonstrated how uneven-aged, multi-cohort stands can simultaneously meet ecological and production goals.

The contributions to this session represent the extent, scope, and quality of ecosystem science focused on the Sierra Nevada, and they also reflect the broader questions facing environmental scientists and managers. For example, a recent conference on future directions for air-quality research identified the ecological aspects of tropospheric ozone and atmospheric nitrogen pollution as priority issues for investigation (Ginsburg and Cowling 2003). The contributors to this session also highlight the importance of conducting area-specific research in potential management areas rather than simply extrapolating research findings from other sites (*sensu* Veblen 2003).

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Biosphere and Atmosphere Interactions in Sierra Nevada Forests¹

Allen H. Goldstein²

In the Sierra Nevada, studies are being conducted to assess the impacts of both anthropogenic and biogenic hydrocarbon emissions on regional tropospheric ozone and fine aerosol production. Impacts of ozone deposition and management practices on ecosystem health are also being studied. Human-induced changes in regional air quality have consequences for Sierra Nevada ecosystems and human health. To explore these consequences, research has been conducted at a site in the central Sierra Nevada since June 1997. The research site is located in a ponderosa pine plantation which is downwind of the significant anthropogenic pollution sources of Sacramento and the agricultural Central Valley (Goldstein and others 2000). To illustrate the complex links between air pollution, biogenic gas emissions, and forest management, three specific results from this research are briefly summarized below.

Anthropogenic emissions of nitrogen oxides contribute to ozone pollution in the Sierra Nevada.

Ozone causes significant problems when it occurs at high concentrations in the troposphere (lower atmosphere). A byproduct of human pollution, tropospheric ozone can damage lungs and trees and is a serious problem in the Sierra Nevada where summer levels regularly exceed State and Federal standards. Damage to ponderosa and Jeffrey pines is routinely observed.

The formation of ozone occurs when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react in the presence of sunlight. These chemicals are produced both by humans (anthropogenic) and through natural (biogenic) processes. For example, VOCs are typically produced by trees. To effectively manage air quality, it is critical to understand the contributions from these various sources so as to appropriately target pollution-reduction measures.

During the summers of 1998 and 1999 continuous, hourly measurements of hydrocarbons were made at the Blodgett Forest Research Station using instrumentation based on a gas chromatograph with dual flame ionization detector (GC-FID). Combining these measurements with knowledge about local meteorology, researchers were able to determine the contributions of anthropogenic and biogenic VOCs to local ozone production.

Researchers found that biogenic, or forest-produced VOCs, contributed to between 40 and 70 percent of total ozone production. Furthermore, they suggested that the amount of ozone produced in this manner was controlled by the NO_x concentrations being delivered from the Sacramento Valley rather than by the biogenic VOC production itself (Bauer and others 2000, Kurpius and others 2002).

Regulations to reduce ozone production can target either human-produced NO_x or human-produced VOCs. Given that trees contribute a large portion of the VOCs and that NO_x

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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seems to control overall ozone production, regulatory efforts can be focused on further controlling anthropogenic NO_x emissions.

Ozone deposition research may improve models for predicting damage to trees.

High levels of ozone due to air pollution in the troposphere can cause significant damage not only to human health but also to forests. In California, ponderosa pines, a dominant tree of Sierra Nevada forests, are particularly susceptible to injury from the uptake of ozone.

Most metrics of ozone damage to date have assumed that maximum injury occurs when ozone is at its highest concentration. A combination of climatic factors and tree physiology, however, refutes this assumption in many cases. To assess the potential impact of ozone on California forests, it is important to better understand the circumstances under which ozone damage occurs (Panek and others 2002).

Since 1997, a number of experiments at the Blodgett Forest Research Station and at sites throughout the Sierra Nevada have been performed to study the environmental and physiological factors that control ozone uptake by trees. Researchers have examined the effect of ozone concentration, drought, and tree phenology (when buds break) on ozone uptake and have also looked at different pathways of ozone deposition in forests (Bauer and others 2000, Panek and Goldstein 2001).

The work has shown that climatic variability from year to year and season to season can have a large impact on the amount of ozone taken up by trees. Drought can greatly reduce uptake owing to the closing of stomata (pores through which ozone uptake occurs and which close in response to lack of water), and only about a third of total annual ozone uptake occurs during the summer when ozone concentrations are highest (Kurpius and others 2002). One of the most surprising findings is that, during the summer months, about half of the ozone deposited is actually lost through gas-phase chemical reactions in the canopy rather than through uptake by trees (Kurpius and Goldstein 2003). All of these results provide a more complete picture of the conditions that influence ozone injury to forests. Contrary to previous assumptions, the greatest damage may occur when ozone concentrations are not at their highest (Goldstein and others 2003).

The research on ozone deposition has resulted in a far more comprehensive understanding of when trees take up ozone through their stomata and how ozone is actually deposited in ecosystems. This information will be critical in developing models to predict and assess pollution damage to California's forests and will put managers in a better position to protect them in the years ahead (Panek and others 2003).

Precommercial forest thinning may affect regional air quality.

Biogenic hydrocarbon emissions contribute to tropospheric ozone and aerosol production. One important class of such compounds, monoterpenes, is emitted by many forest ecosystems. Monoterpenes produce the familiar "pine" smell associated with softwood cutting. Models of monoterpene emission rates from forests typically presume emissions to be driven by temperature and sometimes by ambient light. However, several studies have shown that mechanical disturbances, such as touching, rain, or herbivory, can enhance emissions. It seemed reasonable to expect that forest operations might also affect monoterpene emissions.

In this study, monoterpene flux from a ponderosa pine plantation (Blodgett Forest Research Station) was measured before, during, and after a precommercial thinning operation. The thinning was conducted in spring 2000. Approximately one-half of the plantation biomass was thinned and left onsite.

Measurements indicated that monoterpene output increased tenfold during the thinning. Most of the increase was due to higher basal emission rates. However, a small change in temperature dependence was detected. The thinning increased subsequent yearly emissions by a factor of five.

Given the magnitude of this increase, it is conceivable that regional atmospheric chemistry could be affected by forest operations such as precommercial thinning. If the responses observed here were extrapolated to all the documented timber removal in the pine forests of the United States, national estimates of monoterpene emissions could be underestimated by several percent (Schade and Goldstein 2003).

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Landscape Pattern and Ecological Process in the Sierra Nevada¹

Dean L. Urban²

The Sierran Global Change Program in Sequoia-Kings Canyon and Yosemite National Parks includes a nearly decade-long integrated study of the interactions between climate, forest processes, and fire. This study is characterized by three recurring themes: (1) the use of systems-level models as a framework for integration and synthesis, (2) an effort to extrapolate an understanding from the local scale of field studies to the much larger extent of the two parks and the southern Sierra Nevada, and (3) an iterative model-data dialogue in which model development and analysis provide a context and focus for field studies. This paper provides a brief overview of recent efforts, couched in the framework of a model-data dialogue. The first part presents a systems-level simulation model, developed as a working model, and reviews some implications of applying the model. The second part of this paper illustrates how model development and analysis have helped establish priorities for follow-up field studies aimed at improving understanding of Sierra Nevada systems. This iterative approach has proven to be a powerful method for extending an understanding of a system that would otherwise be intractably large and complicated.

Model-based Synthesis and Exploration

The simulation model is based on a forest gap model, extended to address ecosystem processes (hydrology, nutrient cycling) and the spatial heterogeneity engendered by climatic and edaphic gradient complexes in montane systems. The model consists of four component modules and a fire model that interacts with each in turn (*fig. 1*). Details are provided by Urban and others (2000) and Miller and Urban (1999a–c; 2000a, b).

The model simulates a grid of tree-sized (15 by 15-meter) plots, and the plots interact via shading (and in some versions, via seed dispersal dynamics). The gridded stand is oriented to represent a slope facet defined by elevation, slope, aspect, and soil type, and the model adjusts temperature, precipitation, and radiation to this topographic position. Simulations emphasize the role of soil water balance in governing the distribution of mixed conifer forests in the system: the mixed conifer zone is sandwiched between lower-elevation sites that are too dry to support forests and upper-elevation sites that are too cold. The location of the mixed conifer zone coincides with the elevation at which winter snowpack is sufficient to support trees into the summer (Urban 2000, Urban and others 2000).

The fire regime maps onto the elevation gradient in an intuitively straight-forward manner: at lower elevations, fires are frequent but small, whereas at higher elevations they are less frequent but larger (Miller and Urban 1999a). Fire-climate interactions, however, are more complicated than this gradient suggests. At low elevations, fuels are essentially always dry enough to burn, but fuel loads are often limiting. Thus, fires tend to occur in (typically) dry years which follow an unusually wet year; the wet year provides for larger fuel loads the

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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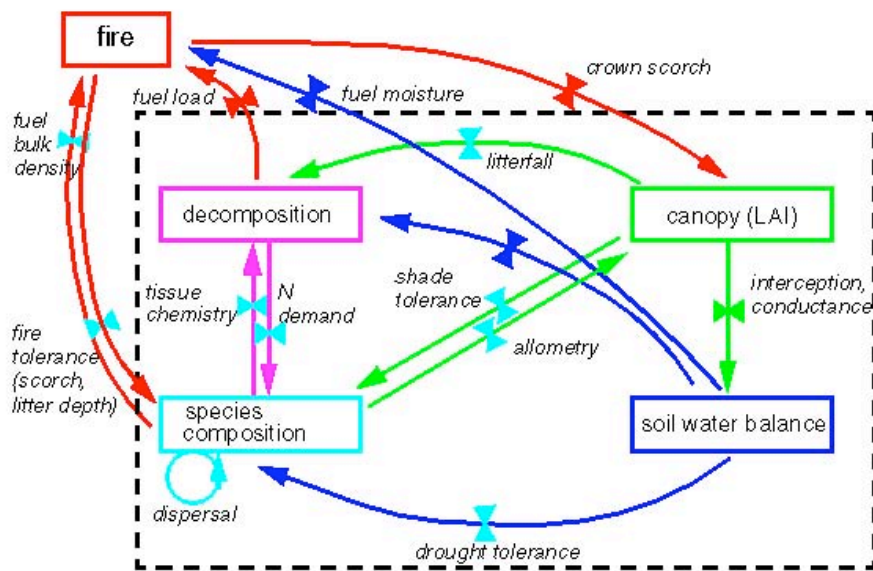


Figure 1— Schematic (Forrester) diagram of the forest simulator ZELIG version FACET as implemented for the Sierra Nevada. Boxes represent component modules, and arrows denote biophysical couplings between modules. Switches (bow-ties) are rate moderators, and those in cyan are couplings in which details of species composition mediate ecosystem processes. The model is detailed by Urban and others (2000) and Miller and Urban (1999a).

next year. Conversely, at higher elevations there is usually plenty of fuel, but it is often too wet to burn; big fires tend to occur during anomalous dry years. Thus, whereas average climate generates a gradient in fire regime with elevation, the variability in climate has a strong influence on the fire regime—and it is opposite extremes in this variation that are important at low versus higher elevations. Model analysis has shown that the indirect effects of climate change on the fire regime—effects mediated by species-specific variation in fuel characteristics—can have substantial influence on transient responses to climate change (Miller and Urban 1999b). These interactions and feedbacks should be considered in all speculations about the possible consequences of anthropogenic climate change.

Scaling from Trees to Landscapes

The gap model operates at a spatial scale of hectares, yet the goal is to extend the analysis to much larger landscapes—spatial scales well beyond the scope of the simulator. The approach to this scaling mismatch has been to develop a second model, one conceptually and parametrically consistent with the gap model but capable of operating at much larger scales. The second model is built as a statistical summary and abstraction of the detailed model, in effect a model of the simulator—a metamodel. Thus far, prototype metamodels of various forms have been developed: a semi-Markovian patch transition model, a stage-structured matrix model, and a cellular automaton (Urban and others 1999). This tandem approach to modeling provides a toolkit of various models, all based on the same assumptions and data, but useful for addressing a variety of issues at different spatial and temporal scales.

Model-guided Field Studies

The preliminary small-scale model described thus far was built largely from existing data. Recent efforts have used this model as a vehicle for establishing priorities for further field

studies. For example, Urban (2000) conducted a formal sensitivity analysis of the soil water model and then mapped climate-sensitive locations in the study area as a way to focus a sampling and monitoring design for the global change program in Sequoia National Park. Spatial analysis of the physical template of the Sequoia National Park (Urban and others 2000) was used to design a sampling scheme that could resolve species-environment relationships at the spatial scales of edaphic, microtopographic, and elevation gradients. Analysis of empirical models built from these data, in turn, allowed researchers to target additional field sites that would best resolve uncertainties in the preliminary model (Urban and others 2002).

New data collected in the most recent field studies bring to a close a multi-year field campaign conducted wholly in response to the initial multi-year effort at model development, exploration, and analysis. Thus, those involved with this study are now prepared to return to the modeling phase of the model-data dialog. The new data will be used to revise and refine the initial models, creating a new synthesis that will further our understanding of Sierra Nevada forest systems.

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Nutrient Cycling in the Sierra Nevada: The Roles of Fire and Water at Little Valley, Nevada¹

Dale W. Johnson²

Spatial and temporal patterns of water flux, ion flux, and ion concentration were examined in a semiarid, snowmelt-dominated forest on the eastern slope of the Carson Range in Little Valley, Nevada (Johnson and others 2001). Variations in data collected from 1995 to 1999 were used to examine the potential effects of snowpack amount and duration on ion concentrations and fluxes.

The analysis of interannual trends in this data set was complicated by the fact that all 5 years had above-normal snowfall; nonetheless, the data show that interannual differences in ion input via snow can vary considerably and quite independently from total snowfall amount. On a spatial basis, increased snowmelt resulted in increased inputs of only some ions (primarily base cations and Cl^- during some seasons). It is therefore not safe to assume that changes in snowfall amount will cause concomitant changes in ion inputs via snowfall in this system. Soil solution NO_3^- and NH_4^+ concentrations and fluxes were uniformly low, and the variations in concentrations bore no relationship to snowmelt water flux or the input of these ions from the snowpack. Apparently, biological uptake controlled NO_3^- and NH_4^+ quite closely at all times. It was clear that weathering caused a net loss of base cations from these soils and that the water flux alone did not greatly influence base cation concentrations; it was equally clear that soil solution cation concentrations were affected by cation concentrations in snowmelt. Soil solution o-PO_4 concentrations were uniformly low and unaffected by either water flux or variations in inputs of o-PO_4 from snowmelt. Soil solution SO_4^{2-} concentrations, although not directly related to water flux, closely followed the patterns in snowmelt water, suggesting minimal buffering by solid-phase soil SO_4^{2-} adsorption. It appeared that Cl^- was a conservative ion in this system: snowmelt Cl^- concentrations did not decrease with increasing water flux, either on a temporal or spatial basis.

Perhaps the most interesting result of this investigation was the timing of ion release during snowmelt. Most studies have found that the majority of ions exit the snowpack in advance of the bulk of the water. This pattern clearly did not hold for the Little Valley site. Possible reasons for this include sublimation and dry deposition of dust and organic detritus to the snowpack during the later periods of snowmelt. Sublimation may well accelerate during the later phases of snowmelt as daytime temperatures rise, causing an increase in the concentration of ions remaining in the snowpack. The presence of both mineral and organic matter in the snow in Little Valley was quite evident during the later stages of snowmelt. These materials may be leached of nutrients as temperatures increase, resulting in higher ion concentrations.

In another study in Little Valley, carbon (C) and nitrogen (N) losses (due to a wildfire and post-fire salvage logging) and gains (due to regrowth and N fixation during a 16-year period) were estimated (Johnson and others [In press]). The wildfire caused minimum losses of approximately 42 percent (100 kg ha^{-1}) of aboveground N in trees, but only 6 percent (3,800

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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kg ha⁻¹) of aboveground C (assuming all foliage was consumed). On an ecosystem level, the fire consumed approximately equal percentages of total C and N (12 and 9 percent, respectively), but a considerably greater proportion of aboveground N (71 percent) than C (21 percent). Salvage logging was the major factor responsible for losses, and C lost from the site will not be replenished until forest vegetation is established and succeeds (that is, largely replaces) the current shrub vegetation. N₂ fixation by *Ceanothus velutinus* (snowbrush) in the post-fire shrub vegetation over the first 16 years appears to have more than made up for N lost by gasification in the fire and may result in long-term increases in C stocks once forest vegetation takes over the site. N loss from the fire was equivalent to more than 1,000 years of atmospheric N deposition and more than 10,000 years of N leaching at current rates. Soil N pools were larger in snowbrush-dominated sites than in an adjacent intact forest, but no definitive value for N accretion in soils could be calculated. The benefits of allowing post-fire N fixation by shrub vegetation to replenish and even exceed the N losses due to fire and logging must be weighed against the severe competition such vegetation creates for regenerating forests.

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Sierra Nevada Grasslands: Interactions Between Livestock Grazing and Ecosystem Structure and Function¹

Barbara H. Allen-Diaz²

Livestock grazing plays an integral role in the grass-dominated ecosystems of the Sierra Nevada. Grazing has been asserted to influence such key ecological characteristics as water quality, net primary productivity, nutrient cycling, plant and animal diversity, wildlife habitat availability, and oak regeneration (Belsky and others 1999, Kauffmann and Krueger 1984). Although there are many reports of these effects, an important task is determining which assertion constitutes reliable knowledge. In other words, how well do we know the cause of change? In fact, there is precious little conclusive experimental evidence (Allen-Diaz and others 1999). We do know that managers have varying control over essential elements of grazing, such as kind of grazing animal, number of grazing animals, and the season of grazing animal use. Many reports on grazing affects either fail to establish adequate experimental controls or are inadequately documented as to the details of grazing (Allen-Diaz and others 1999, Tate and others 1999). The result is uncertainty about the true effects of grazing. We do know that managers can use grazing animals to achieve conservation objectives as well as limit potential adverse impacts (Allen-Diaz and Jackson [in press]).

Case Study

Spring-fed wetlands in the Sierra Nevada oak woodlands are a good example of an ecosystem where grazing animals are expected to have a large, potentially negative impact on plant community dynamics and biogeochemical cycling (Fleischner 1994). Although wetlands in the Sierra Nevada represent a small fraction of the total land cover, they are particularly important areas and affect ecosystem processes at rates disproportionate to their size. Wetlands are very productive, support high biodiversity, provide wildlife habitat, and have significant effects on water quality (Mitsch and Gosselink 1993). In the case of the spring-fed wetlands nestled within the oak woodland/annual grass community of the Sierra Nevada foothills, they exist within a context of historical grazing. If we are to learn the best way to protect these rare and important systems, we must garner a better understanding of how grazing affects them and in what manner they can best be managed.

Long-term (4 to 14 years of continuous data collection, depending on variables) research has been focusing on the effects of various controlled cattle-grazing treatments on spring-fed wetlands of the Sierra Nevada foothills at the University of California's Sierra Foothill Research and Extension Center near Brown's Valley, California. Treatment plots range from 0.75 to 1.2 hectares and are enclosed with a 2-strand electric fence. Each plot contains a spring and ephemeral creek in addition to the annual grassland and oak woodland matrix. Cattle numbers and days of use are recorded during three to four grazing periods per year in order to achieve grazing treatment levels of 800–1,000 kg/ha (light grazing) or 500–600

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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kg/ha (moderate grazing) residual dry matter (RDM) in the uplands. The third grazing treatment removes domestic grazing animals from the plots. Using annual grass RDM as the quantified treatment level follows existing management practices for grazing California annual grassland (Bartolome and others 2002). Researchers have tracked species composition, cover, channel morphology, water quality, and aquatic insects (Allen-Diaz and Jackson 2000, Allen-Diaz and others 1998a, Campbell and Allen-Diaz 1996) and examined carbon, nitrogen, and methane dynamics (Jackson and Allen-Diaz 2002, Oates and others 2004).

Research findings show that, in some cases, plant composition can be manipulated with grazing and that lightly grazed sites maintain a greater diversity and evenness of species. Total plant cover (*fig. 1*) did not differ among the sites after 7 years, but after 10, moderately grazed sites showed significant decreases in cover (indicating the importance of long-term monitoring). The effect on water quality varied. Spring-fed wetlands did not show any response to grazing treatments (*table 1*) during the first 5 years of the study, (Campbell and Allen-Diaz 1996), but further studies showed that removing grazing from spring-fed wetlands resulted in increased nitrate concentrations in spring waters (Allen-Diaz and others [in press], Jackson 2002) (*fig. 2*). On the other hand, removal of grazing also resulted in lesser emissions of methane, a potent greenhouse gas (Oates and others 2004). Channel morphology did not vary with treatment (Allen-Diaz and others 1998), but the species richness of aquatic insects tended to decrease with moderate grazing (Allen-Diaz and others 1998b).

The effect of grazing on spring-fed wetlands is complex, but in a broad sense, these studies indicate that some level of grazing is probably desirable, particularly from the standpoint of species diversity and productivity. In addition, removal of grazing can have a negative impact on water quality by increasing the concentration of nitrates that are released into spring waters. However, the results also suggest that high levels of grazing can damage these systems and grazing in general may increase methane greenhouse gas emissions. Therefore, appropriate management, including adjustments to the timing and intensity of grazing, should be used to maximize the health of these wetlands and their benefit to the larger landscape.

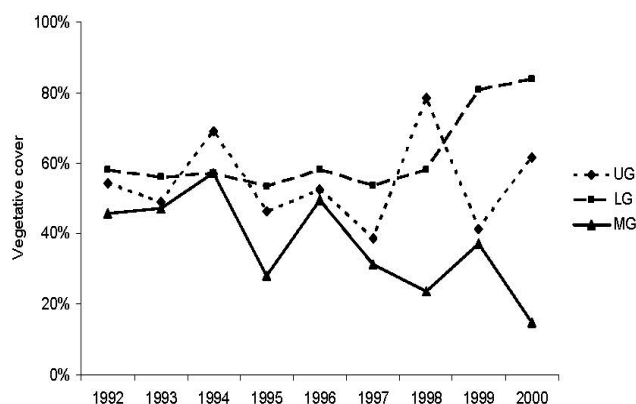
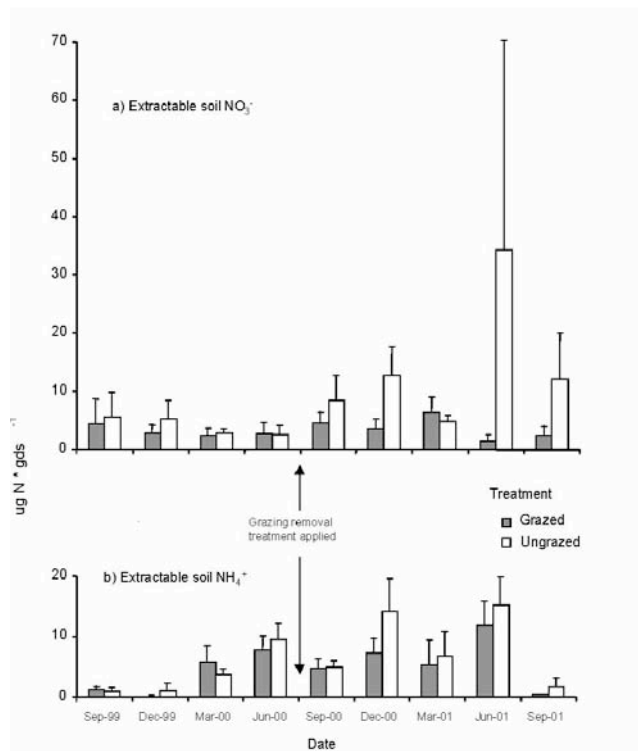


Figure 1— Changes in total mean vegetation cover on ungrazed (UG), lightly grazed (LG), and moderately grazed (MG) springs at Sierra Foothill Research and Extension Center. Adapted from Allen-Diaz and Jackson (2000).

Table 1— *Spring-fed wetlands did not show any response to grazing treatments after 5 years on Sierra Foothill Research and Extension Center springs.*

Water Quality Measures	Moderately Grazed	Lightly Grazed	Ungrazed
Nitrate (mg/l)	1.17 (1.02)	1.78 (1.15)	1.92 (1.08)
Orthophosphate (mg/l)	0.10 (0.05)	0.13 (0.08)	0.15 (0.09)
Dissolved O ₂ (mg/l)	4.85 (1.62)	7.02 (10.96)	5.32 (1.90)
Temperature (degrees C)	17.42 (4.29)	17.62 (3.75)	17.77 (3.43)
pH	6.85 (0.64)	6.81 (0.57)	6.79 (0.56)

Adapted from Campbell and Allen-Diaz (1996).

**Figure 2—** Mean ($\pm$ SE) 2M-extractable soil (a) NO₃⁻ and (b) NH₄⁺ pools from spring-fed wetland sites. Figure indicates increased nitrate concentrations in spring waters with removal of grazing.

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Forest Stand Structure and Development: Implications for Forest Management¹

Kevin L. O'Hara²

A general premise of forest managers is that modern silviculture should be based, in large part, on natural disturbance patterns and species' adaptations to these disturbances. An understanding of forest stand dynamics is therefore a prerequisite to sound forest management. This paper provides a brief overview of forest stand development, stand structures, and disturbance regimes and discusses the implications of applying this information to forest management in the Sierra Nevada. It focuses on three forest types that comprise the bulk of the managed land base: mixed conifer, ponderosa pine, and red fir forests.

In forest stands in all regions of the world, similar stand development processes occur in highly different ecosystems (Oliver 1992). Most descriptions of stand development characterize it as a progression through stages toward an older forest, possibly an old forest, in the absence of disturbance. Disturbances, from human or other causes, can move stand development backward or forward in the process, depending on their type, severity, and timing. As a result, stand development is best characterized as a multidirectional, chaotic process, and a given stand structure can originate from a number of different pathways. From a forest management perspective, this implies that there are a variety of ways to create a stand structure, providing some flexibility in designing silvicultural treatments.

Present forest structures in the Sierra Nevada are the result of a range of disturbances. These include a wide variety of fire regimes, wind patterns, insects, pathogens, and past timber harvest practices, such as high-grading performed in various ways under the guise of "selective" cutting, seed tree harvesting, and, more recently, plantation management. These disturbances and the subsequent regrowth of forests have created a highly diverse series of landscapes and a high level of diversity within those landscapes.

Time-Space Disturbance Continuum

Seymour and others (2002) state it is believed that, in forests in the northeastern United States natural disturbances occur over larger areas as the interval between disturbances increases. Comparing natural disturbances to timber harvest practices, clearcut harvesting usually occurs at shorter disturbance intervals than those typical of natural disturbance events of similar size (20 ha). Shelterwood harvest treatments, because they affect a smaller area, represent a spatial-temporal process that is closer to the norm. Selection treatments are generally within the normal range. Although Western forests experience larger-scale disturbances, these events can occur within the same area at frequent intervals. Nevertheless, the implication that small-scale disturbances naturally occur more frequently than larger-scale disturbances probably holds, in principle, for Sierra Nevada forests as well as other Western conifer-dominated forests.

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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If one accepts the principles that natural disturbance severity, frequency, and spatial extent are related (albeit with some exceptions) and that forest management practices might be pushing the limits of system resilience by directly or indirectly causing more frequent and severe disturbances than would naturally occur, how can forest management be modified to fall more in line with the natural temporal-spatial dynamics of disturbances in the Sierra Nevada? One alternative is to extend rotation lengths for even-aged silvicultural systems. Rotations in California range from 50 to 80 years, or more on slower-growing sites, and are restricted on State and private lands to 50 years or more by California forest practice regulations. Rotation lengths have typically been determined by the point at which mean annual volume increment (MAI) is maximized or the point at which financial returns are maximized. Longer rotations would have lower volume productivity or lower financial returns. A recent examination of patterns of MAI in thinned coast Douglas fir (*Pseudotsuga menziesii* var *menziesii*) in the Pacific Northwest indicates that MAI does not peak as early as previously believed and, in many cases, shows no sign of reaching a maximum in either cubic or merchantable (board foot) units (Curtis and Marshall 1993). Earlier mistaken assumptions regarding the maximization of MAI in thinned Douglas fir stands were attributed to a poor understanding of height growth patterns in Douglas fir, a species with a prolonged height growth pattern, and a poor understanding of the effects of thinning on volume increment. The implication is that rotation lengths could be extended for these forests without any appreciable loss in volume productivity. It is likely that similar results are possible in Sierra Nevada conifers because these species possess similar, prolonged height-growth rates. If similar patterns do occur and if longer rotations were widely adopted in the Sierra Nevada, this would lead to major changes in the distribution of stand structures over broad scales and an increase in the number of stands containing old forest features.

Uneven-aged silviculture also offers opportunities for management strategies that incorporate a more natural distribution of temporal-spatial disturbance patterns. However, this does not include the traditional form of single-tree selection silviculture that relied on very minor disturbances and used negative exponential diameter distributions to guide the selection of target structures. Instead, the creation of simpler two- or three-aged stand structures is recommended, as these require less frequent entries, provide sufficient light resources for regeneration of shade-intolerant species, and more closely represent the effects of natural disturbance processes (O'Hara 1998).

The formation of relatively large gaps for regeneration or group selection represents another alternative to traditional single-tree selection. This method is suitable for management of shade-intolerant species and mimics natural dynamics of Sierra Nevada ecosystems by representing the small cleared patches formed by natural disturbances, such as mixed-severity fires, insects, or pathogens.

A related form of uneven-aged silviculture is currently known as "variable retention": individual trees or clumps of trees are reserved after harvest. The purpose of retaining these trees is to provide structure, future snags, and coarse woody debris to enhance wildlife habitat or improve the visual appearance of units harvested with even-aged methods. The resulting two-aged stands are essentially similar to the products of more traditional regeneration methods, such as seed tree with reserves or shelterwood with reserves. Reserve trees are trees retained through a subsequent rotation.

Data comparing the productivity of these forms of uneven-aged silviculture with that of even-aged systems are scarce. Current opinion assumes some loss in productivity with the more complex systems as well as greater financial costs. O'Hara (1996) compared LAI (leaf area index) and volume growth between even-aged and multiaged (two or more age classes) ponderosa pine (*Pinus ponderosa*) stands and found no differences. In follow-up work, Nagel and O'Hara (2002) found late-season water limitations in even-aged ponderosa pine stands that might contribute to a productivity advantage for multiaged stands. The greater

economic costs associated with managing uneven-aged stands appears to be the result of more expensive harvesting and possibly more frequent stand entries.

Restoration

Restoring existing stands to reflect presettlement conditions or other standards is becoming a frequent goal of forest management in the Sierra Nevada. Among the most common objectives are restoration of old forests and enhancing stand structural diversity in younger forests. Restoration of old forest features generally entails reducing the stand density in younger stands to correspond with that of older forests. This accelerates growth rates and aids the formation of structural elements, such as lichens and mosses. Even old trees can respond positively to a thinning treatment. Latham and Tappeiner (2002) reported that older individual ponderosa pine, Douglas fir, and sugar pine (*Pinus lambertiana*) trees all responded with faster growth and greater vigor to additional growing space in southwest Oregon mixed conifer stands. Ultimately, more trees can be left as snags or coarse woody debris on the forest floor.

Other work in coastal Douglas fir has shown that old forest trees frequently grew in wide spacings, as evidenced by their rapid initial growth rates (Tappeiner and others 1997). These initial growth rates have in some cases exceeded those of the widest spacing trials. The implication is that these old forest trees initially grew with little competition and this contributed to their large size. It is not known whether this is also true for the Sierra Nevada, but the topic warrants further study.

Variable-density thinning is another method to increase stand-level variability such that stand structures may begin to reflect natural disturbance patterns more closely. This thinning concept applies to either precommercial or commercial thinning operations. Variable-density thinning simply applies different prescriptions to different parts of a stand so that some areas might be thinned heavily and others not thinned at all. The result is that some areas develop with wide spacing among trees and other areas of the same stand develop with heavier competition among trees. This method potentially influences the way stands are defined and characterized; they may be classified according to a common operation rather than a common structure.

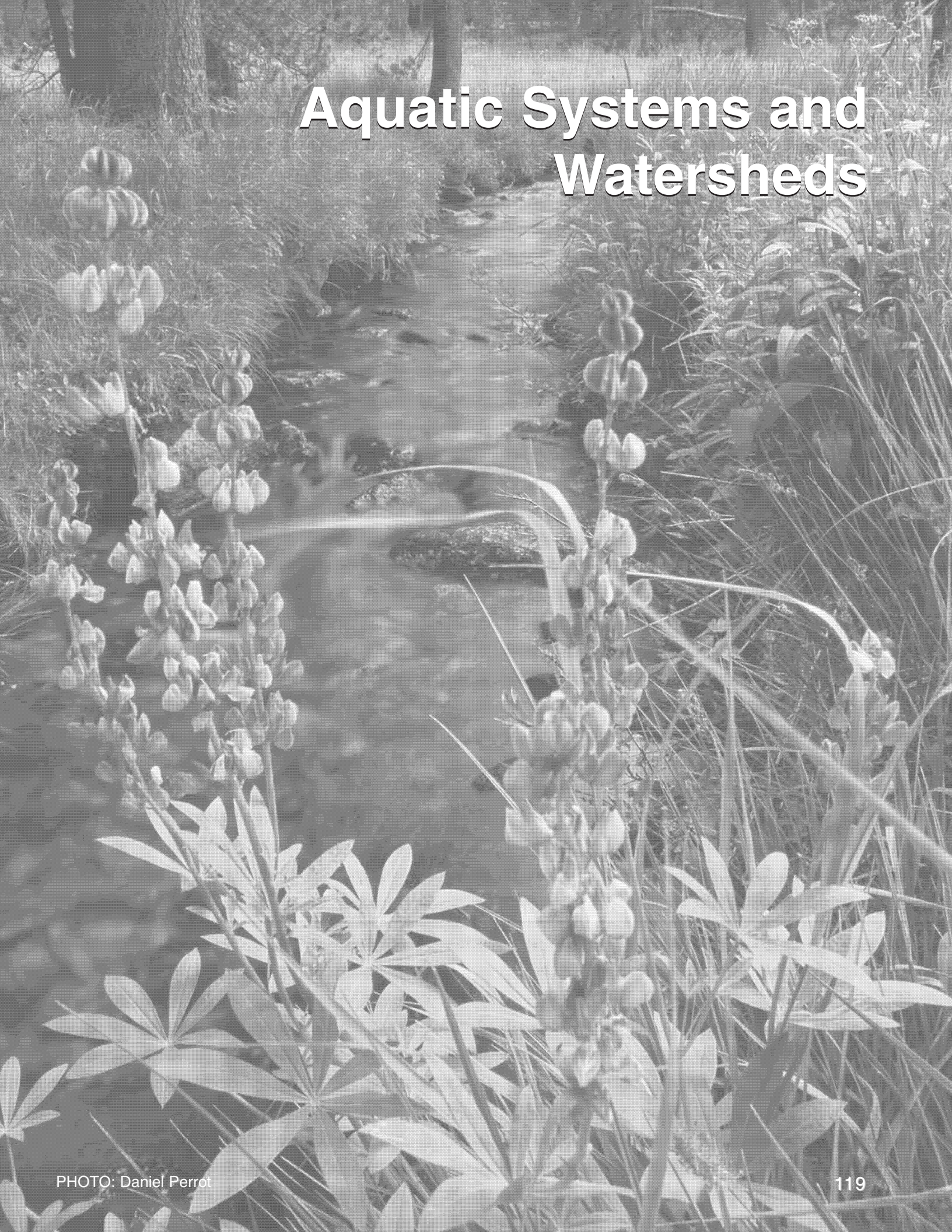
Fuelbreaks are another restoration objective that at the stand scale attempt to restore fire-resistant structures but at the landscape scale serve as strategic impediments to catastrophic fires. Fuelbreak stand structures vary depending upon the pretreatment structure. For dense stands, a typical series of treatments is thinning to reduce density, followed by reducing ladder fuels, with a subsequent effort to reduce surface fuels. An objective of these treatments is often to prepare stands for prescribed burning to prevent future accumulations of fuels (Weatherspoon and Skinner 1996). In the case of the Herger-Feinstein Quincy Library Group Forest Recovery Act objectives in the northern Sierra Nevada, there is also the intent to eventually convert these stands to uneven-aged structures.

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Aquatic Systems and Watersheds

A black and white photograph of a stream flowing through a forest. The stream is the central focus, with water flowing over rocks. In the foreground, two tall lupine plants with multiple flower spikes are prominent, framing the stream. The background shows a dense forest with trees and undergrowth.

Aquatic Systems and Watersheds¹

Rick Kattelman² and Fraser Shilling³

Water is often at the heart of contentious debates over natural resource policy in the Sierra Nevada. Besides the obvious issues of dams, diversions, fish, wetlands, and pollution, connections abound with other resources within the waterways and their watersheds. Whether an argument is over logging, roads, wildfire, endangered species, wilderness, sprawl of foothill communities, ski area expansion, mining, off-highway vehicles, climate change, or overgrazing, potential impacts on water or aquatic habitats quickly enter the discussion. These debates are often dominated by folklore and conjecture because the state-of-knowledge about aquatic systems and their relationship with Sierra Nevada landscapes is remarkably limited. The Sierra Nevada Science Symposium session on aquatic systems and watersheds was a sample of recent research that could contribute to better-informed debates about water-related aspects of natural resource policy in the Sierra Nevada. Six speakers delved into the problems facing specific taxa, the relationships between aquatic organisms and their physical environment, changes in water chemistry and sediment in response to land use, analysis of cumulative impacts at the watershed scale, and policy responses to impacts at the State level.

Much of what is known about water resources, watersheds, and aquatic biology of the Sierra Nevada was synthesized and summarized by the Sierra Nevada Ecosystem Project (SNEP) Report in 1996 (Centers for Water and Wildland Resources 1996). Recognition of inadequacies in scientific knowledge about the Sierra Nevada led to Congressional legislation that spawned the SNEP. A primary goal for this 3-year long project was to compile information to provide a basis for subsequent policy and management decisions. About 30 chapters of the SNEP report dealt with water-related topics. The authors of these various chapters found that development of streams and watersheds over the past 150 years has degraded the quality and availability of water for both ecological and social needs in many locations throughout the Sierra Nevada. Construction of the extensive network of dams and diversions has left few river segments with a natural flow regime. Further degradation of Sierra Nevada rivers has been caused by secondary effects of resource development, road construction, and other alterations from land use in the watersheds (Kattelman 1996). As human-induced impacts have changed the nature of stream characteristics, such as water volume, duration of low flows, peaks of floods, seasonal timing, sediment supply, water temperature, and quantities of organic matter and nutrients, aquatic and riparian ecosystems and their constituent elements have coped in various ways with differing results.

Declines in the health of aquatic ecosystems were particularly apparent from dramatic changes in fish populations: most native fishes have decreased in abundance, although the ranges of several have been artificially expanded, with consequent impacts on native amphibians. Thirty species of non-native fishes have been introduced into streams throughout the Sierra Nevada, and anadromous fishes have been excluded from most of their former habitat by dams (Knapp 1996, Moyle 1996, Moyle and others 1996). These activities

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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have resulted in formal listing of 6 of the 40 native fishes of the Sierra Nevada as endangered or threatened; another 12 species are regarded as species of special concern (Moyle and others 1996). Observed declines in aquatic species were found to be strongly associated with degradation of aquatic habitats and the surrounding landscape (Moyle 1996). A SNEP evaluation of the biotic integrity of 100 watersheds found that the aquatic communities of only 7 watersheds were in excellent condition, 34 were in good to very good condition, 48 were rated as fair, and 9 were judged to be poor (Moyle and Randall 1996).

Since the SNEP report was released, the Forest Service's Pacific Southwest Region has embarked on a program to systematically update the forest plans of Sierra Nevada National Forests, using some of the primary conclusions from the SNEP (USDA Forest Service 2000 and 2001). Considerable attention has been directed to watershed, riparian, and aquatic issues in this bioregional-scale planning effort. In parallel, the State has supported watershed analysis and restoration projects on the west side of the range through CALFED and Proposition 204 and 13 funds. In addition, nongovernmental organizations, such as the Sierra Nevada Alliance, the Sierra Business Council, and the Pacific Rivers Council, have assessed watershed condition, advocated for strong monitoring programs, and proposed an ambitious watershed restoration program for the Sierra Nevada (for example, Pacific Rivers Council 2002).

Meanwhile, pressures on Sierra Nevada aquatic systems continue to mount, largely expressed as concerns about water quantity due to the rapid growth of California's population. Drier-than-average conditions for 1999 through 2002 produced widespread concern about future water availability throughout the State. Shortages of electricity in 2001 led to many warnings about hydropower capacity as well as fears of future water shortages. In turn, such concerns led to increasing political support for more storage and diversion projects on Sierra Nevada rivers. At the close of 2002, a complex debate over the future of water deliveries from the Colorado River to southern California included calls for more water from northern California and the Sierra Nevada to the southern part of the state. These examples suggest ever-increasing demands on the streams of the Sierra Nevada.

Relationship to Other Sierra Nevada Science Symposium Sessions

The fundamental availability of precipitation to generate runoff from Sierra Nevada watersheds was addressed in the Sierra Nevada Science Symposium session on climate change. Reconstruction of past climate from various indicators suggests that California's water resources infrastructure was planned and built during a relatively wet and hydrologically stable period. Significant evidence indicates the occurrence of severe and sustained droughts in past centuries as well as floods greatly exceeding those of the historical period. Modeling exercises suggest the future possibility of markedly different snowfall and snowmelt regimes than those in the recent past. Such climatic shifts would alter vegetation and fire patterns, with consequent hydrologic effects: changes in volume and timing of runoff would affect stream channels and aquatic biota. These potential hydrogeomorphological effects have yet to be examined in detail but may have dramatic impacts on existing ecological resources.

The Sierra Nevada Science Symposium session on forest ecosystems discussed variations in vegetation distribution and stand structure. Terrestrial vegetation and hydrologic systems interact principally through the water and nutrient relations of the soil mantle, with secondary impacts on temperature and evaporation from shading and protection from wind. Alternatives for forest management can greatly affect generation of streamflow and its constituents of sediment and nutrients, riparian structure, and availability of woody debris to stream channels. Similarly, the session on wildland fuels and fires addressed many potential interactions with the hydrologic cycle. Although the 2002 fire season generated only one

major fire in the Sierra Nevada, large wildfires in other western states generated Federal policy initiatives that could have dramatic effects on Sierra Nevada streams (Kattelman 1999).

Although most of the papers in the session on biodiversity dealt with terrestrial species, conservation concepts are largely similar for aquatic species. However, strategies for the design of aquatic reserves and feasible approaches to conserving aquatic biodiversity have not received the same attention as terrestrial species or even individual aquatic species. The more than one hundred posters at the Sierra Nevada Science Symposium represent a wealth of new post-SNEP research that has implications for the conservation of Sierra Nevada aquatic systems.

Papers of the Aquatic Session

The five papers of the Sierra Nevada Science Symposium session on aquatic systems highlighted a sample of the critical issues facing waters of the Sierra Nevada. The SNEP report (Centers for Water and Wildland Resources 1996; Volume 1, page 125) recognized the “best indicators of the health of the aquatic system of the Sierra Nevada may be the group of organisms we know the least about— invertebrates.” The chapter devoted to aquatic invertebrates observed that very few inventories exist and the distribution of most species is unknown (Erman 1996). David Herbst (in these proceedings) documents how rapidly the state-of-knowledge has progressed in the past 6 years about these creatures and their use both as indicators of stream condition and a way of classifying streams in the Sierra Nevada. This bioassessment work has the potential to provide critical information about how the aquatic life of Sierra Nevada streams is coping with human impacts. Similarly, Roland Knapp (in these proceedings) reports on the rapid advance in knowledge about Sierra Nevada amphibians since the SNEP Report. His research in the past few years has established the linkages between introduced fish and severe declines in amphibian populations that were only hypothesized in the mid-1990s.

The other papers in the aquatic session dealt with physical processes, namely the interaction between watersheds and waterways through chemical and sediment inputs. Robert Coats (in these proceedings) updates our understanding of nutrient cycling within the Lake Tahoe basin and consequent effects on lake clarity since the SNEP case study about the lake (Elliott-Fisk and others 1996). Lee MacDonald and others (in these proceedings) and Reid (in these proceedings) both address the difficulties of assessing cumulative impacts of multiple activities on watershed processes and outputs. Both papers focus on accelerated erosion and sediment delivery to streams, which have typically been the impacts of greatest concern from logging operations and associated road construction. Lee MacDonald and others describe a field study and modeling approach, whereas Leslie Reid critiques the inadequacies of operational analyses of cumulative impacts associated with land development and resource extraction.

Art Baggett’s policy discussion (unpublished) that concluded the aquatic session covered several issues at the intersection between water and other resource management activities that the State Water Resources Control Board is grappling with, including: (1) citizen monitoring of water quality as a public involvement and education device; (2) the background load of “legacy” pollutants in waters from activities long abandoned; (3) pollution “offsets”—treating manageable sources while accepting some intractable ones; (4) ecosystem and river basin analysis instead of traditional single-species approaches; (5) examination of interrelationships between ecosystems; (6) deposition of air pollutants as a source of water pollution (for example, Lake Tahoe); and (7) examination of total environmental costs associated with activities and mitigation alternatives.

State of Science and Knowledge

A lengthy quotation from the SNEP Report (Centers for Water and Wildland Resources 1996; Volume 1, page 131) still seems to capture what we know about the waters of the Sierra Nevada:

“The knowledge base for improving water allocation and implementing sound watershed management in the Sierra Nevada is notably weak. Economic values of water in different uses are not well established. Information about water demand and historic water rights is not easily accessible. Records of water quality and sediment yield are available at very few sites throughout the mountain range. Rates of natural and accelerated erosion have not been measured at many locations in the Sierra Nevada. The impacts of various water and land management practices are not quantified or even known in some cases. In the few cases where long-term rangewide surveys exist, such as grazing transects on wet meadows on the National Forests, data have not been summarized until now. The effectiveness of best management practices and restoration techniques are largely untested. In general, the basic data for sound decision making about improving water and watershed management are lacking. Specific habitat requirements of most riparian-dependent terrestrial vertebrate species are poorly documented, and general surveys of species distribution for most aquatic invertebrates are missing. Adequate monitoring of natural processes, impacts, mitigation, and restoration could provide a much better basis for water resources planning and administration. Inadequate information is currently a major constraint on improvements in water and land management.”

Papers presented at the Sierra Nevada Science Symposium helped relieve some of the lack of information and knowledge described in the previous paragraph. In particular, a large number of surveys of aquatic-invertebrate distribution have been completed since the SNEP, as described by Herbst (in these proceedings). Advances in other areas are progressing more slowly, and some areas of needed research continue to be ignored. Nevertheless, policy and management decisions will be made, whether or not there is a scientifically sound basis for those decisions. The term “adaptive management” was heard throughout the symposium as a means of decisionmaking in the light of inadequate knowledge and scientific uncertainty. This management approach requires collecting information about affected systems and impacts of actions taken and synthesizing that data into knowledge to inform future decision making. Hopefully, learning will occur through both experience and deliberate scientific studies.

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Non-Native Fish Introductions and the Reversibility of Amphibian Declines in the Sierra Nevada¹

Roland A. Knapp²

Amphibians are declining worldwide for a variety of reasons, including habitat alteration, introduction of non-native species, disease, climate change, and environmental contaminants. Amphibians often play important roles in structuring ecosystems, and, as a result, amphibian population declines or extinctions are likely to affect other trophic levels (Matthews and others 2002). Avoiding declines or reversing the declines of amphibian populations that are already underway should be a major concern of land and wildlife managers.

The 1996 Sierra Nevada Ecosystem Project (SNEP) included two chapters that reviewed the state of knowledge regarding the status of amphibians in the Sierra Nevada. Jennings (1996) provided a detailed summary of the status and trends of all 32 amphibian species known from the Sierra Nevada and showed that the majority of taxa were declining. The most imperiled species were the true frogs (*Rana* sp.) and true toads (*Bufo* sp.), several of which are endemic to the Sierra Nevada. Knapp (1996) reviewed the effects of non-native trout introductions on naturally fishless lake ecosystems in the Sierra Nevada, and concluded that these introductions were a likely cause of the decline of the mountain yellow-legged frog, *Rana muscosa* (*R. muscosa*). Due to a general lack of detailed information on the distribution of amphibians and causes of declines, however, both chapters provided little guidance on the extent to which amphibian declines in the Sierra Nevada are reversible and, if so, what management actions were necessary.

The objective of this paper is to review the results of selected studies conducted on amphibian declines in the Sierra Nevada since the completion of the Sierra Nevada Ecosystem Project. Although several Sierran amphibian species are in decline, *R. muscosa* has been the focus of the majority of recent research due to the severity of its decline, the recent petition to list this species under the Endangered Species Act, and the potential of such a listing to dramatically alter current trout stocking practices. As such, this review focuses exclusively on *R. muscosa* and concludes that (1) the introduction of non-native trout are a major cause of the decline of *R. muscosa*, (2) this decline can be reversed by removing non-native trout populations, and (3) the current science is sufficiently well developed to inform policy and management related to the species. Additional research, however, is needed to quantify the effects of other potential causes of amphibian declines in the Sierra Nevada, including disease and airborne agricultural contaminants.

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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State of the Science

Background

Mountain yellow-legged frogs are endemic to the Sierra Nevada of California and Nevada, and to the Transverse Ranges of southern California. In the Sierra Nevada, *R. muscosa* was historically a common inhabitant of lakes and ponds at elevations of 1400 to 3600 meters (m). *R. muscosa* is highly aquatic, with adults overwintering underwater and rarely found more than a few meters from water during the summer active season. In addition, the aquatic larvae require two or more summers to develop through metamorphosis. The majority of *R. muscosa* habitat lies within designated national parks and National Forest wilderness areas. Despite this high level of protection, *R. muscosa* is now extirpated from at least 50 percent of its known historic localities (Jennings 1996).

The Sierra Nevada contains abundant streams and natural lakes, nearly all of which were historically fishless. Starting in the mid-1800s, Euro-American settlers began stocking these waters with several species of non-native trout. This practice was greatly expanded in the early 1950s when the California Department of Fish and Game began stocking trout in backcountry lakes using airplanes. Between 1977 and 1990, Sequoia, Kings Canyon, and Yosemite national parks phased out all fish stocking, but the practice continues to the present day on National Forest lands, including within designated wilderness areas. This stocking is conducted by the California Department of Fish and Game and is intended to augment or maintain existing non-native trout populations (see Knapp [1996] for additional details). As a result of this stocking program, non-native trout are now present in approximately 70 percent of naturally fishless lakes (greater than 0.5 hectares in surface area) on National Forest lands, and approximately 35 percent of such lakes in national parks (Knapp and Matthews 2000; Knapp, unpublished data).

Impacts of Non-native Trout

Grinnell and Storer (1924) were perhaps the first to describe the negative effect of introduced trout on *R. muscosa* populations. However, this possible impact received little attention until research by Bradford (1989) suggested that predation by non-native trout could be an important cause of the decline of *R. muscosa*. Knapp and Matthews (2000) and Knapp and others (2003) provided the first landscape scale study of the factors that influence the distribution of *R. muscosa* in which the effects of fish introductions were thoroughly analyzed. Based on surveys of 1,728 lakes and ponds in the Sierra Nevada (*fig. 1*), their analyses indicated that the probability of occurrence by *R. muscosa* at a site is positively influenced by lake depth and the proportion of the near-shore zone dominated by silt, and is negatively influenced by fish presence, lake elevation, and isolation from other *R. muscosa* populations. Therefore, the presence of non-native trout has a strong negative effect on the distribution of *R. muscosa*, even after accounting for effects of significant habitat variables. As an example of the landscape scale negative effects of non-native trout,

Knapp and Matthews (2000) reported that *R. muscosa* were present in only 5 percent of the water bodies in the John Muir Wilderness (Sierra National Forest) where non-native trout are common, but were present in 35 percent of the water bodies in immediately adjacent Kings Canyon National Park, where non-native trout are relatively uncommon.

Reversibility of Declines

To determine whether the decline of *R. muscosa* caused by fish introductions is reversible, researchers have recently studied whether *R. muscosa* is able to recolonize lakes after fish disappear. Knapp and others (2001) compared the probabilities of occurrence and density of

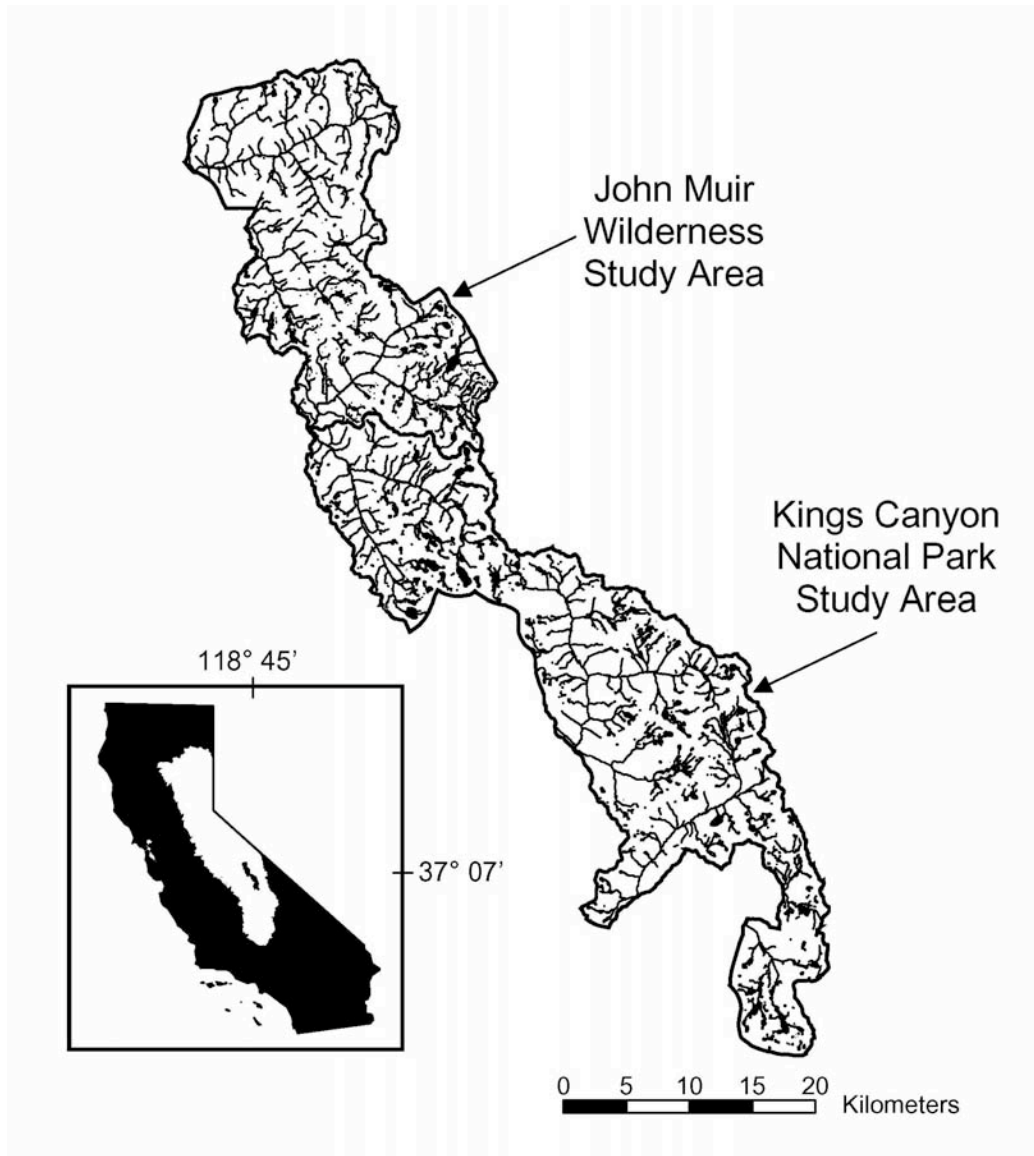


Figure 1— Map of the John Muir Wilderness and Kings Canyon National Park study areas described in Knapp and Matthews (2000) and Knapp and others (2003). Streams and lakes are shown in black. The inset map shows the state of California (black), the Sierra Nevada (white), and the study areas (black area in the Sierra Nevada).

R. muscosa at lakes that were never stocked and at lakes that were stocked historically but that have reverted to a fishless condition as a result of a halt to stocking and a lack of suitable trout spawning habitat. If *R. muscosa* was unable to recolonize lakes following fish introductions, the percentage of lakes containing frogs and the density of frogs should be significantly lower in “stocked-now-fishless” lakes than in “never-stocked” lakes. Instead, there was no significant difference in either the percentage of lakes containing frogs or the density of frogs between the two lake categories (fig. 2), indicating that *R. muscosa* was able to recolonize lakes following fish disappearance. Recent studies in which trout were eradicated from lakes using gill nets (Knapp and Matthews 1998) and the response of resident or nearby *R. muscosa* populations was monitored (Vredenburg 2002) provide additional evidence that declines of *R. muscosa* are reversible. In all cases in which *R. muscosa* were present either in the previously stocked but now fishless lake or nearby ($N =$

6), fish eradication resulted in rapid and dramatic increases in the number of *R. muscosa*. For example, before the eradication of trout from a lake in the John Muir Wilderness, counts indicated an *R. muscosa* population size of approximately 40 adults and 20 larvae. All fish were removed in 1997-1998, and by 2002 the *R. muscosa* population had increased to approximately 700 adults and 3,000 larvae. As a cautionary note, however, lakes that are separated from *R. muscosa* populations by fish-bearing lakes or by excessive distances will likely not be naturally recolonized following fish eradication. For example, Knapp eradicated trout populations from two lakes in the John Muir Wilderness that lacked any *R. muscosa* within 4 kilometers (km). Five years following the fish eradication, neither lake has been recolonized by *R. muscosa*. Recolonization failure in such situations appears to be a consequence of *R. muscosa* typically dispersing only relatively short distances (Matthews and Pope 1999, Pope and Matthews 2001, Vredenburg 2002) and increased dispersal mortality caused by trout predation.

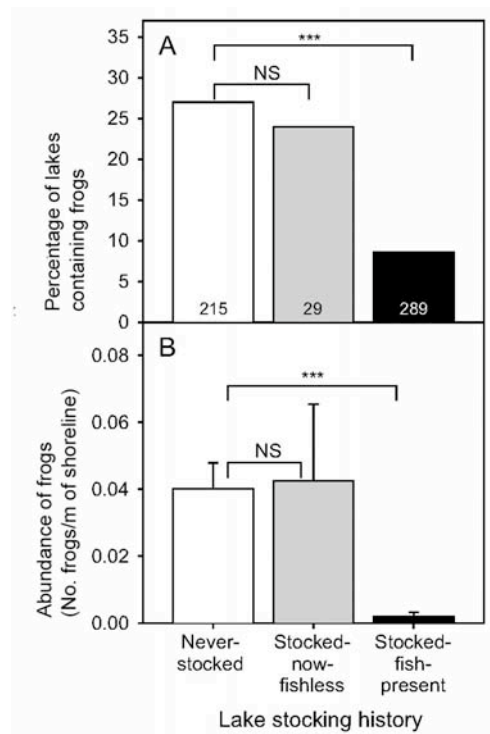


Figure 2— (A) Percentage of never-stocked lakes (open bars), stocked-now-fishless lakes (gray bars), and stocked-fish-present lakes (black bars) containing mountain yellow-legged frog larvae. (B) The abundance of mountain yellow-legged frog larvae in never-stocked, stocked-now-fishless, and stocked-fish-present lakes. Abundance was measured as the number of larvae/m of shoreline and is expressed as $\log_{10}(\text{abundance} + 1)$. Bars indicate means $\pm$ 1 SE. Sample sizes for each lake type are given inside the respective bar in (A). Lines and associated symbols connecting each bar provide the results of pairwise chi-square tests: *** $P < 0.001$; NS, not significant ($P > 0.05$).

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Interface of Science with Management and Policy

Since publication of the SNEP report (1996), the body of scientific information describing the role of non-native trout in causing the decline of *R. muscosa* has expanded dramatically and is now sufficiently well-developed to inform management and policy related to the protection and restoration of aquatic ecosystems in the Sierra Nevada. Indeed, notable

changes in management and policy are already being made on the basis of recent research results. For example, given the critical need for information on the distribution of *R. muscosa* and non-native trout in developing restoration plans, the National Park Service (NPS) and California Department of Fish and Game (CDFG) have recently embarked on an ambitious program to conduct biotic inventories of all lakes and ponds on Federal lands in the Sierra Nevada that have not yet been surveyed. Inventories in Sequoia, Kings Canyon, and Yosemite national parks were completed in 2002, and CDFG surveys are expected to be completed by 2004. In addition, the USDA Forest Service is implementing a comprehensive monitoring program of *R. muscosa* populations on National Forest lands throughout the Sierra Nevada. Backcountry fish stocking by the CDFG is also being curtailed, pending completion of CDFG surveys and basin-specific management plans. In an effort to expand the few remaining *R. muscosa* populations, the CDFG and NPS recently initiated fish eradication projects in Kings Canyon National Park and the John Muir Wilderness. Both agencies are using techniques developed by researchers in previous frog restoration studies (Knapp and Matthews 1998; Vredenburg 2002). Critically needed management actions and policy changes that have not yet been implemented include (1) permanent termination of backcountry fish stocking from the range of *R. muscosa*, except where needed to maintain unique angling opportunities, (2) implementation of an amphibian monitoring program for Sequoia, Kings Canyon, and Yosemite national parks, and (3) a greatly expanded effort to restore *R. muscosa* populations throughout their historic range.

Future Research

Despite the considerable progress made in understanding the causes of amphibian declines in the Sierra Nevada during the past decade, additional research is urgently needed in two areas. First, it remains unclear what level of restoration will be necessary to ensure the long-term viability of *R. muscosa* populations. A formal population viability analysis would be of great utility in describing the conditions under which long-term population persistence could be expected. Such a modeling effort is currently under way. Second, although this review focuses solely on the impact of non-native trout introductions in causing the decline of *R. muscosa*, other stressors may also be playing important roles. These include disease and airborne agricultural contaminants. The disease caused by the fungus *Batrachochytrium dendrobatidis* has caused the decline of many amphibian species worldwide, and this organism is also infecting *R. muscosa* and other amphibians in the Sierra Nevada (Fellers and others 2001). A considerable research effort is currently under way to clarify the role of this chytrid fungus in causing amphibian declines in the Sierra Nevada. In addition, for several species of amphibians in the Sierra Nevada, including *R. muscosa*, Davidson and others (2002) showed that the probability of population extirpation was increasing as a function of the amount of upwind agriculture. Assuming that the amount of upwind agriculture is an accurate proxy of the intensity of pesticide application, these results suggest that agricultural contaminants may be negatively affecting a number of amphibian species in the Sierra Nevada.

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Establishing Reference Conditions for Streams and Measuring Ecological Responses to Management Actions Using Aquatic Invertebrate Biological Assessments¹

David Herbst²

The Sierra Nevada Ecosystem Project provided the first comprehensive status report on the condition and history of natural resources of this mountain region (Centers for Water and Wildland Resources 1996). The report concluded that aquatic habitats were the most altered and impaired ecosystems, after exposure of Sierra watersheds to 150 years of landscape changes resulting from activities such as hydraulic mining, damming and diversions of streams, road building, livestock overgrazing, timber harvest, hard-rock mining, and introductions of exotic species. Continued assessment of watershed conditions is needed to identify problem areas, follow trends, establish standards, and document the effectiveness of restoration actions. Among the most promising biological tools for such monitoring needs is the use of aquatic insects as indicators of habitat and water quality. Watersheds provide an organizing unit for defining local and cumulative effects of landscape alterations and for planning management and conservation. This paper provides an outline of the use of aquatic invertebrate monitoring in guiding watershed management.

A summary of aquatic invertebrate status in the SNEP report (Erman 1996) found that the invertebrate fauna was known primarily from geographically localized studies, special habitats, or taxonomically limited surveys of particular faunal groups (such as stoneflies). In addition, the inventory of the known aquatic insects from the Sierra Nevada showed a high proportion of endemics, including such groups as stoneflies (25 percent) and caddisflies (19 percent), whereas most other groups had received only limited survey attention.

The SNEP report also classified the aquatic environments of the Sierra Nevada (Moyle 1996a), scored the biological health of watersheds (Moyle and Randall 1996), and presented a strategy for conservation of aquatic biodiversity (Moyle 1996b). Some 66 aquatic habitat types were identified in the Sierra Nevada, including standing and flowing waters in west-slope and east-slope geographic provinces. Declines in aquatic biodiversity were documented using data that indicate decreasing range, abundance, or even extinction of more than half the 70 species of native amphibians and fish. These declines were attributed to the loss and impairment of habitat, especially lowland habitats, such as terminal lakes and desert springs, and along many impounded streams at lower elevations. The number and proportion of native aquatic vertebrates and absence of dams, reservoirs, and roads were used to measure biotic integrity of watersheds, rank watershed health, and identify aquatic diversity management areas (ADMAs) for conservation.

The SNEP aquatic status reports indicated the need for invertebrate biological monitoring and inventory data to improve assessment of resource conditions, define ecological health,

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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document habitat stressors and disturbance sources, and develop guidance for conserving native biodiversity (as in ADMAs). The need for bioassessment monitoring should be placed ahead of taxonomic inventory because the data generated are more useful in defining ecological integrity of habitats to provide a foundation for informing resource management decisions and feedback to adaptive management programs.

Principle of Bioassessment

Aquatic insects and other invertebrates are central to the function of stream ecosystems, consuming organic matter (wood and leaf debris) and algae and providing food to higher trophic levels (fish and riparian birds). These organisms also have varying degrees of pollution tolerance and so may be used as indicators of water quality and habitat conditions. For example, distinctive shifts in the structure and function of the aquatic invertebrate community can often be detected above and below a pollution source. Use of the stream invertebrate fauna in evaluating stream ecosystem health is known as bioassessment. This technique uses collections of the benthos (bottom-dwelling fauna) to evaluate the relative abundance of different taxa, feeding guilds, pollution indicators, and diversity to develop a quantitative basis for measuring ecological attributes of the stream. Monitoring relative to reference sites (having little or no impact but similar physical setting) or over time within subject sites, or both, then permits impact problems or recovery to be quantified (Davis and Simon 1995, Rosenberg and Resh 1993). Aquatic invertebrate bioassessment has also become an important means for defining biological integrity of natural waters as required for implementation of the Clean Water Act (Karr and Chu 1999).

Components of Bioassessment Monitoring as Guidance in Water Quality Management

- An ambient monitoring network involving surveys conducted over a range of stream types and sizes (using probabilistic and targeted selection)
 1. Intensive—repeated annual sampling at established sites to measure interannual temporal variability
 2. Extensive—an expanding network of study reaches to measure spatial geographic variability
- Reference monitoring—selective sampling of least-disturbed stream sites as the foundation for developing biological standards or biocriteria
- Targeted monitoring—conducted at sites of concern for purposes of stressor identification, examination of metric response patterns, tracking of restoration, feedback for adaptive management, and appraisal of 303 (d) listed streams
 1. Using disturbance/stressor gradients to study dose-response relationships between stream benthic community structure and different impact sources (for example, livestock grazing, sediment, acid mine drainage); set Total Maximum Daily Load (TMDL) targets
 2. Documenting ‘before-after’ case histories for restoration (by setting preproject baselines and follow-up with subsequent effectiveness monitoring)
 3. For listing or de-listing of 303 (d) impaired water bodies

Since the time of the SNEP report, about 600 stream bioassessment surveys have been conducted in the Sierra Nevada for a variety of purposes, providing a foundation of data on benthic invertebrate community structure. (*Tables 1 and 2 summarize the source, location, and type of information collected.*) These programs represent a geographic mix of localized

and dispersed sampling (intensive and extensive) that have used varied methodologies for collection and analysis but provide a starting point for comparing stream biotic integrity, taxa distribution lists, and ecological impacts across the Sierra Nevada.

Table 1— *Summary of recent and ongoing Sierra Nevada research and monitoring programs involving studies of stream invertebrates¹*

Organization and persons involved in collecting information	Type of information collected	Period of data collection	Location (s) of data collection
Larry Brown and Terry Short—USGS with NPS support	River restoration monitoring using algae and aquatic invertebrates	1993–1996	Merced River and Tenaya Creek, 13 sites Yosemite Valley
James Carter—USGS	Distribution of benthic invertebrates, water residence time, riffle-pool habitat and gradient	1990–1994	Merced River Yosemite Valley 8 stream sites
Jason May—USGS	Algae and invertebrate biomonitoring for NAWQA program	1996–1998	Upper Sacramento River basin; 10 streams in Sierra Nevada foothills
Joseph Furnish, U.S. Forest Service, and Charles Hawkins, Utah State University	Bioassessment for evaluations of biological integrity and condition of National Forest streams	2000–ongoing	Est. 155 stream sites throughout 10 National Forests of the Sierra Nevada
Ian Chan—UC Davis	Prescribed fire effects on headwater stream invertebrate communities	1995–1997 before/after	Mineral King Sequoia Natl. Park five 1° to 2° streams
Rosalie Leech and Vince Resh—UC Berkeley	Organic enrichment effects on streams by livestock	1998–1999	Blodgett Forest Amador County, 4 sites
Leah Rodgers and Vince Resh—UC Berkeley	Prescribed fire effects on stream ecosystem structure and function	1995–2004 before/	Blodgett Forest, Amador County 7 streams, 9 sites
Peter Cranston—UC Davis and Harold Werner —Sequoia National Park	Inventory of aquatic chironomidae from streams	2001–2002	Sequoia National Park; Kaweah R.-5 tributaries in <i>Sequoia</i> groves
Dorothea Panayotou, UC Davis TRG, CA Tahoe Conservancy	Bioassessment contrasts of stream restoration projects in Lake Tahoe watershed	2000–2002	Lake Tahoe basin primarily south and west 10–20 tributaries
Danny Boiano—Sequoia National Park, with Jean Krejca, Joel Despain	Cave invertebrate inventory (including aquatic fauna)	2003–2005	15 caves in Sequoia -Kings Canyon NP, and 1 in Yosemite NP
Jim Harrington and Pete Ode—California Dept Fish Game Aquatic Bioassessment Laboratory	Bioassessment monitoring of ambient water quality and spills pollution	1995–ongoing	80–100 stream sites —most in northern Sierra including references in upper Sacramento River
		Sum:	Est. 300 stream sites sampled to date, excluding repeated sites

¹Excluding volunteer and citizen group monitoring programs and research studies occurring more than 10 years ago (most summarized in Erman, SNEP report).

Table 2— Summary of recent and ongoing Sierra Nevada research and monitoring programs involving studies of stream invertebrates¹ (UC-Sierra Nevada Aquatic Research Lab, SNARL)

Organization and persons involved in collecting information	Type of information collected	Period of data collection	Location (s) of data collection
David Herbst and Roland Knapp—UC-SNARL	Seasonal / annual changes in stream habitat, fish, and invertebrates exposed to livestock grazing	1993–1996	Long Valley drainages of the east slope Upper Owens River 9 repeated sites
David Herbst, UC-SNARL with EPA support	Cumulative effects of livestock grazing on stream invertebrate community structure and function	1996–1998	Eastern Sierra from Upper Owens to Carson River watersheds 85 stream sites
David Herbst, UC-SNARL; Tom Suk, Lahontan Regional Water Quality Control Board	Bioassessment of impacts and recovery related to acid mine drainage	1995–ongoing	Leviathan Mine—tributaries to the East Carson River 16 stream sites
David Herbst, UC-SNARL; Tom Suk, Lahontan RWQCB; B. Emery, UC Santa Cruz	Baseline bioassessment monitoring for livestock grazing management	1999–2002 before/during	West Walker River and tributaries (9 treatment, 9 matched control sites)
David Herbst, UC-SNARL; Tom Suk, Lahontan RWQCB and TRPA	Baseline bioassessment for river restoration and sediment control	1998–2000 before/after	Upper Truckee River Lake Tahoe basin 8 sites on main stem
David Herbst, UC-SNARL City of S. Lake Tahoe	Bioassessment monitoring of channel restoration	1999–ongoing before/after	Trout Creek—3 sites South Lake Tahoe
David Herbst, UC-SNARL US Forest Service	Bioassessment monitoring of channel restoration	1999–ongoing before/after	Bagley Valley Creek (project and 3 controls)
David Herbst, UC-SNARL Tom Suk, Lahontan Regional Water Quality Control Board	Regional reference and test or index site bio-assessment sampling for biocriteria development in ambient water quality monitoring	1999–ongoing	Eastern Sierra basins: Upper Owens, Mono basin, E. Walker, W. Walker, E. Carson, W. Carson, Tahoe basin, Lower Truckee River 55 stream sites to date
David Herbst, UC-SNARL Cadie Olsen, Lahontan RWQCB	Biological water quality targets for sediment TMDL	2000–2001	Squaw Creek and Lower Truckee River 23 stream sites
David Herbst, UC-SNARL Scott Cooper and Erik Silldorff, UC Santa Barbara	Effect of introduced trout on stream community structure / function using paired watershed contrasts	2000–2002	Yosemite National Park 44 streams in Merced and Tuolumne drainages
Scott Cooper, UC Santa Barbara; David Herbst, UC-SNARL; Carolyn Hunsaker, PSW-USFS	Influence of prescribed fire and timber harvest practices on stream invertebrate communities	1999–ongoing before/after	Kings River Experimental Watershed 16 headwater streams in Sierra National Forest
		Sum:	Herbst, UC-SNARL and associates: >275 stream reaches sampled to date excluding repeated sites
David Herbst, UC-SNARL, Don Sada, UNR-Desert Research Institute	Spring invertebrate community analysis in relation to environmental disturbance, habitat type	1996–2000	More than 100 spring sources and spring-brooks surveyed in Lahontan and Owens Valley Basins

Using reference sites to define standards is an essential requirement for evaluating the impairment of streams. The choice of reference stream sites has been typically left to subjective judgments and qualitative screening of what appears to be the “best” streams. To

minimize errors in determining impairment and defend the use of streams as references, there is a need for a more objective selection procedure that rates streams using quantitative criteria to identify which streams are least disturbed. A protocol for reference selection is under development (D. Herbst and P. Ode), comprised of the following steps:

1. Define the geographic region and stream classes to be evaluated.
2. Identify, quantify, and score disturbance and stressors using Geographical Information System (GIS) tools. (This step is presently limited by poor spatial resolution in CalWater watershed planning areas, lack of correspondence of these units to hydrographic watershed boundaries, and incomplete coverage of land use and disturbance available in GIS formats.)
3. Examine frequency distribution of candidate stream scores and select least disturbed as references, using statistical criteria to set acceptance levels.
4. Ground truth reference sites for conformity to optimum quality of sample reach-level habitat (riparian, bank, substrate conditions). Also include test or index sites, selected from stream reaches with known histories of exposure to pollution or habitat degradation.

Applications of Bioassessment and Preliminary Results

As an example of biomonitoring programs under way in the Sierra Nevada, the Lahontan Regional Water Quality Control Board (T. Suk, program manager) and the Sierra Nevada Aquatic Research Laboratory (D. Herbst, principal investigator) have established intensive and extensive stream surveys in the eastern Sierra Nevada that cover the following watersheds: Upper Owens, Mono Basin, East Walker, West Walker, East Carson, West Carson, Tahoe Basin, Lower Truckee River, and Little Truckee River. This includes first- to fourth-order streams with mainly less than 4 percent gradients, from 5,000 to 10,000 feet elevation, and with more than 275 reaches sampled to date (about half as references). Targeted studies among these include:

- Disturbance stressors/gradients to: (a) set sediment TMDL targets, (b) examine the influence of exotic trout in fishless high Sierra Nevada streams, (c) study cumulative effects of livestock grazing, and (d) study prescribed fire and logging regimes in the Kings River Experimental Watershed [some of these as gradient or dose-response designs, some as replicated BACI, some as paired contrasts with/without stressor]
- Case histories developed from planned management and involving before/after sampling and trend analyses: (a) livestock grazing management (West Walker River and Bridgeport Valley); (b) acid mine drainage impairment and restoration (Leviathan mine Superfund site); (c) reconstruction of channelized, dredged, or eroded stream drainages (Trout Creek, Bagley Valley Creek, Upper Truckee baseline)

Another advantage of an intensive and extensive monitoring network is that it permits anticipation of the unexpected. For example, preexisting data have provided the basis for developing case histories for (1) effects of the 1997 New Year flood event, using many previously sampled east-slope streams; (2) effects of severe wildfire (Mill Creek, near Walker); and (3) invasion of the upper Owens River by the exotic New Zealand mud snail and subsequent ecological changes. Continued monitoring of these streams will allow assessment of the biological impacts and potential recovery over time.

Bioassessment studies along gradients of exposure to habitat disturbance and pollution have provided useful data for establishing the extent of impacts and setting recovery targets. For example, using sediment load predicted from an Agricultural Non-Point Source pollution

model (AGNPS), reference watersheds were selected to define the biological recovery target for a sediment TMDL (Herbst 2002a). The references had reduced levels of sediment load and higher biological integrity measures than the TMDL drainage. This approach provided goals for both the amount of sediment reduction needed and the biological status that would indicate recovery.

Cumulative effects of livestock grazing were studied by conducting surveys in streams exhibiting varied levels of grazing-related habitat degradation (bank erosion, sedimentation, and riparian loss). Measures of sediment deposition showed that this variable alone was associated with reduced abundance of the sensitive mayfly, stonefly, and caddisfly groups (EPT taxa). Where cover of fines and sand on the stream bottom was below 25 percent, all stream communities sampled comprised more than 50 percent EPT; where cover of fines and sand exceeded 25 percent, fewer than half of the streams had more than 50 percent EPT (*fig. 1*). Other eastern Sierra Nevada studies have shown that rangeland streams with the most severely degraded habitats have poor biological integrity and exhibit little seasonal change, and streams with less habitat degradation may either maintain healthy stream communities or suffer loss of biological integrity only during grazing and then recover by spring before the resumption of grazing (Herbst and Knapp 1999).

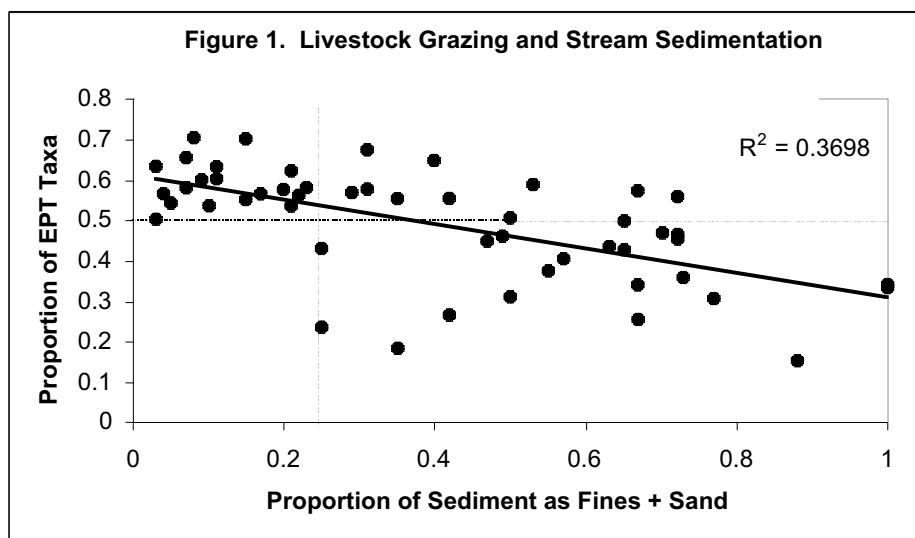


Figure 1— Livestock grazing and stream sedimentation.

Gradients of exposure to stressors can also be examined with distance from the source of degradation. Studies of acid mine drainage from the Leviathan Mine Superfund site have been conducted to define the longitudinal downstream extent of impacts and changes over time as remediation actions have been undertaken (Herbst 2002b). These studies have shown that, although there continue to be several miles of severely impaired stream communities, the use of treatment bioreactors, involving a microbial reversal of the oxidation and hydrolysis that cause acid mine drainage, has produced local recovery of a small stream (*fig. 2*). The biotic index, a measure of composite tolerance of the community to pollution (increases with predominance by organisms resistant to pollution), was reduced in Aspen Creek after bioreactors were established in summer 1999. This index declined to levels near that of the reference stream as more sensitive organisms were able to inhabit the treated flows while the untreated Leviathan Creek drainage remained impaired. Continued monitoring will evaluate whether this recovery persists and the success of other remediation strategies.

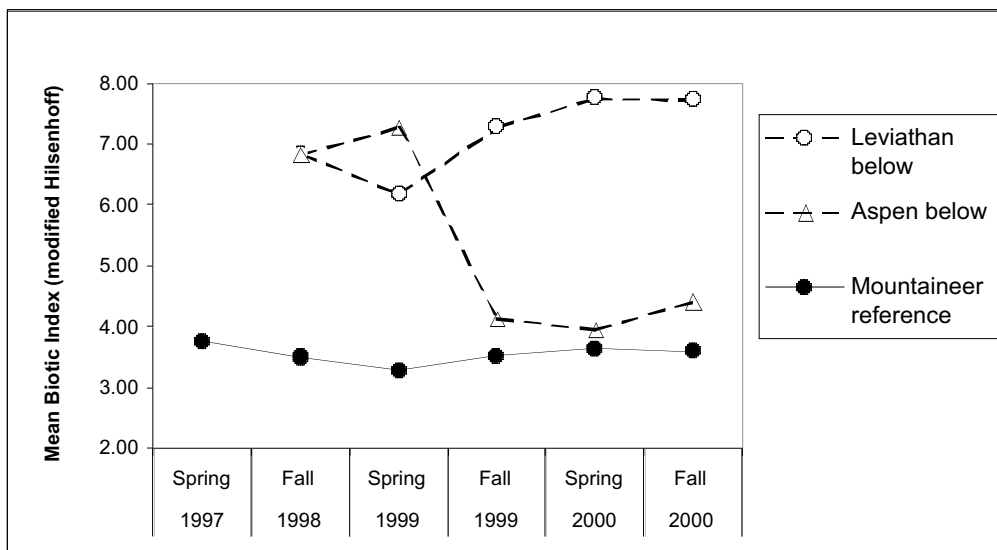


Figure 2— Post-treatment recovery from acid mine drainage.

These serve as a few examples of the extent and type of information generated through bioassessment monitoring; problems remain to be resolved before this type of information can be used most effectively to improve water resource management and biodiversity conservation in the Sierra Nevada.

Needs and Opportunities

This section highlights needs and opportunities for developing bioassessment monitoring as an effective tool for improving watershed management.

Map distribution patterns

Existing data of the macroinvertebrate community structure from bioassessment surveys currently comprise about 600 stream reaches. This provides an initial database for creating zoogeographic maps (taxa distributions and diversity contours) and identifying data gaps (evident for higher-elevation and headwater streams). Mapping biogeography and endemism through taxonomic inventories and establishing a network of monitoring stations as an elevation and latitude grid over Sierra Nevada stream drainages would provide information to evaluate long-term effects of climate change (earlier spring run-off, increased flood frequency, warmer summer stream temperatures, and increased frequency of intermittent stream flows).

Spatially analyze watersheds

GIS analysis for reference site selection will require coverages that have enhanced watershed resolution (from first-order streams, combined to form higher-order aggregate units) and more detailed information for identifying and quantifying stressors (roads and land use intensity). Use of landscape models such as AGNPS may also provide integrated nutrient and sediment loading predictions. Opportunities exist for integrating aquatic invertebrate bioassessment into models and evaluations of cumulative watershed effects. (This requires development of a case history database so that impacts can be better predicted and managed.)

Expand the ADMA concept of Moyle

Invertebrate data (including patterns of total diversity, endemism, sensitivity, biotic integrity) can be used as: (1) a planning tool for defining regional priorities for preserving biodiversity and (2) a means for identifying and protecting reference areas that serve as the basis for standards of biological integrity in water quality assessment. Data can be made available to the Forest Service, National Park Service, and others to encourage integration into conservation strategies that follow ADMA principles (for example, the Sierra Nevada Forest Plan Amendment “emphasis watersheds and critical aquatic refuges” for protecting and restoring watersheds and the Sierra Nevada Ecoregional Plan of The Nature Conservancy (TNC)—a portfolio of 500 sites identified for long-term protection and conservation planning).

Coordinate planned restoration management with monitoring case histories

Natural experiments may often be found in the planned management activities of the Forest Service and National Park Service. These activities provide opportunities for research investigations: foremost among these should be before-and-after studies of dam removal, exotic fish removals, controlled burns, livestock grazing practices, and stream channel restoration projects.

Use of monitoring feedback is a critical component of adaptive management decision-making. The value of aquatic invertebrate data as a performance indicator of the status of biotic integrity and change in streams should be recognized.

Think higher and larger

Thinking *higher* means to consider the role of headwater streams. The fauna of headwater streams should be examined as should the role of variations in intermittent flow conditions on the structure and function of stream communities and as habitat refugia from exotic fish predators. Headwater and other high-elevation streams are the least-understood aquatic environments of the Sierra Nevada.

Thinking *larger* translates to such inclusive assessments as White-Inyo Mountains, Owens Valley, Warner Mountains, and restored Tulare and Buena Vista Lakes. Another example of thinking larger includes the interconnected relationships to the biogeography of basin and range habitats in the Great Basin.

The existing environmental research community and planned Sierra Nevada Research Institute at the University of California at Merced (UC Merced) should develop partnerships with State, Federal, local, and private agencies and organizations to serve management with applied research and monitoring that helps guide decisions (such as “Vital Signs” monitoring in National Parks, development of biological criteria for water quality standards for the State Water Resources Control Board, and ranking of priorities for land acquisition and protection by The Nature Conservancy).

Educational opportunities can be developed by working with community watershed groups and schools (for example, the Yosemite Institute stream biomonitoring program). An introduction to bioassessment for such groups can be downloaded from the following website (Herbst and others 2001, published by the State Water Resources Control Board): <http://www.swrcb.ca.gov/nps/docs/FinRevCAStreamBiosurvey.doc>

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Nutrient and Sediment Transport in Streams of the Lake Tahoe Basin: A 30-Year Retrospective¹

Robert Coats²

Lake Tahoe, widely renowned for its astounding clarity and deep blue color, lies at an elevation of 1,898 meters (m) in the central Sierra Nevada, astride the California-Nevada border. The volume of the lake is 156 cubic kilometers (km³), and its surface area is 501 square kilometers (km²), 38 percent of the total basin area of 1,313 km². The eutrophication of the lake has been studied intensively since the early 1960s (Goldman 2000), when scientists and farsighted political leaders and private citizens began to recognize that human activities, especially the accelerated input of nutrients and sediment, could cause long-term changes in the lake.

To provide an understanding of nutrient and sediment sources in the Lake Tahoe Basin, long-term monitoring programs were established in the 1970s. These monitoring programs included measuring stream discharge and sampling nitrogen, phosphorus, iron, and suspended sediment to calculate total watershed loads delivered to the lake and measuring both wet and dry atmospheric deposition of nitrogen and phosphorus. The programs have led to a better understanding of the causes of eutrophication and clarity loss of Lake Tahoe and, in some cases, have caused refocusing of programs aimed at restoring desired lake conditions. This paper reviews what we have learned from the stream-monitoring program and related research and suggests directions for future work.

Long-Term Changes at Lake Tahoe

The documented ecological changes in Lake Tahoe have been dramatic. Between 1968 and 1997, primary productivity in the lake (measured as the rate of carbon fixation) increased from 48 to 170 grams per square meter per year (g/m²/yr), and clarity (measured by Secchi depth) decreased from 31 to 20 m. In spite of increased land-use controls and export of treated sewage effluent from the basin, primary productivity of the lake continues to increase by more than 5 percent annually, and clarity continues to decrease at an average rate of 0.25 m/yr (Goldman 2000).

Scientists have documented major changes at all levels in the food web, some resulting from changes in the trophic status of the lake and some resulting from introduction of exotic species or extirpation of native species (Richards and others 1991).

Moreover, the accelerated influx of nitrogen has caused a shift in the limiting nutrient status of the lake. Until the early 1980s, nutrient limitation studies showed that primary productivity was nitrogen-limited. Since then, the same experimental procedures have shown that the lake is phosphorus-limited most of the time, and co-limited by nitrogen and phosphorus during July and August (Goldman and others 1993). Such a profound change in a lake with a volume of 156 km³ is astounding and has major implications for policies and strategies aimed at controlling eutrophication.

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Lessons from Stream and Precipitation Monitoring

Since 1980, the Lake Tahoe Interagency Monitoring Program (LTIMP) has been measuring stream discharge and nutrient and sediment concentrations in up to 10 tributary streams in the Lake Tahoe Basin. The objectives of the LTIMP are “to acquire and disseminate the water quality information necessary to support science-based environmental planning and decision making in the basin” (Boughton and others 1997). The LTIMP data set comprises more than 16,000 samples, representing about 300 station-years of records for up to seven water quality constituents.

In the early years of the stream monitoring program, much emphasis was placed on measuring the concentrations and loads of nitrate-N and ammonium-N. This was partly due to the ready biological availability of dissolved inorganic nitrogen (DIN) as well as its ease of measurement. Reliable techniques for measuring concentrations of total Kjeldahl nitrogen (TKN) were not operational until the late 1980s. When data on dissolved and particulate organic nitrogen became available, however, it became obvious that more than 90 percent of the nitrogen load from the watersheds was organic and about 50 percent of it dissolved (DON). Evidence indicates that much of the DON is biologically available, possibly as much as 28 percent of it during low-flow periods and 50 percent during early spring runoff (Stepanauskas and others 2000).

Total runoff explains most of the variation in total nitrogen yield, among both watersheds and years. For the 10 watersheds, regression of average annual total N load versus runoff has an r^2 of 0.79 and standard error (s.e.) of 0.28 kilograms per hectare per year (kg/ha/yr); for the 10 years, the regression of N load versus runoff (averaged over the 10 watersheds) has an r^2 of 0.96 and s.e. of 0.14 kg/ha/yr.

Estimated nutrient loads from watersheds that drain into the lake must be considered in the context of all sources of loading to the lake. Dugan and McGauhey (1974) called attention to the importance of direct atmospheric deposition on the lake surface. A recording and sampling precipitation gage was installed at the head of Ward Valley in November 1972, and a gage near the mouth of Ward Creek was operated in the late 1970s as part of the National Atmospheric Deposition Program (NADP). When Jassby and others (1994) compiled data from these stations with data from collectors mounted on buoys in the lake and compared the resulting deposition estimates, it became clear that atmospheric deposition was the dominant source of nitrogen and a major source of phosphorus input to the lake.

Direct atmospheric deposition to the lake is the dominant source of nitrogen input for two reasons. First, the lake is large relative to its drainage basin. Second, the soil-vegetation systems in the monitored watersheds are relatively efficient at scavenging and retaining nitrogen. A comparison of the loading rates above with DIN deposition for the period 1989 through 1992 (from Jassby and others 1994) shows that Ward Creek retained about 97 percent and Blackwood about 90 percent of the wet plus dry DIN atmospheric deposition.

Sediment Loads to the Lake

Suspended sediment contributed from Lake Tahoe basin watersheds has long been of interest. Glancy (1988) called attention to increased sediment yield associated with development in the Incline area, and suspended sediment was included in the suite of water quality parameters measured by the LTIMP program from its inception. Paerl (1973) showed that suspended sediment particles provide a substrate for microbial activity, which enhances particle aggregation and settling and accelerates the release and mobilization of inorganic nitrogen and phosphorus. Because surface soils are potentially an important source of nutrients, surface soil erosion was the focus of much of the early work on sediment sources in the Lake Tahoe basin.

The sediment budget approach, however, reveals that surface soil erosion is a relatively minor source of suspended sediment to Lake Tahoe. In a study of Blackwood, General, Edgewood, and Loganhouse Creeks, Nolan and Hill (1991) found that erosion of the beds and banks of stream channels accounts for more than 90 percent of the suspended sediment load to the lake. This suggests that runoff changes associated with roads and urban development in the basin may play an important role in increasing sediment production offsite and downstream.

A recently developed model of water clarity in Lake Tahoe has called attention to the fine fraction of suspended sediment in Tahoe basin streams (Schladow and others 2001). It turns out that the clarity of Lake Tahoe is very sensitive to the input of fine sediment (less than 63 micrometers [μm]). Because of its slow settling rate and the long hydraulic residence time in the lake, the impact of fine sediment on water clarity is persistent: a 2- μm particle takes 2 years to settle out of the water column. The actual rate at which sediment settles from the water column is influenced by particle aggregation (a function of particle density and biological activity) as well as internal circulation and mixing.

The shift in nutrient limitation from nitrogen toward phosphorus has also increased the significance of fine sediments as a factor in lake eutrophication. Relatively large sediment particles (sand) may settle near tributary mouths and have little impact on phosphorus availability. Fine particles, with a high surface-to-volume ratio, however, may be a significant potential source of phosphorus. As fine sediment particles enter the lake, where orthophosphorus concentration is lower than in basin streams, adsorbed phosphorus may be released and become available to algae over months or years (Froelich 1988; Hatch and others 1999).

Management Response to Water Quality Problems

Armed with evidence from research and monitoring programs, local government agencies and land managers have implemented various programs to address the degradation of Lake Tahoe. The first major effort, completed in the early 1970s, was to treat all sewage in the basin and export the treated effluent. With that seemingly accomplished, managers turned their attention to controlling land development. The Tahoe Regional Planning Agency established controls on development in meadows and riparian zones (although not soon enough to save the important wetland complex at the mouth of the Upper Truckee River). The Agency has been through several iterations of land-use control programs. The current program sets limits on allowable impervious surface in new development on the basis of the physical characteristics of a site. Developers may, however, propose off-site mitigation in the same watershed and avoid certain restrictions by contributing to a mitigation fund. The next big “push” will be to develop and implement Best Management Practices (BMPs) to control nutrients and sediment from runoff. Unfortunately, the efficacy of many BMPs (such as developing detention basins, armoring roadcuts and inboard ditches, and revegetating bare slopes) is difficult to document because of the difficulty and cost of sampling (Coats and others 2002).

Future Research Directions

Limnological and watershed research in the Lake Tahoe basin have provided the basis for efforts to deter the degradation of the lake’s water quality. Although our understanding of the basic sources, sinks, and impacts of nutrients and sediments has improved substantially over the past three decades, important information gaps remain. Current and future research directions aimed at closing those gaps include:

1. *Research on the role of runoff from urbanized areas.* Most of the area sampled by the LTIMP is undeveloped or lightly developed; the highly urbanized areas at South

Lake Tahoe drain directly to the lake. Preliminary sampling has shown that runoff from commercial and residential areas carries concentrations of suspended sediment, nitrogen, and phosphorus that are 5 to 100 times greater than that from comparable undeveloped areas. A major effort, funded by the Regional Water Quality Control Board's "Total Maximum Daily Load" (TMDL) program, is now under way to sample runoff from developed areas, using automated sampling equipment.

2. *Research on sources and sinks of fine suspended sediment.* Virtually no particle-size data exist for the LTIMP streams. New methods using LASER technology are available to rapidly measure concentrations of small particles in water samples. It would be very interesting and useful to compare the contribution of fine sediment from volcanic soils with that from granitic soils and the contribution of fine sediment from highways and developed areas with that from pristine areas. Work (currently in progress) is also needed to study the aggregation and settling of fine sediment in the lake.
3. *Development of control technologies for fine sediment and nutrients.* Detention basins are effective at trapping bedload and sand-sized suspended particles but ineffective for clay and sometimes silt. Nutrients trapped in a detention basin may infiltrate to the groundwater and continue to move into the lake. New technologies to address the fine-sediment problem need to be developed and experimentally tested. Engineering studies on the integrity of the sewage system, which is now 30 years old, are needed.
4. *Research on biologically available phosphorus (BAP).* On a time scale of days, the biostimulatory impact of stream water is most closely related to the soluble reactive phosphorus (SRP) concentration (Hatch and others 1999). At longer time scales, however, phosphorus released from sediment may be important. The TMDL project is currently funding work at the University of Nevada to address this problem.
5. *Improved methods for estimating total loads of nitrogen, phosphorus, and sediment.* The LTIMP is currently collecting about 30 samples per year for the major stations and fewer samples for the secondary and miscellaneous stations. With only 30 samples per year, the 95-percent confidence limits on an estimate of total phosphorus load by the regression method would be about ± 60 percent (Coats and others 2002). Optical back-scatter turbidity probes have shown promise for *in situ* near-continuous measurement of suspended sediment, which may help with quantitative load estimates for sediment and particulate forms of nitrogen and phosphorus.
6. *Atmospheric sources of nutrient loading to Lake Tahoe.* Direct wet and dry deposition is an important input to the lake; however, it is unknown whether these deposited materials originate within the basin (from wood smoke and automobile exhaust and dust) or in agricultural and urban areas to the west and southwest. Atmospheric modeling and sampling studies are under way to fill this gap.
7. *Implication of climate change for the Lake.* The most likely effect of a warmer climate in the Sierra Nevada will be a shift from snow to rain, a shift in the timing of snowmelt to earlier in the year, and an increase in total winter precipitation (Lettenmaier and Gan, 1990; see also papers from the session on "Climate and Landscape Change Over Time" in this volume). These changes will most likely increase soil erosion and mass wasting in the Lake Tahoe basin. The timing, magnitude, and distribution of these impacts need to be investigated.

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Assessing Cumulative Watershed Effects in the Central Sierra Nevada: Hillslope Measurements and Catchment-Scale Modeling¹

Lee H. MacDonald,² Drew Coe,² and Sandra Litschert²

Cumulative effects result from the combined impact of multiple activities over space and time. Land and aquatic resource managers are particularly concerned with cumulative watershed effects (CWEs). CWEs can encompass a broad range of concerns, but primary issues are changes in runoff, water quality, channel morphology, and aquatic ecosystems at the watershed scale (Reid 1993). CWEs are a class of cumulative effects defined by multiple sources within a watershed that share a common delivery mechanism, the drainage network (*fig. 1*).

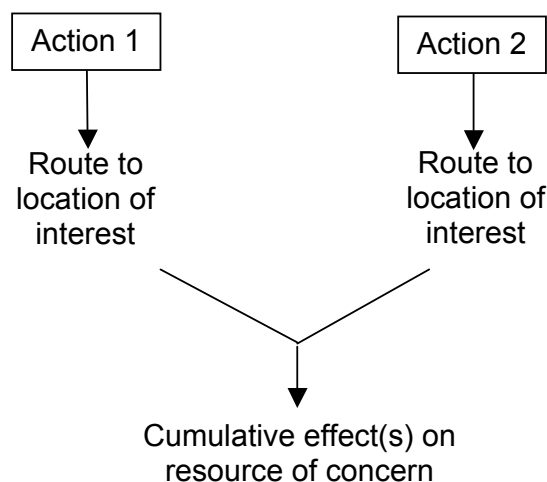


Figure 1— Multiple activities over space can lead to a cumulative watershed effect.

The assessment and prediction of CWEs has long been problematic (CEQ 1997, MacDonald 2000). Key steps in the assessment of CWEs include: (1) evaluating background conditions in the basin of interest; (2) collating and evaluating anthropogenic changes at the site scale, (3) routing the constituents of interest into the stream network, and (4) transmitting those products through the stream network and assessing their impact on the resources of concern.

Assessment of CWEs is further complicated by the need to consider effects of time on actions of concern. At the site scale, there is a need to consider the recovery of different effects over time (for example, hydrologic recovery or declining erosion rates with forest regrowth). Often there is a lag in the delivery of a given effect to a downstream location, and the persistence of a cumulative effect at a downstream location can be quite different from

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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the persistence of the causal actions. Lags in delivery mean that the size of the basin of interest can directly affect the time scale of the analysis. The complexities of these different processes, when combined with the manifestations of these processes over time and space, largely explain the reason for a lack of accepted procedures for assessing or predicting CWEs (CEQ 1997, MacDonald 2000, Reid 1993).

The lack of procedures is surprising, given the number of laws and regulations that require public agencies and private landowners to assess the potential cumulative effects of a proposed action. The National Environmental Policy Act (NEPA) requires Federal agencies to assess the cumulative effect of proposed actions, and the California Environmental Quality Act (CEQA) has similar requirements for State agencies. The Clean Water Act and its amendments also may require the assessment of cumulative watershed effects. For example, the TMDL (Total Maximum Daily Load) process is effectively a cumulative effects assessment. The Endangered Species Act may require public agencies and private individuals to assess the effect of a proposed action on the habitat or population of threatened or endangered species. For aquatic organisms, this may require a watershed-scale assessment of the different factors affecting existing or potential habitat. Finally, the California Board of Forestry explicitly requires private landowners to consider cumulative watershed effects when submitting a Timber Harvest Plan.

Taken together, these laws force Federal and private landowners to qualitatively or quantitatively assess existing and potential CWEs. At present, assessments of CWEs in the Sierra Nevada are severely limited by the lack of field data to quantify the effect of a given action and tools to quantify and aggregate the effects of past, present, and proposed actions on the resources of concern at the watershed scale. The following sections summarize recent efforts to (1) quantify anthropogenic and natural sediment yields in forested areas in the central Sierra Nevada and (2) develop models for predicting changes in runoff and sediment production at the watershed scale.

Current Methods to Assess and Predict Cumulative Watershed Effects

There are a wide range of potential approaches to assessing CWEs (*fig. 2*), ranging from the qualitative checklist used by the California Department of Forestry (CDF) to physically based and spatially explicit models, such as DHSVM (Wigmosta and others 1994). The most widely used model is the Equivalent Roaded Area (ERA) procedure developed by the USDA Forest Service in the early 1980s. This is a lumped, conceptual model that quantifies total disturbance in the watershed through the use of empirical coefficients and recovery curves for each activity (Cobourn 1989). This approach has two major limitations: (1) it does not

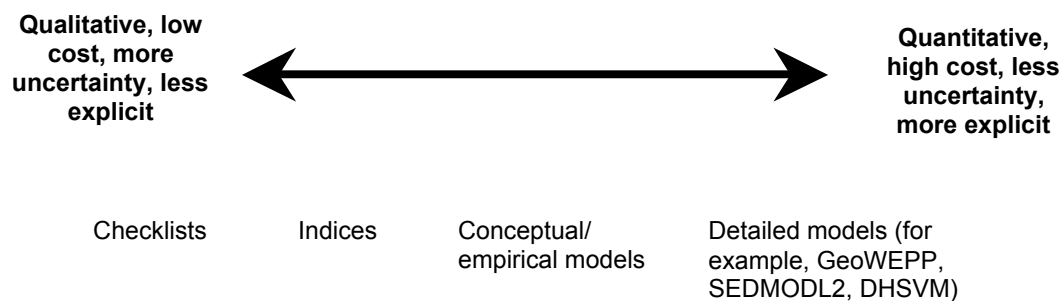


Figure 2— Continuum of approaches for assessing cumulative effects.

clearly indicate whether changes in flow or changes in sediment yields are being assessed and (2) it is not spatially explicit (in other words, the effect of an activity does not vary with its location in the watershed).

Development and use of more physically based models to predict CWEs in the Sierra Nevada are severely hindered by the lack of primary data to predict site-scale changes in runoff and erosion. The working presumption of the authors is that changes in sediment production due to forest management activities are of greater concern in the Sierra Nevada than changes in flow induced by management. Studies from other areas have shown that roads and other anthropogenic disturbances can increase sediment production rates by one or more orders of magnitude at the hillslope scale relative to undisturbed conditions (Megahan and Kidd 1972, Reid and Dunne 1984, Swanson and others 1987, Weaver and Dale 1978). Increases in sediment production at the hillslope scale are likely to increase sediment delivery to streams, and this can adversely affect downstream aquatic ecosystems (Cederholm and others 1981, Nelson and Booth 2002, Wemple and others 1996).

In contrast, timber harvest and roads on small research watersheds typically increase the size of peak flows by only 10 to 20 percent or a couple of cubic feet per second per square mile (Austin 1999). The authors' preliminary assessment of stream channel conditions on the Eldorado National Forest suggests that increased sediment loads are a larger problem than channel degradation caused by increases in the size of peak flows. It is extremely difficult to measure management-induced changes in discharge, and it is much more feasible to measure hillslope-scale changes in sediment production rates.

In fall 1999, hillslope-scale sediment production rates were measured as a first step toward the calibration and development of more spatially explicit CWE models for use in the Sierra Nevada. Specific objectives were to (1) quantify sediment production and sediment delivery from timber harvest, roads, wild and prescribed fires, off-road vehicles, and undisturbed areas; (2) quantify year-to-year variability in sediment production; and (3) determine the effect of key site variables, such as elevation, slope, percent cover, soil type, and contributing area on sediment production rates. Sediment production rates were measured by capturing sediment behind sediment fences and then removing and weighing the captured sediment (Robichaud and Brown 2002, www.fs.fed.us/institute/middle_east/platte_pics/silt_fence.htm). Group comparisons were made using F-protected LSD.

In the first year, 91 sediment fences were established. The working hypothesis was that roads and severely burned areas would generate more sediment than other sources, so 27 sediment fences were installed at the outlets of road drainage structures (such as waterbars, rolling dips, and cross-relief culverts), 36 sediment fences at the outlets of waterbars on skid trails, 7 sediment fences on rills and gullies draining off-road vehicle (ORV) trails, 15 sediment fences on hillslopes burned by prescribed fires, 3 fences on hillslopes burned by a high severity wildfire, and 3 fences on minimally disturbed hillslopes (*table 1*).

Table 1— Number of sediment fences by land use type for each of three wet seasons.

Land use type	Wet season		
	1999-2000	2000-2001	2001-2002
Roads	27	47	66
Skid trails	36	48	10
Off-road vehicle	7	7	7
Fire	18	18	3
Undisturbed	3	3	0
Totals	91	123	86

Considerable variability in sediment production rates was evident between the different land uses within the first wet season. The median sediment production rate from roads was 0.2 kg m^{-2} , or nearly an order of magnitude higher than any of the other sources (*fig. 3*). In general, sediment production rates for a given land use were highly skewed, with a few sites producing the majority of the sediment from that land use. Hence, the mean sediment production rate from roads was 0.9 kg m^{-2} , or nearly five times the median value. In comparison, the mean sediment production rate was 0.1 kg m^{-2} from skid trails, 0.4 kg m^{-2} from ORV trails, and just 0.001 kg m^{-2} from minimally disturbed sites. When burned sites were separated by burn severity, the sites burned at high severity had a mean sediment production rate of 1.1 kg m^{-2} ($n = 3$), or approximately 1,000 times greater than the mean value of 0.001 kg m^{-2} from sites burned by prescribed fire ($n = 15$).

Native surface roads produced 10 to 50 times more sediment than rocked roads. Skid trails on Holland soils produced an average of 0.9 kg m^{-2} of sediment ($n = 2$), which was significantly more than the mean value of 0.04 kg m^{-2} for the skid trails on all other soil types ($n = 34$).

Results from the first wet season supported the initial hypothesis and caused a focusing of efforts in the second and third years on sediment production from unpaved roads. Although additional sediment fences were not placed in areas burned by high-severity fire, the number of fences on roads increased from 27 in the first year to 47 in the second year and 66 in the third year (*table 1*). Because some of the lower-producing sites were not monitored for all 3 years, the study includes a total of 300 fence-years of data.

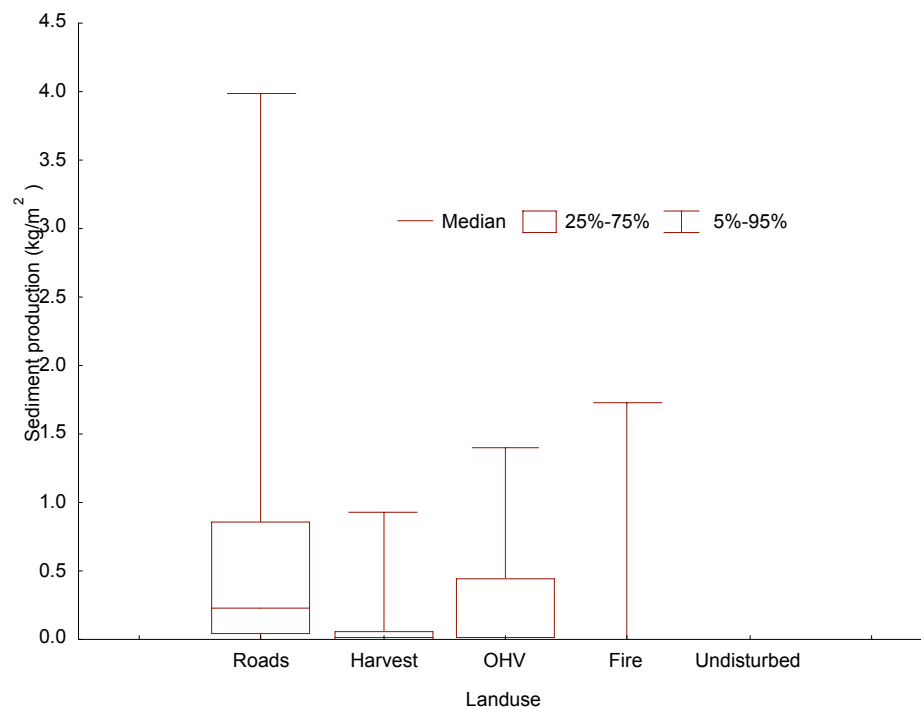


Figure 3— Sediment production by dominant land use for the 1999–2000 wet season.

Sediment production rates from roads in the second and third wet seasons were only 10 to 30 percent of the values measured in the first wet season (*fig. 4*). A similar decrease was observed for sediment production rates from skid trails, ORV trails, burned sites, and undisturbed areas. The largest decline was for the three sites burned at high severity, as the second-year sediment production rates were an order of magnitude lower than in the first year, and the third-year sediment production rates were another 70 percent lower than the

values measured in the second year. This decrease is attributed primarily to the increase in vegetative cover, because percent cover has been shown to be the largest control on post-fire sediment production rates in other areas (for example, Benavides-Solorio 2003).

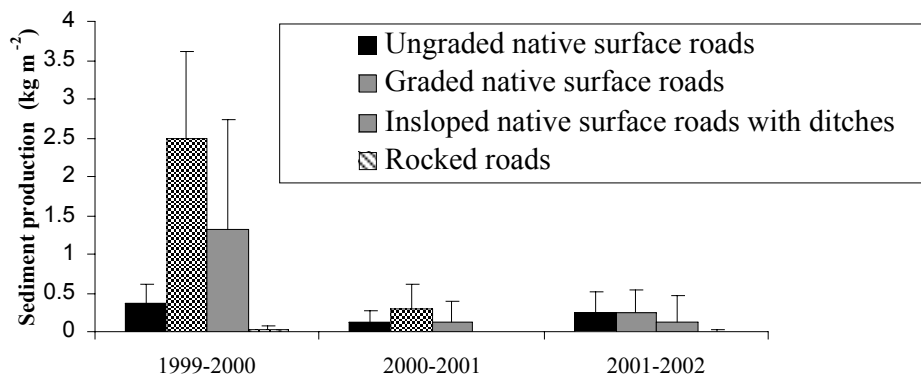


Figure 4— Magnitude and interannual variability in sediment production rates for various road drainage types and surfaces. Bars represent one standard deviation.

Declines in sediment production rates in the second and third seasons for the other land uses can be generally attributed to differences in magnitude and type of precipitation. Total precipitation in the first wet season was very close to the long-term mean but only 70 percent and 83 percent of normal in the second and third wet seasons, respectively. Perhaps more importantly, storms in the second and third wet seasons generally were colder than in the first wet season, so more of the precipitation fell as snow. Hence, rainfall erosivity in the second and third wet seasons was only $440 \text{ MJ mm ha}^{-1} \text{ hr}^{-1}$, or slightly more than half of the erosivity in the first wet season and only about 40 percent of the long-term mean. The larger and more persistent snowpack at most of the sediment fence sites apparently protected surfaces from rain splash erosion and may also have slowed overland flow.

Taken together, the 3 years of data confirmed that roads, high-severity wildfires, ORV trails, and certain skid trails were the dominant sources of sediment at the hillslope scale. Sediment production rates were highly variable between sites within a year as well as between years. Although the sample size for minimally disturbed sites was small ($n = 3$), none of these sites produced any sediment. Recent research indicates that long-term erosion rates are dominated by catastrophic but infrequent pulses of erosion triggered by wildfires and extreme storms (Kirchner and others 2001). The implication is that natural erosion rates between such events are very low, and this is consistent with the authors' field observations.

Univariate analyses and stepwise multiple regression both indicated that road segment area times slope ($A \cdot S$), annual erosivity (EA), and road maintenance (recently graded versus ungraded) were significant controls on unpaved road erosion. An empirical model using these three variables explains 54 percent of the variability in annual road sediment production (*fig. 5*). Study results also showed that native surface road segments receiving runoff from adjacent rock outcrops produced four times more sediment than comparable segments unaffected by rock outcrops. However, a dummy variable for the presence of rock outcrops was not significant in the multivariate analysis. The observed variations in sediment production rates between sites and between years illustrate the difficulty of developing accurate predictive models for CWEs.

Developing Models for Predicting Cumulative Watershed Effects

The authors' goal for modeling is to develop flexible, user-friendly, geographic information systems (GIS)-based models to predict changes in flow, sediment production, and ultimately sediment delivery for watersheds ranging from approximately ten to several hundred square kilometers. As indicated by *figure 2*, a wide range of potential models exists for assessing CWEs. Reid (1993) noted that simpler models are widely used but are incapable of representing underlying processes and are largely unverified, whereas more physically based, spatially explicit models should be more accurate but are rarely used.

The authors of this paper have attempted to take a middle road. One objective was to explicitly separate the procedures used to assess changes in flow from those used to assess changes in sediment production. Another objective was to use the capability of spatially explicit models, while recognizing basic data limitations and the desire for models that could

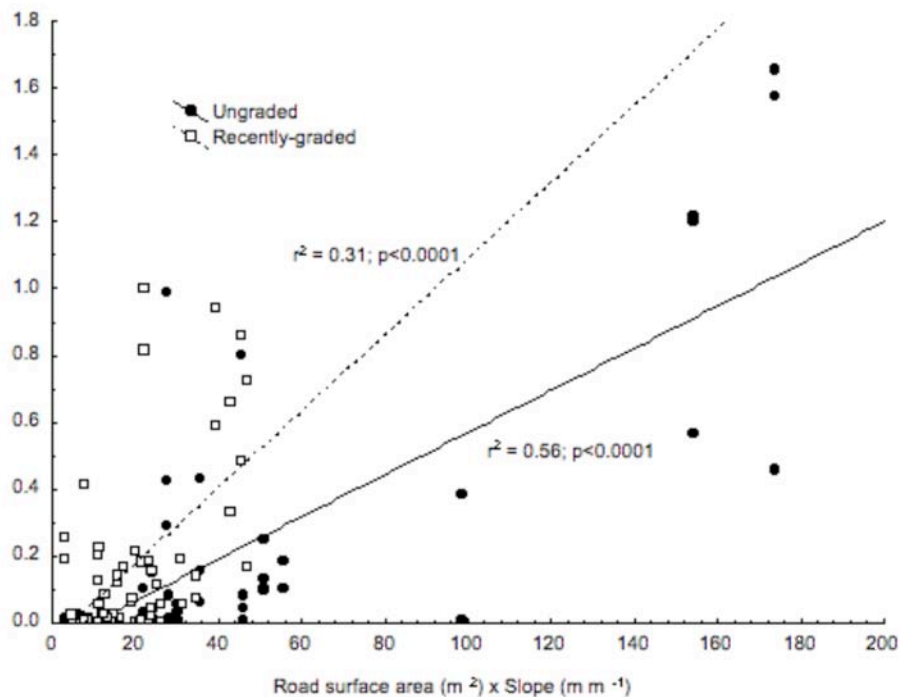


Figure 5— Sediment production versus the product of road surface area and road slope for recently graded and ungraded native surface roads. Sediment production was normalized by annual erosivity. The regression lines for recently graded and ungraded roads are significantly different ($p = 0.03$).

be easily applied by a range of users. The third objective was to provide users with the flexibility to change values and recovery rates to better represent local conditions. The ability to readily change coefficients and rates of recovery facilitates an assessment of model sensitivity to the selected values; this is an important tool given the uncertainty in predicting the effect of a given disturbance on different sites. Finally, a modular approach was used so that new procedures could be added as they are developed or different issues arise.

The first model, DELTA-Q version 1.0, calculates changes in runoff on the basis of activities such as forest harvest and fires (see modeling link at <http://www.cnr.colostate.edu/frws/people/faculty/macdonald/macdonald.html>). This calculates catchment-scale changes in

high, median, and low flows resulting from changes in forest cover due to timber harvest or fires. Changes can be calculated in absolute terms or as a percentage. The input data are GIS layers representing the extent, type, and years of the different activities. Users determine the flows of interest and select values for the change in flow for each activity type and the time to hydrologic recovery. Help files list the calculated changes in flow for different flow percentiles from 26 paired-watershed studies (Austin 1999). Each model run calculates the change in flow over the chosen time period for one activity layer (for example, forest harvest or fire). The model sums the changes in flow from multiple runs using different activity layers to determine the total change in flow for the area of interest. Tables of the individual and total changes in flow over time can be exported as text files for plotting, report preparation, or further analysis.

The second model is the Forest Erosion Simulation Tool (FOREST). This model is designed to calculate changes in surface erosion resulting from forest harvest, unpaved roads, and fires. The explicit separation of changes in flow and surface erosion should help users recognize differences in the magnitude of change and length of the recovery period for these two different types of CWE. Once FOREST is released, the authors will begin working on a third model to route the calculated sediment production rates into and through the stream network. As in the case of DELTA-Q, the input data for FOREST are one or more ArcInfo coverages with the activities of interest. There are separate procedures for calculating sediment production from linear features (such as roads) and polygons. The modular structure means that FOREST provides the user with several options for calculating sediment production rates, depending on data availability and the desired level of complexity.

For roads and other linear features, the options within FOREST include fixed sediment production rates per unit road length for each road type and empirical models (for example, Luce and Black 1999). Alternatively, the user can run a set of simulations outside of FOREST using models such as WEPP:Road (<http://forest.moscowsl.wsu.edu/fswepp/>). Depending on available data and desired level of complexity, users can stratify their roads layer and then use FOREST to assign spatially explicit values to different road segments. A lookup table of published road erosion values is provided to help users determine values for their sites.

The polygon module calculates sediment production rates from activities such as forest harvest or fires. The required input is one or more polygon coverages that include the type(s) of disturbance and year of each activity. Users assign first-year sediment production rates to each activity and the time needed for erosion rates to return to background levels. At this stage, a linear recovery is assumed, although users can also specify no recovery, as might be the case for continuously used unpaved roads. An additional polygon coverage can be used to adjust sediment production rates for factors such as fire severity, soil type, or elevation.

To help users assign sediment production rates, FOREST provides a lookup table of published post-fire erosion rates. Alternatively, programs such as Disturbed WEPP can be used to calculate sediment production rates, which can then be brought into FOREST. In contrast to DELTA-Q, FOREST converts vector data to rasters to perform raster-based calculations. Model outputs include sediment production grids for each year as well as a summary table of sediment production rates over time for the areas of interest. When FOREST is run on multiple layers of overlapping activities, the results can be combined into a grid to show maximum sediment production rates for the time period of interest.

The raster-based approach of FOREST will facilitate development of modules to deliver the sediment into and through the stream network. Given the data limitations and uncertainties in predicting sediment transport, it is expected that the sediment delivery model's modules will use a combination of empirical data and relatively simple algorithms based on key variables, such as slope and drainage area. The final step will be to test the validity of these CWE models against data from a range of managed and relatively unmanaged watersheds.

The authors are expanding the scope of their field studies to sites in the southern Sierra Nevada and southern Cascades.

Conclusions

Cumulative watershed effects are an important concern of resource managers, and both state and Federal laws require assessment of CWEs. There is a need for improved models to more explicitly assess changes in flow and sediment production for forested watersheds in the Sierra Nevada. Current methods are hampered by both the lack of accurate input data based upon field measurements and the absence of spatially explicit, user-friendly models.

The field studies described here have focused on measuring sediment production rates in forested areas in the central Sierra Nevada. In general, unpaved roads and areas burned at high severity have the highest sediment production rates. Within the study area, sediment production rates from roads can be predicted on the basis of road surface area times slope, rainfall erosivity, type of road surface (rocked or native surface), and whether the road has been recently graded. Sediment production rates from severely burned areas declined rapidly over time although this decline was confounded by lower rainfall erosivity in the second and third wet seasons. Sediment production rates varied considerably between sites and between years, and this illustrates the difficulty of assessing CWEs.

The DELTA-Q model has been developed to calculate changes in flow resulting from fires and forest management activities, and a separate model to calculate changes in surface erosion is being finalized. A third model is proposed to route sediment into and through the stream network. Continuing field studies will provide additional data on sediment production rates and delivery of this material to the stream channel. Once the various models are operational, predicted changes in runoff and sediment yields at the watershed scale need to be tested against measured values and compared to aquatic resource conditions for forested watersheds with varying levels of natural and anthropogenic disturbance.

Acknowledgments

This work has been supported by grants from the Eldorado National Forest, USDA Forest Service, and the California Department of Forestry and Fire Protection, and the authors are grateful for their support. The authors also thank the Wildland Resources Center at the University of California at Berkeley for supporting the participation of the senior author in the Sierra Nevada Science Symposium and Rick Kattelman and Fraser Shilling for organizing the session on Aquatic Systems and Watersheds and providing comments on an earlier draft of this paper.

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Turning Stumbling Blocks into Stepping Stones in the Analysis of Cumulative Impacts¹

Leslie M. Reid²

Federal and state legislation, such as the National Environmental Policy Act and the California Environmental Quality Act, require that responsible agency staff consider the cumulative impacts of proposed activities before permits are issued for certain kinds of public or private projects. The Council on Environmental Quality (CEQ 1997) defined a cumulative impact as "...the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (40 CFR 1508.7). "Cumulative watershed impacts" are cumulative impacts that involve the generation or transport of water through a watershed and so include impacts arising from changes in hydrology, erosion, in-stream woody debris, channel form, and water quality. Evaluations of impacts on freshwater biota, flooding, and sedimentation thus require analysis of cumulative watershed impacts.

The CEQ (1997) discusses implications of the definition and describes a procedure for cumulative impact analysis. A useful analysis would evaluate existing and potential impacts affecting resources, ecosystems, and human communities of concern, determine how the proposed project would influence those impacts, and evaluate the significance of each relevant impact by determining the extent to which the entities of concern are affected.

Considerable effort is devoted to impact analysis, and efforts are under way to improve the efficiency and effectiveness of analysis procedures. The author examined 14 cumulative impact analyses for forestry-related activities on private lands in northwest California to determine whether they provide the necessary information and to identify opportunities for improving analyses. The reviewed documents include a combined environmental impact statement and environmental impact report, several timber harvest plans, a habitat conservation plan, a watershed analysis, and analyses of sediment source and causes and impacts of flooding. Specific documents are not identified here so that the discussion can remain focused on the content of these analyses. Although these sample analyses are from projects in northwest California, this analysis offer insights that should be relevant to future evaluations of cumulative impacts in the Sierra Nevada.

A variety of problems were found that detracted from the utility of the analyses. These fell into four broad classes: (1) problems involving the definition of cumulative impacts, (2) problems concerning evaluation of impact significance, (3) problems in designing measures to mitigate impacts, and (4) problems involving interpretation of technical information.

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Definition Problems

The most profound analysis problems arose from misinterpretations of the definition of cumulative impacts. One analysis, for example, simply argues that the plan is more protective than current regulations, so its cumulative effect will be positive, regardless of the plan's impact on the environment. This approach is inconsistent with the definition, which specifies that a cumulative impact is "...the impact *on the environment*..." (emphasis in this and following quotations is added); it is the environmental impact that must be evaluated, not a change relative to a hypothetical alternative. Another document argues that because impacts will be minor from the project in isolation, the project will not contribute significantly to cumulative impacts. This, too, directly conflicts with the definition: "Cumulative impacts can result from *individually minor but collectively significant* actions...." Several analyses imply that because earlier activities originally caused the impacts, contributions from planned activities can be disregarded. However, cumulative impacts result "from the incremental impact of the action *when added to other past, present, and reasonably foreseeable future actions*...."

Many analyses assume that if natural influences dominate, human-induced effects can be ignored. The effect of land use activities on landslides and floods, for example, is argued to be insignificant because landslides and floods occur during large storms, which are natural. However, the impact to be evaluated is the human-induced *change* from natural conditions: "'Cumulative impact' is the impact...*of the action when added to other...actions* regardless of what agency...or person undertakes such other actions." A useful analysis would evaluate the extent to which human activities increase flood severity or landslide incidence when a triggering event occurs.

Analyses also commonly confuse an impact's cause with the impact itself. Several note that planned projects will prolong alteration of conditions that cause a significant impact but argue that the projects will not worsen the impact and so will not contribute to it. However, the cumulative damage experienced by those affected—the severity of the cumulative impact—increases with increasing impact duration. For example, if flood risk increases by 40 percent for 50 years, the excess cost of flood damages will average about 10 times higher than for the same level of increase that lasts only 5 years. The altered conditions remain constant, but the resulting damages—the impacts—accumulate through time.

Decisions from both Federal and state courts indicate that misinterpretation of the definition can lead to cumulative impact analyses that are not legally valid (for example, *Los Angeles Unified School District v. City of Los Angeles* (2d Dist. 1997) 58 Cal.App.4th 1019 [68 Cal.Rptr. 2d 367]; *Kings County Farm Bureau and others v. City of Hanford* (5th Dist. 1990) 221 Cal.App.3d 692 [270 Cal.Rptr. 650]; *Blue Mountains Biodiversity Project v. Blackwood* (9th Cir. 1998) 161 F3d 1208).

Problems in Evaluating Impact Significance

A second set of problems involves evaluation of impact significance. CEQ (1997) notes that significance is to be assessed with respect to those affected: "Each affected resource, ecosystem, and human community must be analyzed in terms of its capacity to accommodate additional effects, based on its own time and space parameters." None of the reviewed analyses takes this approach. Instead, most select significance thresholds arbitrarily and without evaluating impacts generated at the selected threshold level. One simply asserts that a 67 percent increase in flood frequency is insignificant and another that an expected logging-related increase in landslide frequency is "considered acceptable."

Some analyses consider changes insignificant if they fall within the range of natural conditions. However, the distribution of natural conditions is more important than the range: a 100-year flood is within the range of natural conditions, but impacts accrue if floods of that

size begin to recur frequently. Several analyses adopt arbitrary metrics to compare natural and managed conditions. A watershed analysis, for example, simply asserts that the density of trees with diameters of more than 8 inches is a suitable basis for comparing second-growth stand conditions to the “functional needs and old-growth stocking levels” of old-growth coastal redwood forests. No explanation is provided for why an 8-inch-diameter redwood would satisfy the “functional needs” that had previously been fulfilled by 80-inch-diameter trees.

One analyst argues that because an impact is already large, additional contributions from the project will be insignificant, thereby defying the definition of cumulative impact: “...incremental impact of the action *when added to* other...actions.” Additional contributions necessarily contribute to significant impacts if impacts are already significant. Another analysis attempts to evaluate the risk of surpassing a significance threshold for cumulative impacts without considering the existing impact level. However, the *cumulative* impact cannot be evaluated if the existing impact is not considered, and the risk of surpassing a threshold depends on how near the threshold already is.

Most problems concerning the identification and significance of cumulative impacts are readily addressed by adopting an analysis approach that reflects the established definition of cumulative impacts, such as that outlined by CEQ (1997). Such an analysis would identify the impacts to which a project might contribute and would evaluate the level of contribution to each. The significance of each impact would be assessed with respect to the effects experienced by those affected.

Problems in Designing Mitigation Strategies

Many plans rely on management strategies to avoid cumulative impacts, and such strategies introduce a third set of problems. For example, plans often incorporate “design mitigations,” whereby activities are modified to lessen their impact. Analyses supporting this strategy would need to evaluate the extent to which the mitigated activities, in combination with past, present, and reasonably foreseeable future activities, would contribute to cumulative impacts. None of the documents examined include this kind of analysis.

A second management strategy employs “offsetting mitigations,” which are activities intended to cancel out the impacts of other activities. Offsetting mitigations include the “zero net discharge” approach to sediment control, in which planned sediment inputs are offset by curtailing an equal amount from sources already present. But, as in the case with design mitigations, analyses do not adequately evaluate the effectiveness of planned mitigations. Several errors occur repeatedly. Many sediment sources targeted for offsetting mitigation—such as road-related erosion—would have already healed had forestry activities not continued. Their current levels of sediment input result from on-going activities and so represent the sediment “overhead” cost of those activities (*fig. 1*). Mitigations to reduce these sources do not offset the plan’s sediment input; they simply prevent the plan’s input, when the “overhead” is included, from being even larger.

Analyses also overestimate the effectiveness of offsetting mitigations by assuming that most (usually 80 percent) of the mitigated sediment would have otherwise soon reached a stream. In reality, a much lower proportion of the mitigated sediment is likely to have contributed to stream sedimentation. Furniss and others (1998), for example, show that less than 30 percent of the sediment “saved” by culvert redesign may be effective in offsetting other sources, even during very large storms. If the culverts that will fail cannot be identified beforehand, the potential effectiveness is even lower. Disregard of the timing of impacts also leads to overestimation of mitigation effectiveness. Data in one analysis suggest that sediment curtailed by mitigation would have entered streams gradually over 130 years, if at all; thus, less than 15 percent of the mitigated sediment would offset inputs expected from proposed projects over the next 20 years, allowing sediment-related impacts to accumulate (*fig. 2*).

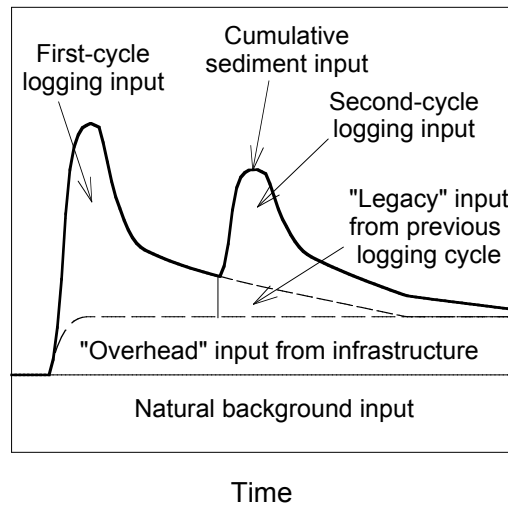


Figure 1— Relation between different categories of sediment inputs. Inputs are represented by characteristic time distributions; actual inputs would vary according to weather conditions.

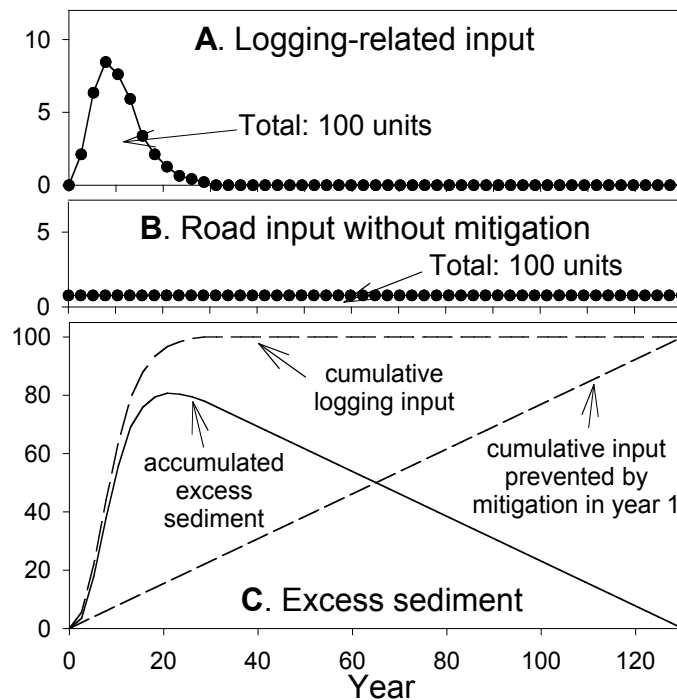


Figure 2— Hypothetical case illustrating the effect of offset timings of project and mitigated sediment inputs. **A.** Timing of sediment inputs from logging in year 1. **B.** Timing of road inputs had sources not been mitigated in year 1—mitigation removed sources contributing an average of 0.77 units per year, so 100 units would be “saved” over 130 years. **C.** The cumulative excess sediment from the project (calculated as cumulative logging input minus cumulative mitigated input) will not be offset until year 130 and may contribute to cumulative impacts until then.

Other mitigations are clearly incapable of offsetting the kind of impact for which they were proposed. For example, road repairs designed to decrease future erosion will not offset immediate increases in flood risk due to increased runoff after logging.

In any case, no amount of offsetting mitigation can prevent cumulative impacts from new activities if the activities themselves can generate the impacts. For example, if a plan needs to reduce sediment input to less than 20 percent over background, control of all pre-existing anthropogenic inputs will not lead to compliance if the planned projects will themselves introduce sediment at 30 percent over background levels. Furthermore, a strategy of offsetting mitigations prolongs existing impacts—and thereby increases impact severity—because activities that reduce impacts are offset by activities that cause them.

An analysis that identifies the impacts to which a project might contribute and evaluates the level of contribution to each would provide the information necessary to design appropriate impact management strategies. No single strategy is useful for all impacts. Design mitigations are appropriate if a particular practice can prevent a problem from developing, and offsetting mitigations can be effective in systems that are not already affected at undesired levels if the mitigations will indeed cancel out expected impacts at the appropriate locations and times. If the desired activities necessarily contribute to potential impacts, the rate of impact-generating activities can be modified to maintain acceptable levels of impact. This rate-based strategy is readily combined with others: higher use intensities are possible if mitigations are effective. Selection of the appropriate strategies for a particular location and project requires a valid analysis of the cumulative impacts of the mitigated projects.

Technical Errors

The most disquieting problem encountered is the low level of technical expertise exhibited. Most reports incorporate invalid analyses, significant technical errors, and conclusions not supported by the available information. For example, one analysis argues that, despite observations by streamside homeowners that substantial aggradation has occurred, “The marked absence of change in the channel pattern...suggests that the channel has not been aggrading to a significant degree.” However, channels held in place by bedrock-cored terraces cannot migrate, and the analysis itself documents the presence of such terraces.

Some analyses employ technical arguments that conflict with fundamental principles. A geological report for one logging plan, for example, argues that a study showing that earthflows move faster without a forest cover does not apply to the site in question because the active earthflow on the project site is on a steeper slope— therefore is asserted to be “more stable”—than the studied earthflows. On this basis, the report concludes that logging the steep, active earthflow will not significantly affect it.

Many analyses use the existence of “conflicting information” to argue that no impacts are discernible. In each case examined, though, either the conclusion is not supported by the conflict or the apparent conflict is an artifact of invalid analysis. One report, for example, reports that recent fine-sediment aggradation had caused a 15 percent reduction in the area of a channel cross section, but that a nearby cross section had been reduced by 44 percent. On the basis of this variability, aggradation is concluded to be “uncertain” and is completely disregarded. In reality, even a change of less than 15 percent would significantly increase flood severity and ordinarily would be carefully evaluated.

The problem of technical inadequacy is the most difficult to address. Ordinarily, the solution would be increase technical review, but each problem discussed above had been identified by reviewers and none of the errors were corrected in final documents. Review comments, if addressed at all, were often rebutted by simply restating the original argument or conclusion.

That technical review is so easily disregarded suggests that standards for technical adequacy differ between research and land management settings. Researchers consider technical review

indispensable for producing high-quality, technically valid publications, and journal editors—whose primary concern is the technical validity of the documents—act as independent and technically astute arbiters in weighing the quality of opposing technical arguments.

In contrast, arbiters for environmental planning documents usually are the government agency staff responsible for overseeing or preparing the documents. The primary goals in this case often are approval of the desired project and avoidance of legal challenges. Both Federal and state courts provide agency staff with considerable discretion for decisions based on technical information. A Federal Circuit Court stated, for example, that “When, as here, the issue of procedure relates to the sufficiency of the presentation in the statement, the court is not to rule on the relative merits of competing scientific opinion” (Committee For Nuclear Responsibility, Inc., and others, v. Glenn T. Seaborg and others [1971] 149 U.S. App. D.C. 380 [463 F.2d 783]). At the State of California level, courts found that “Determinations in an EIR must be upheld if they are supported by substantial evidence; the mere presence of conflicting evidence in the administrative record does not invalidate them” (Barthelemy v. Chino Basin Municipal Water District [4th Dist. 1995] 38 Cal.App.4th 1609 [45 Cal.Rptr.2d 688]). Agency staff may choose between conflicting bodies of substantial evidence or technical arguments without regard for their relative strength (Browning-Ferris Industries of California, Inc. v. City Council of the City of San Jose [6th Dist. 1986] 181 Cal.App.3d 852 [226 Cal.Rptr. 575]); the presence of other substantial evidence that would lead more strongly to other conclusions is essentially irrelevant (Remy and others 1999). Because courts look primarily for the *existence* of a technical argument to support a decision, a simple restatement of the original argument is usually sufficient legally to rebut a technically valid review comment.

Technical adequacy might be improved if independent technical arbiters were assigned to documents or if technical validity was made a priority within the relevant agencies. However, as long as technical errors do not influence the acceptability of planning documents and do not detract from their legal adequacy, there appears to be little motivation to address the problem.

Conclusions

Examination of a series of cumulative impact analyses revealed a variety of problems that prevented the analyses from providing technically valid foundations for land use planning. Recent court decisions suggest that problems arising from invalid definitions of cumulative impacts need to be addressed to ensure that documents are legally adequate. Other problems concerning technical inadequacies and strategies for managing cumulative impacts would also need to be addressed if management decisions are to be based on technically valid information, if stated management objectives are to be achieved, and if the agencies’ technical credibility is to be sustained.

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Biodiversity



Biodiversity in the Sierra Nevada¹

Dennis D. Murphy,² Erica Fleishman,³ and Peter A. Stine⁴

The earliest explorers of the Sierra Nevada hailed the mountain range for its unsurpassed scenery. Although a significant component of that beauty was an especially rich assemblage of plants and animals, it was not until many decades later that the Sierra Nevada's wealth of biodiversity was appreciated fully and documented in earnest. Indeed, by the time naturalists, including the legendary John Muir, began to write of the range's biological assets, features such as ancient forests, alpine meadows, and stream corridors were under full assault from unsustainable levels of logging, livestock grazing, and mining. Grizzly bears, wolverines, mountain sheep, and condors had disappeared outright or were far along the path toward disappearance in the Sierra Nevada. Unknown populations of more cryptic species were likely extirpated also, reducing the species' genetic diversity and either disrupting or permanently altering ecological interactions. We will never have complete knowledge of species richness, composition, and distribution of the native biodiversity of the Sierra Nevada prior to European-American settlement.

Although the number of species in a given landscape and the distribution of individuals among species are the most commonly implied meanings of the term "biodiversity," biodiversity encompasses the full range of life, from genes to complex ecological communities, at all spatial, temporal, and organizational levels. Conservation of biodiversity cannot be achieved without also conserving the ecological and evolutionary processes that sustain life. Those processes, in turn, may be affected by changes in the identity, abundance, and geographic distribution of species. Most theoretical and empirical work on biodiversity has tended to focus on species, assemblages, and communities. These units are among the most intuitive and easily delineated forms of biodiversity, and intentional or inadvertent alterations to their dynamics, structure, and composition are relatively amenable to detection and management.

As the contributions in this section emphasize, conservation and management of the biodiversity of the Sierra Nevada not only is a priority on its own merits, but also is affected by and tightly linked to our ability to achieve other environmental goals. For example, invasion of non-native species of plants—at rates that may be exacerbated by climate change—can affect fire regimes and, by extension, forest health. Because water is a limiting resource for a majority of native species as well as for humans, water allocation strategies for human uses have direct and indirect effects on patterns of biodiversity. In some cases, individual species play key roles in sustaining ecological processes and community structure. These taxa include species that contribute disproportionately to the transfer of matter and energy (sometimes called keystone species), structure the environment and create opportunities for additional species (ecological engineers), or exercise control over competitive dominants, thereby promoting increased biotic diversity (strong interactors).

¹ This paper provides an introduction to the biodiversity session presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Few geographic regions illustrate the full suite of economic and aesthetic values attributed to biodiversity as well as the Sierra Nevada. Not coincidentally, few regions can boast a similar range of underlying topographic and climatic gradients, creating a variety of local environments that collectively support a substantial array of life forms, land cover types, and associated animal and plant species. Species richness and endemism of temperate conifer forests in the Sierra Nevada is among the greatest in the world, and the effect of giant sequoia on forest structure has been recognized as a globally outstanding rare phenomenon (Ricketts and others 1999). Using a rarity-weighted index, The Nature Conservancy ranked the species richness of the Sierra Nevada among the top 11 regions in the United States (Stein and others 2000). The World Wildlife Fund considers the Sierra Nevada to be among the 32 most biologically distinct of the 116 ecoregions in the United States and Canada (Ricketts and others 1999). High endemism has been documented among mammals (especially rodents), butterflies, and vascular plants. Lesser-known taxonomic groups, including non-vascular plants and many groups of invertebrates, are likely to be equally distinct.

The cumulative effects of a century and a half of human activity now threaten the viability of a number of species that primarily occur within the Sierra Nevada Bioregion. At lower elevations, extraction of timber and fire suppression have simplified the structure of ponderosa pine and mixed conifer forests, increased the probability of major fire events, and facilitated outbreaks of herbivorous insects and pathogens. Introduced fishes are a major contributor to declines in populations of amphibians (and an unknown diversity of aquatic invertebrates), whereas resources for native fishes are degraded by dams, livestock grazing, and logging. More recently, deposition of ozone and other airborne pollutants at intermediate elevations has begun to have demonstrable effects on some species of trees and lichens (Ricketts and others 1999).

Although the conservation outlook for the Sierra Nevada is by certain measures cause for concern, vulnerability assessments presented in the recent Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement (Volume 4, Appendix R) offer some grounds for optimism. The spatial extent of area occupied by more than half of the region's species of birds, for example, is either stable or increasing. Of 23 identified threats to species persistence, those that affected the greatest proportion of plant species assessed—such as roads (0.65), mechanical treatments (0.61), and off-highway vehicles (0.56)—result from patterns of human land use that can be modified or changed, as opposed to now-altered ecological processes that may be difficult to reconstruct.

The vulnerability assessments in the Forest Plan demonstrate that conservation priorities and strategies are likely to vary among versus within taxonomic groups. For example, amphibians accounted for only 27 of the 427 species of terrestrial vertebrates evaluated (6 percent) (*fig. 1*). However, nine of those species—a higher proportion than in any other taxonomic group—are judged to have relatively high risk of losing viability due to combinations of natural phenomena and human land uses (*fig. 2*). Of the 37 taxa of fishes native to the Sierra Nevada, 19 are considered to be highly vulnerable and 12 are moderately vulnerable (Forest Service 2001). Clearly certain taxonomic groups are disproportionately vulnerable and managers need to better understand why that is so and be prepared to respond accordingly. In addition, there are several noticeable differences among taxonomic groups with respect to the three variables used to score overall vulnerability (population size, population trend, and change in distribution). Mammals have the greatest proportion of species with population sizes larger than 10,000 (0.60, *table 1*), but the smallest proportion of species with stable or increasing geographic ranges (0.19, *table 2*).

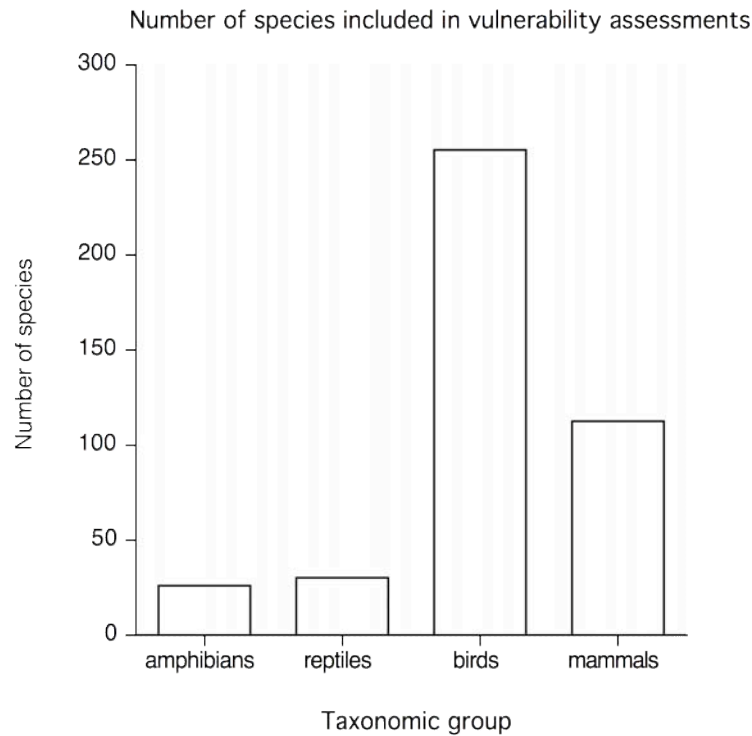


Figure 1— Numbers of species included in vulnerability assessments in the Sierra Nevada Forest Plan Amendment Environmental Impact Statement (2001) Appendix R.

Table 1— Population size (number of individuals) of terrestrial vertebrates in the Sierra Nevada.

Population size (number of individuals)	Proportion of species				
	all taxa	amphibians	reptiles	birds	mammals
may be extirpated	0.02	0.07	0.00	0.02	0.04
1 - 100	0.06	0.07	0.00	0.09	0.00
101 – 1,000	0.27	0.38	0.16	0.34	0.12
1,001 – 10,000	0.15	0.22	0.10	0.11	0.25
greater than 10,000	0.50	0.26	0.74	0.44	0.59
	1.00	1.00	1.00	1.00	1.00

Table 2— Decline in area occupied by terrestrial vertebrates in the Sierra Nevada.

Percent decline in area occupied	Proportion of species				
	all taxa	amphibians	reptiles	birds	mammals
90 – 100 percent	0.04	0.15	0.00	0.02	0.05
50 – 89 percent	0.07	0.19	0.10	0.05	0.08
Less than 50 percent	0.44	0.37	0.45	0.35	0.68
Stable or increasing	0.45	0.30	0.45	0.58	0.19
	1.00	1.00	1.00	1.00	1.00

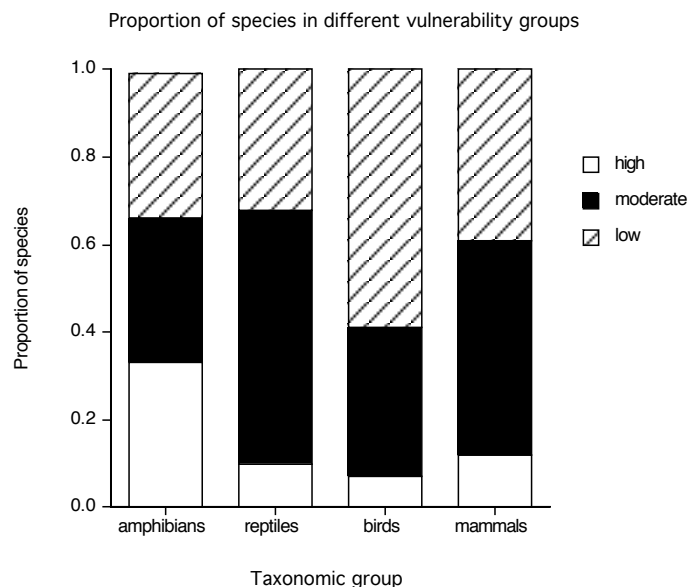


Figure 2— Proportions of species in different vulnerability groups, from the Sierra Nevada Forest Plan Amendment Environmental Impact Statement (2001) Appendix R.

In addition to evaluating the status of native terrestrial vertebrates in the Sierra Nevada Bioregion, vulnerability assessments have addressed dependence of individual species on four high-priority land cover types: late seral and old growth forest, west-side foothill oak woodland, riparian and meadow, and aquatic. Aquatic ecosystems have the highest proportion of dependent (highly resource-specific) species (0.79), whereas late seral and old growth forest had the lowest proportion of dependent species (0.69) (*fig. 3*). Patterns of dependence, however, vary among taxonomic groups; for instance, a much higher proportion of amphibians (0.78) than birds or mammals (both 0.19) facultatively use late seral and old growth vegetation. By contrast, because amphibians inhabit uplands for much of their adult life stage, the proportion of species dependent on aquatic systems is higher among birds (0.73) and mammals (0.96) than among amphibians (0.41).

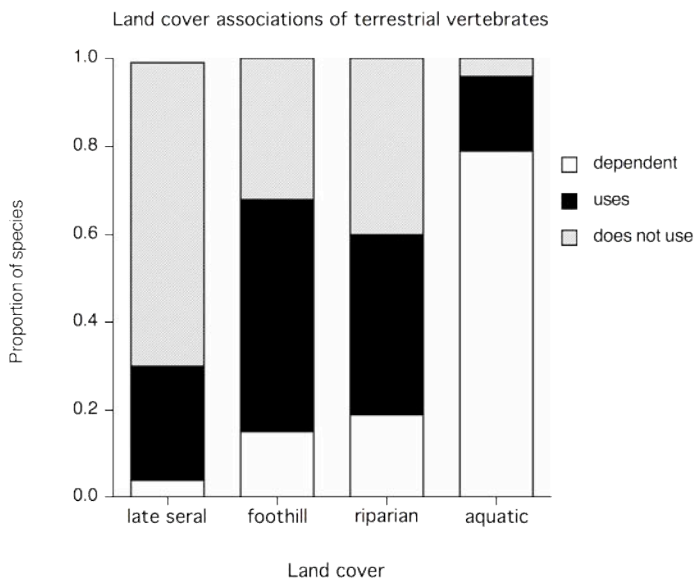


Figure 3— Land cover associations of terrestrial vertebrates.

Comparison of vulnerability assessments for terrestrial vertebrates and aquatic vertebrates (fishes) again highlights both similarities and differences. The proportion of species with downward population trends is nearly equal among terrestrial vertebrates and fishes (0.48 and 0.46 respectively, *fig. 4*), but declines in area occupied are more pronounced among fishes than among terrestrial vertebrates (*fig. 5*). This suggests a general pattern of higher vulnerability among aquatic species. Aquatic habitats of the Sierra Nevada are probably those most sensitive to anthropogenic disturbances. Wet meadows, streams, riparian corridors, ponds, and lakes have experienced varying, but elevated, levels of degradation in recent decades; Correspondingly, it should not be a surprise that aquatic biodiversity appears to be most vulnerable.

Floral diversity in the Sierra Nevada is especially notable. Some 3,000 species of vascular plants alone are associated with vegetation communities including, but by no means limited to, chaparral, foothill, and pinyon-juniper woodlands; forests of ponderosa pine, mixed conifers, white fir, red fir, and lodgepole pine; alpine meadows; and sagebrush scrub. Yet of the 135 species evaluated in the Sierra Nevada Forest Plan Amendment Environmental Impact Statement (Forest Service 2001)—species either listed as endangered or threatened, proposed for federal listing, or considered sensitive by the Forest Service—only 26 (19 percent, comprising less than 1 percent of the total number of vascular plants) are considered to be at high risk of losing viability. A full third of plant species are judged to have low risk of viability loss. Perennials (mainly herbs) accounted for the majority of species in the high and moderate vulnerability groups (81 and 63 percent, respectively). As noted above, human land uses, ranging from urbanization and development of ski areas to livestock grazing and mining, are currently the most pervasive threats to plants in the Sierra Nevada. Over the next several decades, the importance of managing more diffuse and insidious threats, such as noxious weeds and altered hydrologic regimes (both of which affect about 30 percent of the plant species evaluated), is likely to increase.

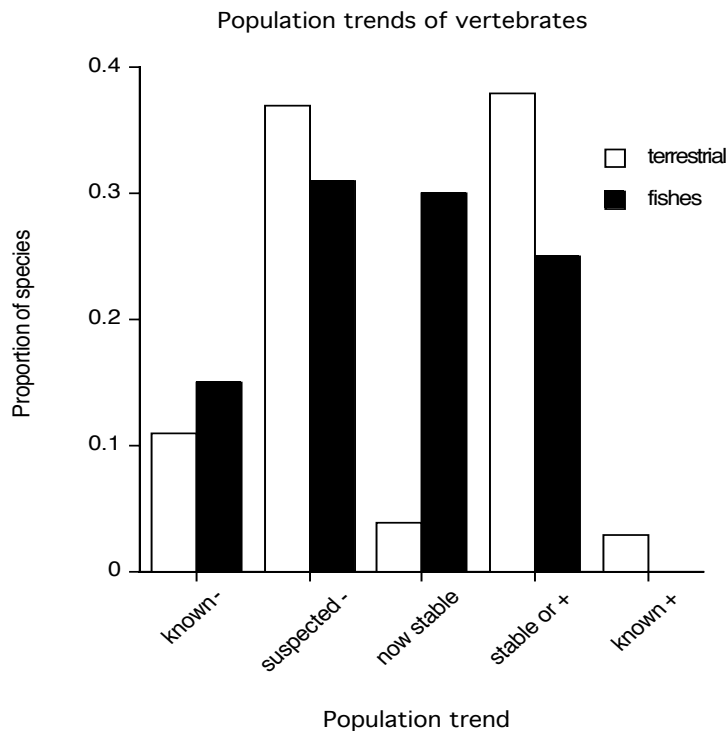


Figure 4— Population trends of vertebrates.

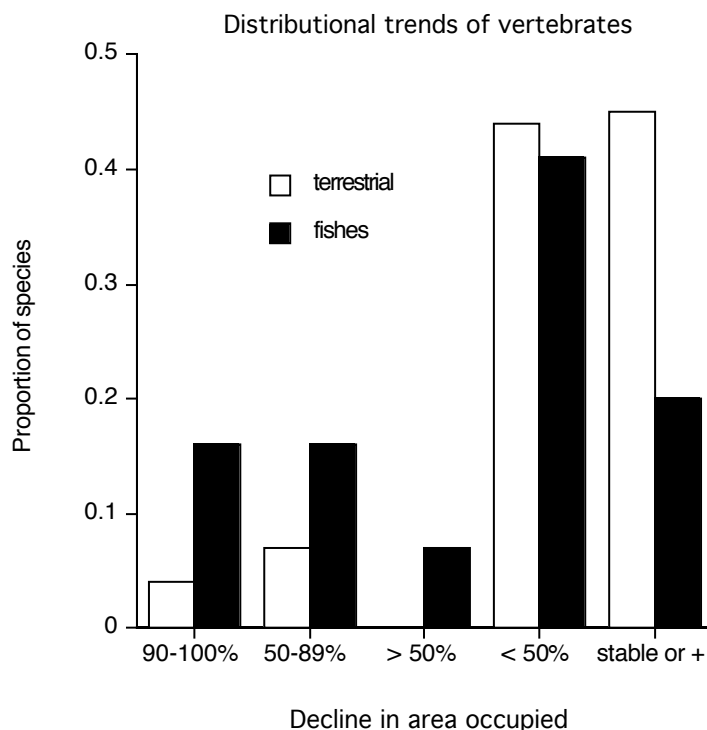


Figure 5— Distributional trends of vertebrates.

Perhaps most heartening is that these frank and reliable assessments of the Sierra Nevada's biodiversity have been developed by the dominant land management agency itself. The summary statistics compiled by the Forest Service are mirrored by other treatments. Dobson and others (1997) used data on the distributions of federally listed threatened and endangered species to identify "hotspots" of imperiled biodiversity from a nationwide database of occurrence by county. Although several Sierra Nevada counties are included among those with the highest numbers of listed plants, those same counties are conspicuously absent from the lists of counties with the highest numbers of listed mammals, birds, fishes, and select invertebrates. Although portions of coastal southern and central California, the Mojave Desert, and Owens Valley are considered to be national hot spots of species at risk, the Sierra Nevada is not. A less systematic assessment can be drawn from "Life on the Edge," a portrait of 100 species of listed and at-risk animals from across California. Just three of the 17 mammals presented have portions of their ranges in the Sierra Nevada. Similarly, only five of 29 birds, three of 19 fishes, one of 17 reptiles, and none of the 18 species of invertebrates considered to be imperiled in California occur in the Sierra Nevada. Accordingly, despite relatively high levels of endemism, a substantial number of ecological associations with narrow distributions, and a long history of intensive human land use, the Sierra Nevada retains most of its most irreplaceable elements.

Presentations from the Sierra Nevada Science Symposium cannot possibly embrace the breadth and depth of biodiversity issues, the challenges faced by land managers, and associated scientific efforts. For example, this symposium could have addressed the current hot list of species that are under active review for listing under the Federal and State endangered species acts, such as California spotted owls, willow flycatchers, mountain yellow-legged frogs, among others. However, we believed that it would be more informative in this forum to examine the more generic forms of current and future threats to biodiversity within the bioregion. The authors in this section discuss four key issue areas in which science is helping to guide management of biodiversity in the Sierra Nevada mountain range. Pat Manley describes her assessment of biodiversity in the Lake Tahoe basin, in which

intensive deforestation dramatically altered composition and structure of forest stands and intensive grazing had substantial impacts on riparian communities and upland meadows. Although these environmental ravages ceased many years ago, even more-pervasive impacts are now manifest as the basin is subject to the highest rates of human visitation and recreation in the Sierra Nevada. Manley fairly argues that if conservation efforts to maintain Tahoe's biotic diversity succeed, then the likelihood that those resources can be sustained elsewhere in the range is considerable. Bill Zielinski considers the fate of one particularly critical group of species in the Sierra Nevada. He argues that mesocarnivores, including wolverines, fishers, martens, and Sierra Nevada red foxes, are especially important to ecosystem function because of their diversity of ecological roles. Zielinski also documents significant declines of several species and makes recommendations for recovery efforts and future management. Carla D'Antonio and colleagues grapple with the most far-reaching and insidious threat to native biotic diversity in the Sierra Nevada: invasive non-native species. They document the scope of the challenge posed by plant invasions in locations ranging from foothill grasslands, in which assemblages of native plants have been nearly completely replaced by non-native species, to high-elevation communities that remain nearly free of non-natives. Frank Davis and colleagues highlight the need for a framework to deliver the information necessary to evaluate conservation opportunities and help planners and managers develop effective long-term and comprehensive conservation and land-protection strategies for the Sierra Nevada. They discuss how site prioritization can be carried out using available data on the distribution of biotic resources, threats to those resources, and costs of conservation optimized over a large landscape.

The fate of the biodiversity of the Sierra Nevada in a state that will have fifty million human residents in the near future is uncertain. But it appears that significant opportunities are available to land managers to retain and sustain the Sierra Nevada's biological diversity. Relatively few portions of this region have undergone the irreversible habitat conversions witnessed in many other parts of California. Despite unsustainable logging, heavy livestock grazing, even hydraulic mining, planners are nonetheless still left with a landscape capable of restoration, and a species assemblage that is largely still intact. The ill effects of large scale urbanization and invasive species are only just beginning to make their mark in this ecoregion. Immediate attention needs to be pointed to the foothills where significant urbanization has occurred at locations along transportation corridors, and will become more serious in the coming decades.

Suffice it to say that the need for effective management of the Sierra Nevada's resources, and the need for good science to inform that management, will only increase. Lessons can be drawn from previous successful programs, from the systematic approaches that have been taken to understand the structure and dynamics of sequoia forests to viability analyses of declining populations of California spotted owls. The history of scientific review, synthesis, and assessment documented in the Sierra Nevada Ecosystem Project volumes (SNEP 1996), as well as in the recent Sierra Nevada Forest Plan Amendment, also will serve as essential resources for future generations of decision-makers and land managers.

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Invasive Exotic Plant Species in Sierra Nevada Ecosystems¹

Carla M. D'Antonio,² Eric L. Berlow,³ and Karen L. Haubensak⁴

Introduction

The Sierra Nevada is a topographically and floristically diverse region of the western United States. While it comprises only a fifth of the total land area of California, half of the native plant species in the state occur within the range. In addition, more than 400 plant species are endemic to the Sierra Nevada and many of these are listed as threatened or have other special conservation status (Shevock 1996). As in many areas of the world, the biodiversity of the Sierra Nevada region is undergoing change due to alterations in human uses and fire regimes, climate change, and invasions by non-native species. This paper provides an overview of invasive non-native plants and potential threats they pose to currently held values for Sierra Nevada ecosystems.

Throughout California, urban and suburban development, livestock, roads, and agriculture have been cited as the predominant causes of native plant population declines; however, on a local scale, the introduction and spread of non-native plants has also been implicated in the decline of numerous special status plant species (State of California 1992, www.dfg.ca.gov/hcpd/species/t_e_spp/ann_te_rpt.shtml). Exotic plant species can directly compete with natives and cause their local displacement. In addition, they may have a number of indirect impacts that can change the aesthetic values, biological diversity, and services of ecosystems. Potential impacts include alteration of disturbance regimes, changes in the food base for wildlife species, soil erosion and loss of soil carbon storage, decreases in range or forest productivity, and altered recreational or aesthetic values. Because a number of non-native plants species that are already established in California have had large ecological impacts, land managers in the Sierra Nevada have become increasingly interested in identifying these species and developing approaches to control and eradicate them.

This paper briefly assesses the potential threat of invasive non-native plant species to the Sierra Nevada and addresses the following points: (1) What exotic species are invading the Sierra Nevada region and what habitats are being most invaded? (2) Which species have the potential to dramatically reduce local native diversity or transform ecosystems? (3) What environmental conditions are likely to promote the spread of these species and consequent impacts? This information can ultimately help identify ecosystems at risk of invasion by potentially undesirable species and prevent further invasions.

General distribution patterns of non-native plant species in California and the Sierra Nevada

The distribution of California's exotic flora is described in detail in Randall and others (1998), who report that species richness of exotic plants is highest near the coast and declines toward the interior of the state and that the number of exotic species is greater at lower compared to

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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higher elevations. For example, there are 77 non-indigenous plant species per 10 square kilometers (km²) in Sierra foothills, and 67 non-indigenous plant species in the same area in the higher Sierra Nevada (Randall and others 1998). Few exotics are reported above 1,800 meters (6,000 feet) elevation in the Sierra, and an extremely limited number of these are known to invade habitats above 2,600 meters (9,000 feet). Consistent with these general patterns, Keeley and others (2003) report that, in the greater Sequoia/King's Canyon (SEKI) area, the number and percent cover of exotic species decreases dramatically above 1,800 meters. The decrease in number of exotic species with elevation parallels the decline in native species with elevation, although it is steeper and more consistent (Keeley and others 2003).

What exotic species are invading the Sierra Nevada region and what habitats are being most invaded?

There is no thorough published plant list that describes the distributions of invasive, non-native species for the entire Sierra Nevada region. Such a list would likely include many species of minor ecological concern. The Sierra Nevada Forest Plan Amendment (2003, www.r5.fs.fed.us/sncf/eis/feis/) provides the best available list that describes potentially ecologically 'damaging' species. The list includes 59 noxious weeds or California Exotic Pest Plant Council (CalEPPC)-listed species and also provides estimates of areas covered by those species as of the late 1990s. Though not exhaustive, this list illustrates some interesting trends. For example, 71 percent of these invaders are forbs, and 50 percent of the species on the list are thistles and knapweeds. Grasses, shrubs, and trees each comprise approximately 12, 12, and 7 percent of the invaders listed, respectively (*table 1*).

Table 1 was used as a basis to query the Cal Flora Database (www.calflora.org) to evaluate where these species have been found within counties of the Sierra Nevada region. Occurrence records were classified as being from disturbed sites if the collection locale was a roadside, ditch, disturbed pasture or field, or was near human structures or part of a fuel break. Of the species on the list, 100 percent were associated with disturbance in at least one of their listed records (note, however, not all records describe the habitat from which the specimen was collected). For 80 percent of the species, where habitat was described, all collection sites could be classified as disturbed habitats (*table 1*). Thus, there appears to be a strong association of exotic plant species with disturbed circumstances, as described in broad literature surveys from elsewhere (for example, Hobbs and Huenneke 1993, D'Antonio and others 1999).

Also classified was species elevation range, based on either CalFlora or collection site data. Lower elevation (below 1,800 meters) meadows and foothill woodland-grasslands had the most potential invaders from this list, while intact conifer forest areas and higher elevation (above 1,800 meters) meadows had the fewest invaders. This pattern was again consistent with surveys of Keeley and others (2003) who report that coniferous forest habitats in the SEKI region have consistently low abundance and richness of exotics. They found exotic species richness was higher in mid-elevation chaparral and low-elevation oak savanna, and that exotic richness generally paralleled native richness in these lower elevation habitats.

Consistent with these elevation trends, in a pilot survey of 32 high elevation (2,205 to 3,440 meters) meadows in SEKI, the authors found exotic species to be rare. Preliminary results suggest exotic plants occurred in only 12 percent of the meadows, and in all cases of occurrence, exotic plant species were rare (less than 5 percent cover). The most frequent non-native plant species present were the perennial grass *Poa pratensis* and the forb *Taraxacum officinale*. Interestingly, in contrast to the extremely low abundance of exotic species in these high-elevation meadows, 60 percent of the meadows surveyed contained saplings of the native lodgepole pine (*Pinus contorta* ssp. *murrayana*). These pine saplings were observed in a range

Table 1— Invasive non-native plant species occurrence in Sierra Nevada National Forest (modified from SNFPA, 1999). † = where estimates exist. ‡ = all species records from disturbed habitat; more specific habitat types are listed.

Scientific name	Common name	Life form	Estimated area infested (acres)	Upper elevation boundary (ft)	Habitat‡
<i>Acroptilon repens</i>	Russian knapweed	Forb		6,200	Fields, roadsides
<i>Aegilops cylindrica</i>	Jointed goatgrass	Grass (a)		4,900	Fields, roadsides, foothills, grasslands
<i>Aegilops triuncialis</i>	Barbed goatgrass	Grass (a)		3,280	Foothills, grasslands
<i>Ailanthus altissima</i>	Tree of heaven	Tree	111	4,100	Ditches, fields
<i>Brassica nigra</i>	Black mustard	Forb	700	4,921	
<i>Bromus tectorum</i>	Cheatgrass	Grass (a)	280,000	7,000	Many
<i>Cardaria drabalpubescens</i>	Hoary cress/whitetop	Forb	5	3,940	Fields, saline
<i>Carduus acanthoides</i>	Plumeless thistle	Forb	10	4,265	Fields
<i>Carduus nutans</i>	Musk thistle	Forb	1010		Fields
<i>Carduus pycnocephalus</i>	Italian thistle	Forb	600	3,281	Fields
<i>Carthamus baeticus</i>	Smooth distaff thistle	Forb		1,640	
<i>Carthamus lanatus</i>	Wooly distaff thistle	Forb		3,609	
<i>Centaurea calcitrapa</i>	Purple star-thistle	Forb		3,281	
<i>Centaurea iberica</i>	Iberian starthistle	Forb		3,281	
<i>Centaurea diffusa</i>	Diffuse knapweed	Forb	2000	7,546	Fields
<i>Centaurea maculosa</i>	Spotted knapweed	Forb	1584	6,562	Fields
<i>Centaurea melitensis</i>	Tocalote	Forb	1400	7,118	Woodlands and fields
<i>Centaurea solstitialis</i>	Yellow star-thistle	Forb	27,830	4,265	Fields, woodlands
<i>Centaurea squarrosa</i>	Squarrose knapweed	Forb	1050	1,969	
<i>Chondrilla juncea</i>	Rush skeletonweed	Forb		4,593	
<i>Cirsium arvense</i>	Canada thistle	Forb	625	5,006	
<i>Cirsium ochrocentrum</i>	Yellowspine thistle	Forb	10	10,000+	Yellow pine forest; PJ, sagebrush scrub
<i>Cirsium undulatum</i>	Wavyleaf thistle	Forb		5,249	
<i>Cirsium vulgare</i>	Bull thistle	Forb	16,625	7,546	

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<i>Convolvulus arvensis</i>	Field bindweed	Forb	150	4,921	Orchards, gardens
<i>Crupina vulgaris</i>	Bearded creeper	Forb	200	1,000	Grasslands
<i>Cynodon dactylon</i>	Bermuda grass	Grass (p)	100	3,000	Disturbed, wet
<i>Cytisus scoparius</i>	Scotch broom	Shrub	7,711	3,281	Forests
<i>Elaeagnus angustifolius</i>	Russian olive	Tree		5,000	Riparian
<i>Elytrigia repens</i>	Quackgrass	Grass (p)	200	5,905	Fields
<i>Euphorbia esula</i>	Leafy spurge	Forb		4,600	Grasslands, old fields
<i>Euphorbia oblongata</i>	Oblong spurge	Forb	5	<1,000	
<i>Foeniculum vulgare</i>	Fennel	Forb	5	<1,200	Grasslands
<i>Genista monspessulana</i>	French broom	Shrub	200	<2,000	Conifer, grass, woodland
<i>Halogeton glomeratus</i>	Halogeton	Forb	20	6,000	Saline, shrubland, flats
<i>Hydrilla verticillata</i>	Hydrilla	Forb		<1,000	Water, wetlands
<i>Hypericum perforatum</i>	Klamath weed	Forb	4,010	4,500	Forest, fields
<i>Isatis tinctoria</i>	Dyer’s Woad	Forb	10,010	3,281	Fields
<i>Iva axillaris</i>	Poverty weed	Forb		6,700	Saline
<i>Lepidium latifolium</i>	Perennial pepperweed	Forb	70	6,234	Saline, roadsides, riparian, wet meadows
<i>Leucanithemum vulgare</i>	Ox-eye daisy	Forb	233	6,562	Mountain meadows, fields
<i>Linaria genistifolia ssp dalmatica</i>	Dalmation toadflax	Forb	2,004	3,280	Grasslands
<i>Lythrum salicaria</i>	Purple loosestrife	Forb	5	4,000	Wet meadows, riparian
<i>Myriophyllum spicatum</i>	Eurasian milfoil	Forb		500	Water
<i>Onopordum acanthium</i>	Scotch thistle	Forb	30,680	5,250	
<i>Robinia pseudoacacia</i>	Black locust	Tree	<20	6,233	Springs, riparian
<i>Rubus discolor</i>	Himalayan blackberry	Shrub	4,220	5,250	Riparian, uplands, moist
<i>Salsola paulsenii</i>	Tumbleweed	Forb	50	5,900	
<i>Salsola tragus</i>	Russian thistle	Forb	110	8,858	Shrubland
<i>Salvia aethiopsis</i>	Mediterranean sage	Shrub	2,000		Roadsides
<i>Silybum marianum</i>	Milk thistle	Forb	20	1,640	
<i>Solanum elaeagnifolium</i>	White horsenettle	Forb	10	3,940	Dry areas; fields

Session No. 5— Invasive Exotic Plant Species—D’Antonio, Berlow, Haubensak

<i>Sorghum halepense</i>	Johnson grass	Grass (p)	50	2,624	Ditches, roadsides
<i>Spartium junceum</i>	Spanish broom	Shrub	700	2,000	
<i>Taeniatherum caputmedusae</i>	Medusahead	Grass (a)	5,270		Many
<i>Tamarix chinensis</i>	Tamarisk	Tree	175		
<i>Tribulus terrestris</i>	Puncture vine	Forb	55	3,280	
<i>Ulex europaeus</i>	Gorse	Shrub		1,300	Pastures, fields
<i>Verbascum thapsus</i>	Woolly mullein	Forb	11,050	15,000	Open

of conditions, from trailside disturbances, dry disturbed soil, and de-watered meadows near erosion gullies, to relatively undisturbed areas and boggy meadows. The authors’ work on large meadows of the Kern Plateau in the southern Sierra Nevada also suggests that, while exotic invaders are rare, native woody invaders (in this case, largely *Artemisia rothrockii*) are widespread and can rapidly invade many high elevation meadows (Bauer and others 2002, Berlow and others 2002, 2003). The authors believe that these native woody species have greater potential to affect forage production, wildlife, native species diversity, and other ecosystem characteristics than do the current suite of non-native plant species likely to enter most high elevation areas.

Which exotic species have the potential to reduce local diversity or transform ecosystems?

Exotic plant species that managers should focus on for control and prevention are those that can either greatly reduce local native biological diversity and/or substantially alter Sierra Nevada ecosystems. Richardson and others (2000) formalized use of the term “transformer species” to describe those species with potential to form monotypic stands, and greatly alter resource availability, trophic structure, ecosystem productivity, and/or disturbance regimes. Some potential non-native transformer plant species invading the Sierra Nevada include: cheatgrass (*Bromus tectorum*), medusahead (*Tanacetum caputmedusae*), yellow star thistle (*Centaurea solstitialis*), spotted, diffuse and Russian knapweed (*Centaurea maculosa*, *C. diffusa*, and *Acroptilon repens* respectively), perennial pepperweed (also called tall whitetop-*Lepidium latifolium*), purple loosestrife (*Lythrum salicaria*), Dalmatian toadflax (*Linaria genistifolia* var. *dalmatica*), leafy spurge (*Euphorbia esula*), broom species (including gorse-*Ulex europaea*, striated broom-*Cytisus striatus*, french broom-*Genista monspessulana*, scotch broom-*Cytisus scoparius*, and spanish broom-*Spartium junceum*), Himalayan blackberry (*Rubus discolor*), Russian olive (*Eleagnus angustifolia*), and saltcedar (*Tamarix parviflora*, and *T. ramosissima*). A few of these species are already widely distributed, but many are still relatively restricted within the Sierra Nevada (see Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement 2001). These should be top-priority species for early detection and rapid response eradication efforts. Some species, such as the riparian invaders (*Tamarix*, *Eleagnus* and *Lythrum*), are restricted in their habitat requirements so search and local eradication can be targeted. Others, such as the grasses *B. tectorum* and *T. caputmedusae*, occur over broad areas, have wide habitat tolerances, and will be very difficult to control. Rather than discuss the distribution and potential threat for each of these, highlighted here are a few species about which much is already known regarding their impacts elsewhere.

Bromus tectorum (cheatgrass) is considered to be a transformer species because it has greatly altered disturbance regimes throughout the Intermountain West with a variety of effects on species diversity and ecosystem function (see Whisenant 1990, D’Antonio and Vitousek 1992). The invasion of cheatgrass, for example, has allowed fires to burn across larger areas and at higher frequencies, resulting in communities with fewer shrubs and more cheatgrass over time. Cheatgrass has been observed in most Sierra Nevada counties (Calflora database), and is fueling fires in northeastern California and along the eastern Sierra Nevada and Carson Range near Reno, Nevada. While it is not yet abundant in the majority of Sierra Nevada locations, cheatgrass has been observed at elevations up to 2,800 meters on eastern slopes of the range adjacent to shrublands and pinyon/juniper woodlands. It has also become an element of bitterbrush (*Purshia tridentata*)/sagebrush (*Artemisia tridentata*) shrublands below Mammoth Lake, near Carson City, and at southeastern Lake Tahoe, where it has the potential to alter fire frequency with as yet unknown consequences. Cheatgrass has also invaded the understory of ponderosa pine (*Pinus ponderosa*) forests in SEKI (McGinnis and others, this volume).

The highly competitive yellow star thistle might also be considered a transformer species because it can become quite abundant, reduce water availability for native species (Gerlach and others 1998), and decrease recreational, livestock, and aesthetic values (Jetter and others [in press]). It has been observed in flower in Tuolumne Meadows (at 2,600 meters) in Yosemite National Park (Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement, 2001), and is forming increasingly large populations near Reno and along the eastern Sierra Nevada. However, the majority of yellow star thistle populations occur on the western slope of the Sierra Nevada (for current distribution see http://pi.cdfa.ca.gov/map_yst/).

On the eastern slope of the Sierra Nevada, *Lepidium latifolium* (perennial pepperweed or tall whitetop) has invaded many areas and is widely recognized as a problem in wet meadows, riparian zones, and saline sinks where it forms monospecific stands to the exclusion of all native species. It is also abundant in portions of California's Central Valley so entry points for invasion into the Sierra Nevada could come from either side of the range. It is currently found primarily below 5,000 feet, but that could soon change. Blank (2002) found that perennial pepperweed dramatically alters soil fertility characteristics with potentially great consequences for revegetation efforts in affected areas. It is extremely difficult to control, even with herbicides. Thus, the best control is preventing establishment of or obliterating new populations.

Another wet area invader of potential concern is *Lythrum salicaria* (purple loosestrife, for current distribution see <http://pi.cdfa.ca.gov/purpleloosestrife/>). This species is a widely distributed pest throughout the eastern and central United States (U.S. Congress Office of Technology Assessment, 1993) where it clogs waterways, excludes native species, and is the target of biological control efforts. Biocontrol has been successful in Canada and some northern states, including Oregon (Hight and others 1995). This species is currently restricted to lower elevation sites on both western and eastern slopes of the Sierra Nevada. Biological control is a potential option, but its overall efficacy in environments like those of the Sierra Nevada remains unknown.

Other potentially important riparian invaders include Russian olive, a tree widely planted for the berries it provides for wildlife, and *Tamarix* (saltcedar). Both these species invade riparian areas on arid landscapes and spread rapidly. *Tamarix* can form dense thickets, change water flow patterns in streams, and alter wildlife habitat. The high economic costs of not controlling *Tamarix* have been estimated (Zavaleta 2000), and it is currently the target of biological control efforts in California, including the Owen's Valley. Although biocontrol agents have been released in California (Dudley and others 2001), none have yet been successfully established.

What environmental conditions are likely to promote the spread and consequent impacts of exotic species in the Sierra Nevada?

Natural disturbances (fire and animal activity) and human-caused disturbances (such as logging, fire and fuels management) will undoubtedly play a role in the future spread of exotics into intact, or as yet uninvaded, plant communities. These disturbances may affect the current resistance of the conifer zone, high elevation areas, and alpine meadows to invasion. Fuel breaks may act as dispersal corridors for exotics, and fires themselves may temporarily provide a window of opportunity for species establishment. In a series of controlled burns in SEKI, Keeley and others (2003) found that non-native species respond positively to fire in conifer forests, and this response is greater under higher intensity fires. It is unknown whether these invaders will persist and delay the re-establishment of conifers, or promote more rapid fire return intervals, and how invasions will affect the timing of burns and age of stands subject to fire.

Research on processes influencing invasion of the native woody invader, Rothrock’s sagebrush (*Artemisia rothrockii*), into herb-dominated meadows suggests that climate, soil moisture, local soil disturbance, seed supply, and potentially livestock grazing all play roles in the ongoing woody species invasion of mesic montane meadows. Despite the fact that *A. rothrockii* is a native species, its takeover of meadow communities is generally viewed as undesirable. Natural recruitment of sagebrush seedlings in mesic herbaceous meadows occurs most frequently on rodent disturbances, and establishment of shrub patches is higher in years following heavier spring snow packs (Bauer and others 2002, Berlow and others 2002). When the authors mimicked livestock grazing by clipping background vegetation combined with soil disturbance, they observed the highest rates of sagebrush seedling survival and fastest times to reproduction (table 2). The data suggest that an understanding of the interaction of climate with disturbances (grazing and gopher activity) and seed dispersal is essential to understanding vegetation change in these sites.

Table 2— *Effect of clipping background vegetation and disturbing soils on four-year survival and reproduction of Artemisia rothrockii in Mulkey Meadow, CA (from Berlow et al. 2002).*

Treatment	Soil condition	Percent survival	Percent reproductive
Herbs clipped	Soils Undisturbed	40	0
Herbs unclipped	Soils Undisturbed	0	0
Herbs clipped	Soils Disturbed	100	40
Herbs unclipped	Soils Disturbed	40	0

Conclusions and Recommendations

Species change has been the norm for plant communities in North America throughout the Pleistocene era (Davis 1986, Delcourt and Delcourt 1992). Even within the last few centuries, climate change has influenced vegetation change in the Sierra Nevada (see papers on climate from this symposium). Thus, the invasion of species into the Sierra Nevada (or range expansion of species already present) is not an unexpected phenomenon, and it should increase in intensity or rate as climate continues to change.

An initial conclusion, particularly if one compares the Sierra Nevada to the California coastal ranges and Central Valley, is that invasions by many potentially problematic plant species in the Sierra Nevada are still at a relatively early stage. This does not mean, however, that managers can put aside thinking about them. Indeed, targeting species for removal at an early stage of invasion is essential to their successful control; hence, early detection is a critical monitoring challenge. More knowledge is needed regarding pathways of introduction and dispersal, including the roles (and effects) of logging, roads, trails, human visitation, cars, heavy equipment, pack animals, and livestock. This knowledge would aid in understanding where to look for incipient outbreaks and identifying vegetation communities that will be most vulnerable to full scale invasion. While programs such as Weed Free Feed have been instituted (<http://www.extendinc.com/weedfreefeed/> and <http://pi.cdfa.ca.gov/weed/wff/>) in an effort to reduce the potential entry of weeds into backcountry habitats, better documentation of pathways on a species-by-species basis will help target control efforts. Coordinated region-wide early detection and rapid response systems need to be developed.

Second, the extensive conifer forests of the Sierra Nevada are currently less invaded than adjacent lower elevation habitats. This may be due to ecological resistance as a result of the dense shade in the conifer forest understory, or relatively low seed supply to these vast areas (see Keeley and others 2003). Because activities such as logging and controlled burning can eliminate ecological processes that might otherwise make communities resistant to invasion (D’Antonio and others 1999), a better understanding of how changing land uses, logging roads, and fire management will influence invasion of these habitats is needed. In particular, research is needed to evaluate the effects of the interaction of disturbances and climate on the

spread of potential transformer species. Species that are likely to invade the conifer forest belt (such as Himalayan blackberry and several broom species) may not persist as conifers re-establish but this temporal dimension of invasion needs greater attention, particularly as political pressure mounts to do more forest clearing and fire control.

Third, in establishing priorities for control efforts, it is essential to ascertain which species (a) are moving from disturbed corridors into wildland habitat and (b) pose the greatest ecological threats once they become established. To what extent will movement depend on propagule buildup on the corridor, climatic fluctuation, fire or other natural disturbances off the corridors?

Fourth, the threat posed to endemic or rare native species by invasive exotics needs to be evaluated. Initially, a distribution matching approach, whereby the distribution of problematic species is overlain with that of threatened species, could be used. This would require landscape-scale (spatial) analyses. Shevock (1996) provides a reasonable description of the distribution of endemic and threatened species in the Sierra Nevada.

Lastly, managers will benefit from systematic surveys of distribution and abundance of the main problem invaders, with coordination for monitoring and control efforts at a regional scale. Over the past decade, great strides have been made in this area. Interactive web-based databases, such as the CRISIS Weed Map and Data Server (<http://cain.nbii.gov/cgi-bin/mapserv?map=../html/cain/crisis/crisismaps/crisis.map&mode=browse&layer=state&layer=county>), are now available that allow users to input occurrence data and download distribution maps. The national parks in the Sierra Nevada have at least preliminary information on the occurrence and distribution of problem species within their jurisdictional boundaries. Information sharing between managers and owners of lands throughout the Sierra Nevada will be an essential part of successful regional scale management.

Acknowledgements

The authors would like to thank the USDA-ARS lab in Reno Nevada for feedback on early versions of the presentation from which this manuscript was derived. Dr. James Young provided valuable feedback on an earlier draft. The authors thank the National Park Service for support for the SEKI survey.

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The Status and Conservation of Mesocarnivores in the Sierra Nevada¹

William J. Zielinski²

Carnivores play important roles in structuring communities, and their populations are useful indicators of ecosystem condition (Wennergren and others 1995, Buskirk 1999, Crooks and Soulé 1999, Terborgh and others 2001). As many as 4 of 20 native mammalian carnivore species have been extirpated from the southern Cascade Mountains and Sierra Nevada, with unmeasured effects on ecological communities. Given the loss of a number of significant carnivores from the system, understanding the status and ecological roles of the remaining species has assumed new urgency. Mesocarnivores (intermediate body-size mammalian carnivores; Buskirk and Zielinski (2003) are of particular importance because of their diversity and variety of ecological roles, and unlike the more conspicuous large carnivores, their populations can decrease with little notice.

Status

An essential step in assessing the status of wildlife populations is comparing current and historical distributions (Zielinski and others [In press]). Although site-specific autecological or demographic studies are important, they often lack the extensive spatial context to identify the effects of human activities on population size, trend, and distribution (for example, Kareiva and others 1997, Ceballos and Ehrlich 2002). Recent extensive mesocarnivore surveys in California, using baited track plates and cameras (Zielinski and Kucera 1995), provide an opportunity to evaluate changes in population distributions. Comparing the results of these surveys with historical distributions from the work of Grinnell and his colleagues in the early 1900s (Grinnell and Storer 1924, Grinnell and others 1930, Grinnell and others 1937) provides an opportunity to evaluate changes in carnivore distributions during a period of dramatic human influences on California forests.

Systematic surveys were conducted throughout the central portion of the Sierra Nevada Ecosystem Project area (Sierra Nevada Ecosystem Project 1996). A total of 334 sample units (six track plates and one camera station) were distributed at approximately 10-kilometer intervals from 1996 through 2002, and the species that made the tracks and visited these baited sites were identified. These surveys and other recent information indicate that two native mesocarnivores, the wolverine (*Gulo gulo*) and the Sierra Nevada red fox (*Vulpes vulpes necator*), have not been verified to occur in the Sierra Nevada for more than 60 years. Red foxes occur in the region of Lassen National Park (Kucera 1995; J. Perrine, pers. comm.), but they have not been genetically distinguished from the more common and exotic subspecies (Lewis and others 1995, J. Perrine, pers. comm.). Wolverines and Sierra Nevada red foxes were vulnerable to historical trapping; however, they are also described as being extremely sensitive to the presence of people (Grinnell and others 1937, Carroll and others 2001, Rowland and others 2003). Most of the native generalist mesocarnivores (gray fox

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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[*Urocyon cinereoargenteus*], striped skunk [*Mephitis mephitis*], spotted skunk [*Spilogale gracilis*], and ringtail [*Bassariscus astutus*], and one large carnivore (black bear, *Ursus americanus*) appear to occupy regions today that were also occupied in the early 1900s (Zielinski and others [in press]). Over the same period of time, the distribution of two exotic and generalist species, the lowland red fox (*V. vulpes*; Lewis and others 1995) and the opossum (*Didelphis virginianus*; a non-carnivoran that is detected regularly at track-plate stations), have increased.

The regions currently occupied by two forest specialists, the fisher (*Martes pennanti*) and the marten (*M. americana*), appear to have decreased compared with their historical distributions (figs. 1 and 2). Fishers are apparently absent from the region from Mt. Shasta south to Yosemite, and martens are distributed patchily in the southern Cascades and northern Sierra Nevada. Fishers and martens are among the most habitat-specific mammals

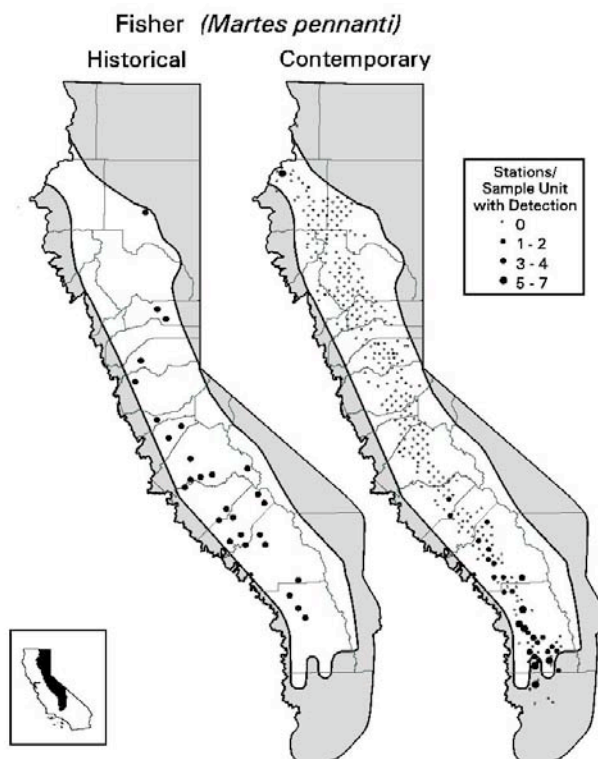


Figure 1— Historical and contemporary distributions of fishers within the Sierra Nevada Ecosystem Project (1996) planning boundary in California. The historical distribution is a combination of results derived from Grinnell and others (1937) and Grinnell and others (1930). Black circles in the historical map represent a single record (specimen or location of trapped animal) reported for the period of approximately 1919–1925. The contemporary distribution is the result of track-plate and camera surveys conducted from 1996 to 2002. Circles indicate sample units where six track plates and one camera were baited, scented with carnivore lure, and deployed for 16 days (112 sample days/sample unit). Small open circles indicate locations where fishers were not detected, and larger black circles indicate where fishers were detected at one or more stations (see key). Undulating lines indicate the distributional limits identified by Grinnell and others (1937); gray-scale areas are outside the distribution.

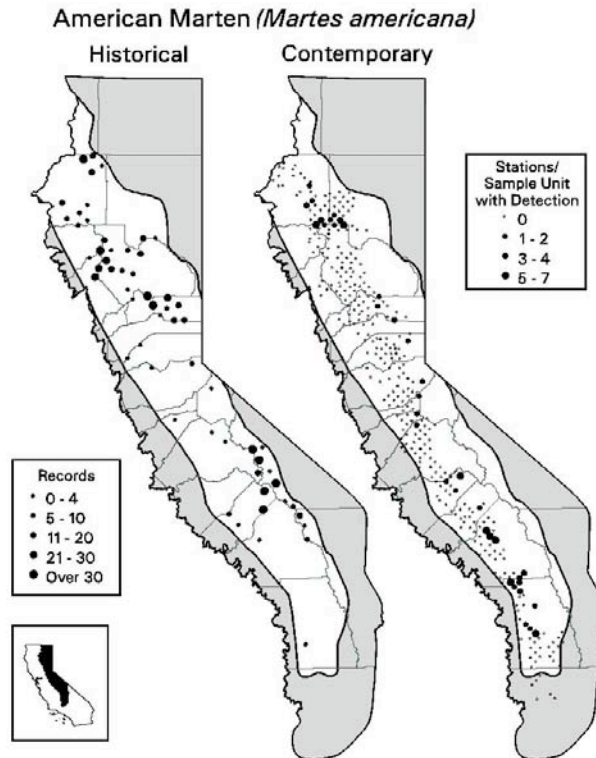


Figure 2— Historical and contemporary distributions of martens within the Sierra Nevada Ecosystem Project (1996) planning boundary in California. The historical distribution is derived from Grinnell and others (1937). Black circles in the historical map represent marten records (specimen or location of trapped animal) reported for the period of approximately 1919–1925 (see legend). The size of the circle reflects the number of individuals reported for that location. The contemporary distribution is the result of track-plate and camera surveys conducted from 1996 to 2002. Circles indicate sample units where six track plates and one camera were baited, scented with carnivore lure, and deployed for 16 days (112 sample days/sample unit). Small open circles indicate locations where martens were not detected, and larger black circles indicate where martens were detected at one or more stations (see key). Undulating lines indicate the distributional limits identified by Grinnell and others (1937); gray-scale areas are outside the distribution.

in North America, occurring primarily in contiguous mature forests in the western United States (Buskirk and Powell 1994, Powell and Zielinski 1994, Bissonette and others 1997, Powell and others 2003). In California, they are associated with mature forest conditions in the mixed conifer (fisher) and the true fir (marten) zones (Zielinski and others 1997). Each species predominantly uses large trees, snags, and logs as their daily resting sites (Spencer 1987, Zielinski and others 2004).

A comparison of the historical and contemporary distributions of martens indicates that they are currently absent, or at low densities, outside parks or other reserves in the northern part of the surveyed area (*fig. 3*). Martens are especially sensitive to forest fragmentation (Bissonette and others 1997), so this pattern may be due to the loss of old-growth and mature forests in the Sierra Nevada (Franklin and Fites-Kaufman 1996, Beardsley and others 1999), especially in the northern portion of the region (McKelvey and Johnson 1992). This assumption, however, needs to be validated by direct studies of marten habitat ecology in this area.

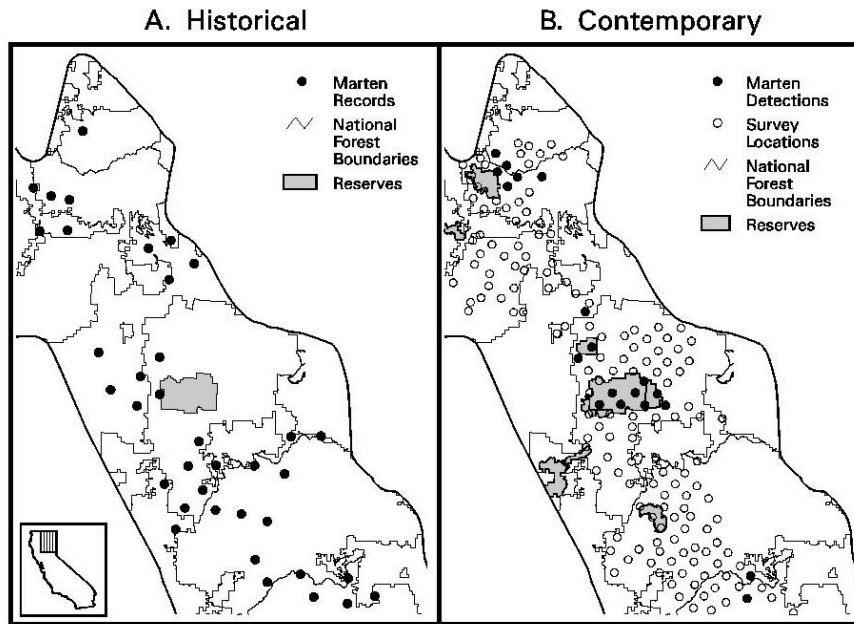


Figure 3— Exploded view of the historical boundary of the distribution of martens (Grinnell and others 1937) in the southern Cascades and northern Sierra Nevada region. Black circles in the historical map represent one or more record (specimen or location of trapped animal) at the location reported for the period of approximately 1919–1925 (Grinnell and others 1937). The contemporary distribution is the result of track-plate and camera surveys conducted from 1996 to 2002. Circles indicate sample units where six track plates and one camera were baited, scented with carnivore lure, and deployed for 16 days (112 sample days/sample unit). Open circles indicate locations where martens were not detected, and black circles indicate where martens were detected at one or more stations. Reserves are indicated in gray and indicate the boundaries of the national parks and wildernesses that were designated during the time period that each map reflects.

Fishers appear to be absent from an approximately 400-kilometer-long region of their historical range in the northern and central Sierra Nevada, producing a significant gap in their distribution in California (Zielinski and others 1995). The creation and maintenance of this gap are likely related to a combination of factors, which may include historical patterns of logging, trapping, and porcupine (*Erethizon dorsatum*) poisoning; deeper snows in the northern Sierra Nevada (Krohn and others 1997); greater density of human development and roads in northern portions of the range (Duane 1996); and the current distribution of other generalist carnivores (Campbell 2003). The current pattern may also be attributed, in part, to the constraints on movements—current and historical—imposed by the long, peninsular distribution of montane forests in the Pacific states (Wisely and others 2004). Historical and current distributions of fishers are not strongly associated with parks and wildernesses (fig. 4), unlike that described for the contemporary distribution of martens in the north. This is probably because fisher habitat occurs in mid-elevation forests in the Sierra Nevada (Grinnell and others 1937, Zielinski and others 1997), largely below the elevations of national parks and wilderness areas.

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generalist carnivores (Campbell 2003). The current pattern may also be attributed, in part, to the constraints on movements—current and historical—imposed by the long, peninsular distribution of montane forests in the Pacific states (Wisely and others 2004). Historical and current distributions of fishers are not strongly associated with parks and wildernesses (*fig. 4*), unlike that described for the contemporary distribution of martens in the north. This is probably because fisher habitat occurs in mid-elevation forests in the Sierra Nevada (Grinnell and others 1937, Zielinski and others 1997), largely below the elevations of national parks and wilderness areas.

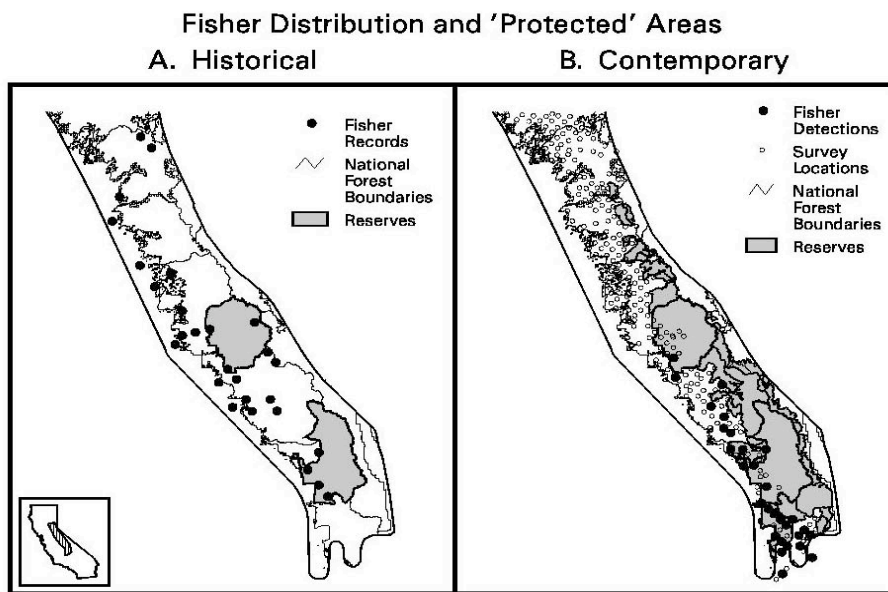


Figure 4— Exploded view of the historical boundary of the distribution of fishers (Grinnell and others 1937) in the central and southern Sierra Nevada. Black circles in the historical map represent one or more record (specimen or location of trapped animal) at the location reported for the period of approximately 1919–1925 (Grinnell and others 1930, Grinnell and others 1937). The contemporary distribution is the result of track-plate and camera surveys conducted from 1996 to 2002. Circles indicate sample units where six track plates and one camera were baited, scented with carnivore lure, and deployed for 16 days (112 sample days/sample unit). Open circles indicate locations where fishers were not detected, and black circles indicate where fishers were detected at one or more stations. Reserves are indicated in gray and indicate the boundaries of the national parks, national monuments, and wildernesses that were designated during the time period that each map reflects.

Conservation

Despite the extensive size of the Sierra Nevada, the conservation needs of wide-ranging carnivores (including the fisher and marten, which have disproportionately large home ranges for their sizes) should be considered over even larger bioregions (Noss and others 1996, Aubry and Lewis 2003). For example, only two native fisher populations occur in the Pacific states: one in the southern Sierra Nevada, and the other in the western California/Oregon border region (Aubry and Lewis 2003). Fishers are extirpated from Washington and most of Oregon, and populations are sparse in southern British Columbia (Proulx and others 2004). Studies have revealed genetic patterns that appear to be affected by the disjunct nature of fisher population distributions in the Pacific states and indicate reduced diversity in the southern Sierra Nevada population (Drew and others 2002, Wisely and others 2004). Population genetic data from fishers in the Pacific states (Wiley and others [unpublished draft]) suggest that dispersal is limited and that conservation strategies may need to encourage connectivity among the few remaining populations. The maintenance of

the southern Sierra Nevadan fisher population is important for its own sake, but it may also be critical to the conservation of fisher populations in the western United States.

Martens appear to be well distributed throughout most of their historical range in the interior western United States (Gibilisco 1994, Proulx and others 2004), and genetic studies have not reported results that indicate that marten populations are at risk there (Koepf 1998, Kyle and others 2000). However, the pattern of isolated groupings of detections in the Cascades and northern Sierra Nevada resembles that in other interior regions where local populations have been affected by fragmentation of mature forests (for example, in Utah: Hargis and others 1999).

A number of new research activities are under way to assist managers in evaluating the effects of land management practices on fishers and martens in California. These include (1) creating spatially explicit descriptions of suitable habitat for fishers and martens (Carroll and others 1999, Truex [in preparation], Campbell 2003) (2) developing an understanding of the role of other carnivores on the distribution of fishers (Campbell 2003), and (3) evaluating alternative designs for monitoring change in population status and habitat (Zielinski and Mori 2001). In 2002, the USDA Forest Service began implementing a plan to monitor the distribution of fishers and martens in the Sierra Nevada. This plan will provide annual estimates of the area occupied by each species and an index of population change. Although this program is an important precaution for assessing the unintended effects of land management on the habitats of these species, many questions about the effects of human activities on fishers and martens can be resolved only by initiating long-term studies on their demography and the relationship of population growth rates to the distribution and quality of habitat. These studies could also help identify natal and maternal den structures and document the dispersal routes used by juveniles to establish home ranges. This knowledge would allow managers to (1) protect the special habitat elements that these species require for reproduction and (2) create forest landscapes that facilitate the movements of dispersing juveniles. Both needs are critical to maintaining late-seral associated species on landscapes managed for multiple purposes.

Fishers and martens are important predators in dense, mature forests that have abundant, large standing and down woody material. Thus, providing habitat and restoring populations for these species are challenges in the face of growing human demands for timber, fuel reduction, and increased protection from the threat of wildfire. New studies, some of which are under way, will be necessary to understand the vulnerability of martens in the northern portion of the region to vegetation management activities and effects of fuels treatments on fisher habitat and catastrophic wildfire. The latter issue, in particular, will be difficult to resolve because fishers select dense stands as habitat in mid-elevation forests, where fire is a frequent threat to rural communities. Balancing the need to protect fishers and their habitat from the short-term effects of fuels treatments with the need to address the threat of wildfire will be a significant challenge.

Acknowledgments

The author is indebted to the various scientific companions who have assisted him and his thinking during the course of the work that is summarized here. They include R. Truex, C. Carroll, L. Campbell, K. Aubry, R. Barrett, and R. Schlexer. The author also recognizes the nearly 100 field assistants, field crew leaders, and support staff who helped collect the field data, in particular, R. Truex, R. Schlexer, T. Kirk, L. Campbell, and C. Ogan. This research would not have been possible without the institutional support of the USDA Forest Service, Pacific Southwest Research Station and Pacific Southwest Region, and the managers and biologists that represent each of the National Forests and national parks in the Sierra Nevada. Diane Macfarlane, of the USDA Forest Service, was an especially influential

supporter and facilitator of the work. The author thanks J. Werren and R. Schlexer for helping produce the figures.

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A Framework for Setting Land Conservation Priorities in the Sierra Nevada¹

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In California, hundreds of different public and private organizations are involved in prioritizing and acquiring new conservation lands (California Environmental Dialogue 1999, California Continuing Resources Investment Strategy Project 2001). Although the State of California owns less than 3 percent of the land (Davis and Stoms 1998), it plays a significant role in the conservation of biodiversity, public open space, and commodity production. State government funding for land acquisitions and conservation easements comes from a variety of sources, including special funds, park-related bonds, and water-related bonds. Although bonds provide considerable public funds for conservation, they fall short of what most agencies and conservation groups believe is required to meet even short-term demands for farmland, open space, and habitat conservation (California Environmental Dialogue 1999). Thus, competition for these public funds is intense, and State funding agencies must make decisions in what are often acrimonious public forums.

In a 1996 analysis of State agency land conservation activities, the California Legislative Analyst's Office found that the State was unable to set clear conservation priorities because it lacked a comprehensive and cohesive statewide land conservation plan, suffered from poor coordination among departments, and had limited ability to formally evaluate conservation opportunities as they arose (California Legislative Analyst's Office 1996). In response, the California legislature mandated the creation of a new conservation planning program known as the California Legacy Project (CLP) (formerly named CCRISP, the "Continuing California Resource Investment Strategy Project") under the Resources Agency. The CLP's mission is "to enable the state and its partners in conservation to develop and implement a strategic and inclusive approach to conserving and restoring California's lands and natural resources" by addressing five fundamental questions:

What are California's significant lands and natural resources?

What are the key emergent threats and opportunities to improve our lands and natural resources?

What are the highest priorities for protection and restoration?

What is the most appropriate way to protect and restore these important, high-priority lands and resources?

How effectively are the State of California and its partners in conservation implementing this strategic approach to conservation?

In 2001, the Resources Agency contracted with the National Center for Ecological Analysis and Synthesis (www.nceas.ucsb.edu) to convene a working group to help bring systematic conservation planning theory and methods to bear on the design and implementation of CLP.

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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The framework described below is one of the products from that working group. This paper provides a brief sketch of selected elements of this planning tool and illustrates its application to the Sierra Nevada bioregion. A detailed technical description of the framework can be downloaded from http://www.nceas.ucsb.edu/nceas-web/projects/4040/TerrBiod_framework-report.pdf.

Prioritizing Places for Conservation Investments

This framework is intended to serve the dual purposes of helping decision makers evaluate current opportunities (for example, current proposal applications for State conservation funds) as well as supporting development of longer-term conservation strategies. It is an analytical, data-driven planning process that has been applied and tested at planning scales ranging from single counties to multi-county bioregions.

The planning framework is organized into a hierarchy of conservation goals and objectives, each of which is further elaborated in terms of specific objectives, criteria, and sources of evidence. The highest level has three categories of conservation goals: resource production capacity, natural capital, and public open space (*table 1*). Although the high level of interrelatedness among these three concerns is recognized, individual conservation programs and stakeholder groups tend to emphasize one over the other two, and the logic of priority setting is somewhat different among these concerns. Conservation of cultivated lands, rangelands, and timberlands is included within the category of production capacity goals. Terrestrial and aquatic biodiversity are included under natural biodiversity goals.

Table 1— *Hierarchy of conservation goals.*

Conserve California's lands and natural resources						
Maintain resource production capacity			Conserve natural capital		Provide adequate high- quality public open space	
Protect productive rangelands	Protect productive timberlands	Protect productive cultivated lands	Conserve aquatic and wetland biodiversity	Conserve terrestrial biodiversity	Preserve urban open space	Provide rural recreation

Spatial Units and Objectives for Conservation Planning

The framework involves four different kinds of spatial units.

The *planning region* encompasses the entire area under consideration for conservation investments. This could be a country, an ecological region, a state, or more local area. For the Sierra Nevada demonstration, the authors used the system of 10 bioregions for California that are defined by ecological and political boundaries and are already used by State resource agencies.

Sites are discrete spatial units that are the candidate areas being prioritized for conservation investments. The example below uses township quadrants from the Public Land Survey System. These roughly 3- by 3-mile areas conform closely to land ownership boundaries, and their relatively uniform size and shape facilitate the analysis of biodiversity patterns and spatial neighborhoods.

A *reference region* is the area considered when evaluating a site with respect to a particular conservation concern. For example, the Sierra Nevada bioregion could be the reference region for evaluating how well a species is represented in existing reserves. The entire State could be the reference region for examining how much a site contributes to protecting the known statewide distribution of a threatened or endangered species.

Observations are data pertaining to a particular resource concern that are available across the entire planning region at some minimum spatial resolution. This resolution could be the minimum mapping unit of a map of irregular polygons or the cell size of a regular grid, such as those produced by classification of remotely sensed imagery. For this demonstration in the Sierra Nevada, the observation unit for most of the data is a 100-meter grid cell. The demonstration also uses point observations of some threatened and endangered species as well as 5- by 5-kilometer grids of current and projected housing density.

This paper illustrates conservation planning for terrestrial biodiversity by using five general conservation objectives:

- Protect hotspots of rare, endemic, threatened, and endangered species (Dobson and others 1997, Noss 2000);

- Protect underrepresented species and community types (Cocks and Baird 1989, Pressey and others 1993, Scott and others 1993, Margules and others 1994);

- Protect wildlands for large carnivores and other “area-dependent species” (Soule 1991, Noss and others 1996, Noss 2000);

- Protect biophysical landscapes to maintain ecological and evolutionary processes (Belbin 1993, Forman and Collinge 1996); and

- Expand existing reserves (Cowling and others 2003).

These objectives are not completely independent; however, each represents a different policy for prioritizing conservation investments, and each invokes a distinctive set of biological and spatial criteria. In the authors’ experience in the Sierra Nevada, site conservation values for the different objectives may exhibit very low correlation with one another.

Simple functions were developed to estimate the conservation value of each planning unit with respect to each of these conservation objectives on the basis of the current conservation status of the reference region and goal-specific measures of resource value and threat (Davis and others 2003). These functions require information on both the extent and condition of terrestrial biodiversity resources.

A Simple Index of Ecological Condition

Because the focus is on setting conservation priorities for rural lands over large areas, the authors used relatively generic measures of ecological condition that could be obtained by operational remote sensing and did not require detailed site surveys. These include land conversion to urban or intensive agricultural use, residential housing density, road effects, and forest structure. Techniques have been developed for forecasting the future state of these variables, providing a means for formally estimating the threat to resource values over the planning period. These variables were assessed at a relatively fine scale (generally 1 hectare or finer) and integrated over the 3- by 3-mile planning units and multiple reference regions. The condition score increases if the area is not converted, has lower impact from residential development, is less affected by roads and, if forested, has mid- or late-seral forest structure (see Davis and others [2003] for details).

Maps of present and predicted future condition were derived from statewide GIS data on land use/land cover (California Department of Forestry and Fire Protection [CDFFP] FRAP),

roads (U.S. Census TIGER data), forest structure (CDFFP FRAP), and predicted housing densities for 2000 and 2040 (Spero 2001). Threat to biodiversity was measured as the difference between mapped condition in 2000 versus 2040 (*fig. 1*). This analysis considered only threat of development on private lands, focusing on new housing development and associated environmental degradation. Other scenarios of threat are certainly conceivable and could be substituted. For this demonstration, the authors also assumed that forest conditions remained constant and no new highways were constructed.

Modeled threat was highest on private lands in the western foothills of the Sierra Nevada, most notably in Butte, Nevada, El Dorado, Calaveras, and Madera counties (*fig. 1*). This threat was concentrated in valley oak, blue oak, and blue oak-foothill pine habitat types, as previously described by Duane (1996), Davis and Stoms (1996), and Spero (2001).

Marginal Conservation Value

The conservation value of protecting a site for a particular resource is calculated as a function of (1) the conservation goal for that resource (expressed as area, fraction of total resource in the region, number of occurrences of the resource, or some other quantity), (2) amount of the resource that is predicted to remain in the reference region at the end of the planning period in the absence of conservation action, and (3) the additional amount of the resource that would remain at the end of the planning period if new conservation actions were taken to protect the resource wherever it is currently threatened in the site.

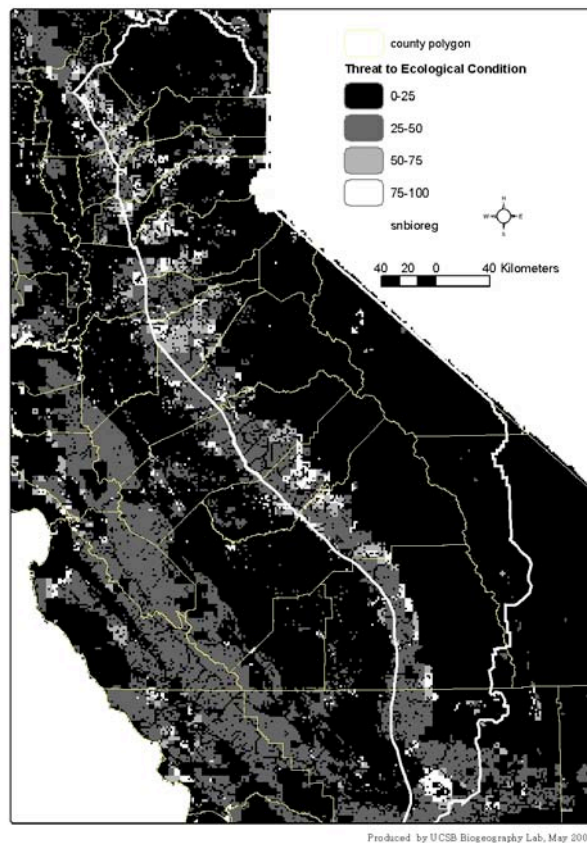


Figure 1— Calculated threat to current ecological condition from new housing development projected to occur between 2000 and 2040 A.D. The threat levels range from 0 to 100 and are calculated as the difference between modeled cell condition in 2040 and 2000.

This approach requires establishing a relationship between the level or amount of a resource (for example, acreage of a particular habitat type) and the “utility” associated with the resource. Utility is measured with respect to the amount or level of a resource in the reference region, rather than the level of protection of the resource. Total utility level of the resource is assumed to decrease as the resource is reduced in the region. (In principle, the utility level could also increase through rehabilitation and restoration activities.) An infinite variety of shapes are possible for this utility function, but the authors assume that utility is gained or lost most steeply at low levels of the resource and changes relatively little at very high levels of the resource (in other words, there are “diminishing returns” on increasing amounts of the resource in the region). One can also specify a goal beyond which increasing levels of the resource are seen as adding no utility. A utility curve and associated marginal benefit curve that capture these ideas are shown in *figures 2a* and *2b*. Utility is zero when the level of the resource is zero, increases at a constant rate to some specified level of the resource, and then increases in a quadratic form up to a target level beyond which no additional utility accrues. This produces a piecewise linear form for the marginal benefit curve. The marginal conservation value of any particular site is measured as the total utility that is retained by conserving that site (*fig. 2c*).

To measure a site’s value for conserving terrestrial biodiversity, its marginal conservation value is estimated for each of the five conservation objectives listed above. These are combined by weighting each objective and summing the weighted values for each site.

Allocating Conservation Funds

The final step in the framework is a budget allocation model. This approach to measuring conservation value is based on a cost-effectiveness framework similar to that of Hyman and Leibowitz (2000). Conservation investments, which are allocated at the site scale, may be the cost of outright acquisition of currently unprotected lands, purchase of development rights, stewardship incentives, or whatever action is deemed necessary to remove the threat. The authors attempt to identify the set of sites, which, if conserved, would minimize the loss of terrestrial biodiversity during the planning period. This requires consideration of each site’s resources, location, and spatial context; severity of threats; and conservation cost.

Identifying the “best” set of sites for conservation investments given a fixed budget can be an extremely difficult problem to solve because of the astronomically large number of feasible solutions. Several heuristic algorithms are available to ease implementation of the model for large problems. This demonstration uses a simple heuristic that involves a stepwise procedure in which the site that provides the greatest utility per conservation dollar (in other words, conservation “bang for buck”) is chosen first. Then, all resources and values are re-calculated on the basis of that conservation action, and the procedure is repeated until the budget has been spent. This is a version of the “greedy algorithm” in integer programming.

Example Results for the Sierra Nevada Bioregion

Marginal Conservation Values

Figures 3 and *4* illustrate patterns of marginal conservation value (or marginal utility) for two of the five metrics for terrestrial biodiversity: hotspots of rare, threatened, and endangered species (*fig. 3*) and areas supporting wildlife habitat types that are not well represented in existing public lands or private reserves (*fig. 4*). Results for the other metrics are described by Davis and others (2003).

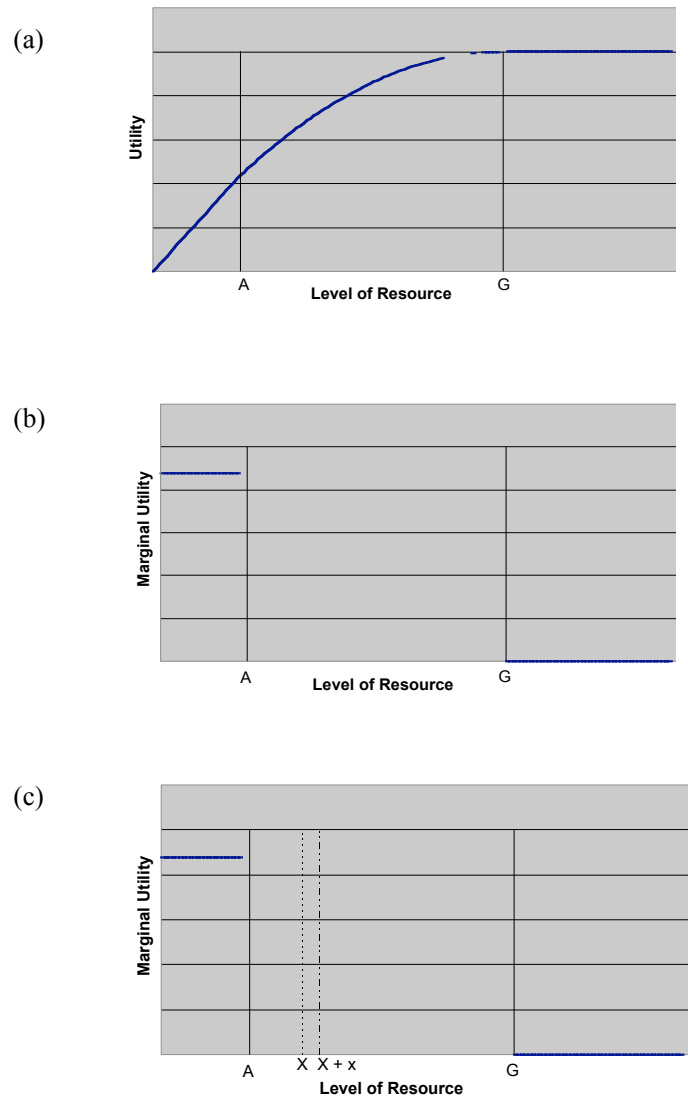


Figure 2— Utility functions and associated marginal utility functions for estimating site conservation value: (a) the utility function used here for evaluating terrestrial biodiversity in the Sierra Nevada bioregion; (b) the marginal utility function associated with (a); (c) change in marginal value associated with a conservation action today that increases the predicted future level of the resource from X to $X+x$. The total benefit of the conservation is calculated as the area under the marginal value curve.

The hotspot score (*fig. 3*) is based on the distribution of G1 and G2 plant and animal species according to the California Natural Diversity Database. A site has higher hotspot conservation value if it has more unprotected land that is in good condition and that land accounts for a large fraction of the known distribution for a relatively large number of rare, threatened, and endangered (RTE) species. Clusters of high-scoring sites are scattered across the private lands of the western foothills. Many of the high-scoring sites are areas with

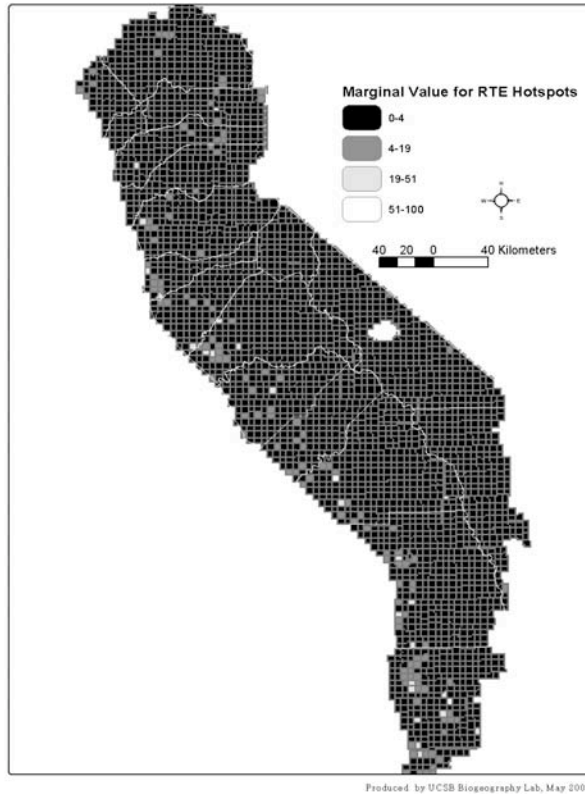


Figure 3— Hotspot value of township quadrants in the Sierra Nevada bioregion for rare, threatened, and endangered plant and animal species. Scores reflect documented distributions of all G1 and G2 species in the 2002 version of the California Natural Diversity database.

distinctive soils and associated concentrations of rare plant species. For example, the highest scoring cells in the foothills of Nevada, Placer, Amador, and El Dorado counties are locations of serpentine and gabbroic soils that support chaparral communities with rare endemic plant species such as *Calystegia stebbinsii* and *Fremontedendron californicum* ssp. *decumbens*. Similarly, several high-scoring sites at the southern end of the region in Kern County are areas of blue oak (*Quercus douglasii*) woodlands on adobe soils that support rare plant species, such as *Mimulus pictus* and *Fritillaria striata*. Because the majority of special-status species in the Sierra Nevada comprise narrowly distributed plant taxa, scores are largely dictated by plant species. A map of values based solely on animal species shows a quite different pattern (Davis and others 2003).

Site scores for protecting underrepresented habitat types (fig. 4) were derived for wildlife habitat types as defined in the California Wildlife Habitat Relationship (CWHR) System (Mayer and Laudenslayer 1988). A current map of CWHR types at 100 meters was obtained from CDFFP FRAP. The highest marginal values were associated with threatened CWHR types, including commercial conifer types, such as ponderosa pine forest and eastside pine forest, and oak woodland types, such as blue oak–foothill pine woodland and valley oak woodland. Township quadrants scoring the highest were those where habitat types with high marginal value and in relatively good condition occurred on threatened private lands (fig. 4). Thus, high-scoring sites are clustered at low- to mid-elevations on the western slope of the Sierra Nevada, where rural housing density has increased in recent decades and is projected to continue to increase (Duane 1996).

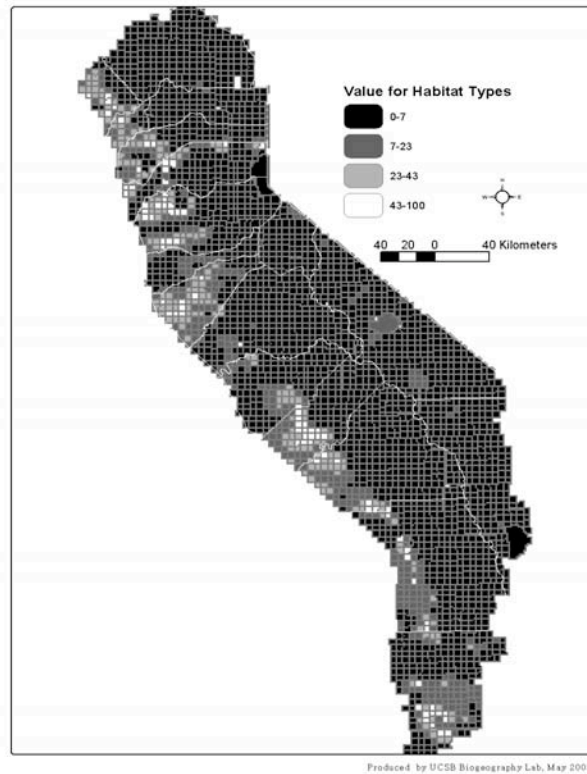


Figure 4— Marginal value of private lands by township quadrants in the Sierra Nevada bioregion for conserving wildlife habitat types.

The spatial patterns of conservation value vary considerably among the five objectives, with scores for RTE species showing the lowest correlation with other objectives. If the five objectives are weighted equally, many township quadrants in the Sierra Nevada bioregion show moderately high scores (*fig. 5*). Very few sites score highly in all objectives. Larger regions of high-scoring cells include central Placer County, southwestern and southeastern El Dorado County, central-western Calaveras County, central Madera County, south-central Tulare County, and south central Kern County.

Perhaps more to the point is that, based on relatively crude surrogates for biological composition, condition, and threat, many areas of the foothills and lower montane zone of the Sierra Nevada bioregion have high value for one or more objectives and at least moderate conservation value when all objectives are considered. A few areas of the eastern Sierra Nevada also appear consistently, although scores are generally lower because of lower projected threat of development and the high percent of public ownership. Thus, variations in costs and opportunities could play a significant part in determining priorities, as demonstrated below.

A Sample Investment Portfolio

For demonstration purposes, the authors considered conservation in the Sierra Nevada study area solely by outright acquisition. Land prices for undeveloped rural lands were estimated using 2002 data from the California Chapter of the American Society of Farm Managers and Rural Appraisers [available online at <http://www.calasfmra.com/landvalues/2002/index.html>]. County-level estimates for land value of rangeland were used for Butte, Placer,

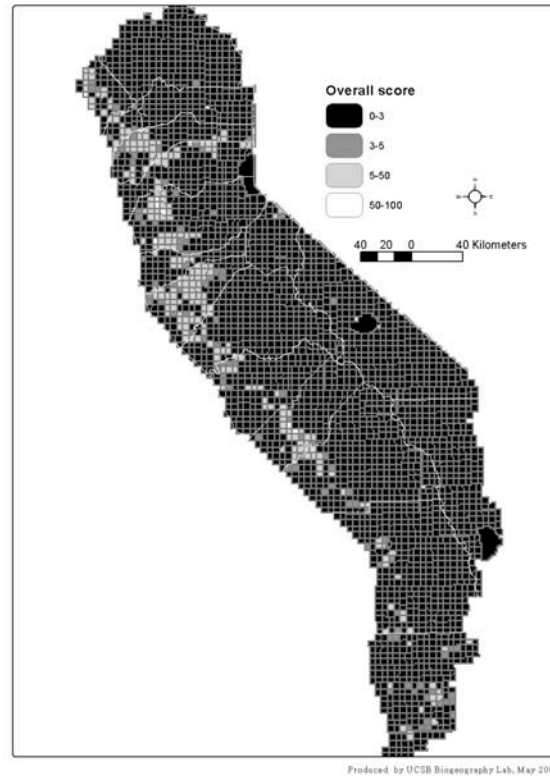


Figure 5— Composite conservation scores for terrestrial biodiversity private lands in township quadrants of the Sierra Nevada bioregion given equal weighting among the five conservation objectives.

Madera, Fresno (eastern half), Tulare, and Kern (eastern half) counties. Land values for the remaining counties were chosen to reflect the broad pattern of land use and development pressure relative to known county values. Counties in the eastern part of the Sierra Nevada bioregion were assigned the lowest land values; those in the central western foothills were assigned medium land values; and those lying just east of Sacramento were given relatively high values. For this demonstration, land values ranged from \$988 to \$2,470 per hectare (\$400 to \$1,000 per acre). The total conservation cost of a planning unit is the product of the per-hectare cost and the total area in hectares of land available for conservation in the planning unit (total land area minus public land and converted land).

A quick comparison of these land values with prices actually paid in recent years through California bond initiatives showed that the values used for this demonstration tended to correspond to the low end of the range for a county. Often, the high end of the range was several times the price used here, and where there were many acquisitions, the price range in a county was extremely variable. This suggests that county-level estimates grossly oversimplify the geography of the real estate market. However, the purpose here is to demonstrate the use of the model.

Using estimated land values and the measure of overall marginal value for terrestrial biodiversity conservation with equal weighting between conservation objectives, the greedy algorithm was run until an arbitrary 50 sites were selected at a predicted total acquisition cost of \$44 million for approximately 25,000 hectares, or about 10 percent of the remaining available land in the Sierra Nevada bioregion (*fig. 6*). This represents an average of \$1,760 per hectare, very close to the \$1,800 per hectare average estimated price in the bioregion. This scenario should be interpreted as one possible alternative, based on

an equal weighting of conservation objectives. The outcome is very sensitive to the very crude estimates of land values used here, choice of reference regions and goals, and the model of future urbanization.



Figure 6— A sample run of the greedy site selection algorithm. The algorithm was run until an arbitrary 50 sites were selected at a predicted total acquisition cost of \$44 million for approximately 25,000 hectares, or about 10 percent of the remaining available land in the bioregion.

In general, the mean marginal value for each objective in selected sites was much greater than the mean for all sites. Forty-two of the 50 selected sites had no marginal value for at least one of the five objectives. Interestingly, the spatial pattern of selected sites is quite scattered. Although spatial clustering is an important consideration in two of the metrics, with even weighting of all five objectives the selected sites are not clustered. Different weights would result in a different pattern.

A large fraction of the 50 sites occur in the eastern Sierra Nevada counties of Alpine, Mono, and Inyo, which were assigned the lowest estimates of land values. The composite marginal value for these eastside sites was four times less than those selected on the west slope of the Sierra Nevada, but the mean benefit-cost ratios were almost identical. Clearly, the estimates of land values used for this demonstration had a strong influence on the scenario, by allocating funds to more land of moderate conservation value than spending it all on relatively fewer hectares of land with the maximum marginal conservation value. This result underscores the point that making efficient and effective conservation investments requires more information than simply identifying sites with the highest biodiversity conservation value (Ando and others 1998).

Discussion

This framework developed for the California Legacy Project has not been fully vetted by the relevant State agencies or other stakeholder groups, so it remains to be seen whether the ideas and methods will prove useful in real planning efforts. Most of the calculations are relatively straightforward and easily implemented in ArcGIS and Access, so the framework should be widely accessible. The authors believe that the strengths of the framework are its generality, explicitness, applicability with readily available data, flexibility for exploring alternative goals and objectives, consideration of threats and costs as well as biodiversity values, and perhaps, most importantly, its ability to reveal short-term priorities and its usefulness in helping to choose among competing projects on the basis of a formal cost-effectiveness analysis.

The framework as currently implemented is somewhat cumbersome and needs a simple user interface and software to facilitate analysis and planning. The authors are currently developing such a planning support environment in collaboration with NatureServe (<http://www.natureserve.org/>). After developing such software, it will be much easier to conduct sensitivity analyses on models of development threat, different planning horizons, classification schemes, parameters, and marginal value functions, which are integral to estimating site conservation value.

The usefulness of this data-driven framework obviously depends on the quality of the data. The authors have deliberately limited the application to statewide data that are widely used, with accuracy and biases relatively well understood. In doing so, biological detail has been sacrificed for better consistency and accuracy. However, some Sierra Nevada counties (for example, Placer and Nevada) have recently developed more detailed geospatial databases that could be used in subregional analyses.

A major concern with the current framework is that it does not consider the effects of taking conservation actions on ensuing distribution of development threats. The authors are looking into ways of updating the threat surface as part of updating calculations of conservation value. This will be especially important for applications of the framework at finer spatial scales.

Acknowledgments

The authors gratefully acknowledge the financial and logistical support of The Resources Agency of California and the National Center for Ecological Analysis and Synthesis, a Center funded by the National Science Foundation (Grant DEB-0072909), the University of California, and the Santa Barbara campus.

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The Future of Biodiversity in the Sierra Nevada through the Lake Tahoe Basin Looking Glass¹

Patricia N. Manley²

The Sierra Nevada's biological distinction and diversity are almost as legendary as its spectacular peaks and beautiful granite landscapes. The Sierra Nevada is recognized as a zoogeographic region on the basis of the coincidence of species ranges (for example, Udvardy 1969, 1975; Welsh 1994). Udvardy (1969) defined the Sierra Nevada bioregion as bounded by the Great Basin to the north and east, the Mojave Desert to the south, and the Central Valley of California to the west. Welsh (1994) further delineated the Sierra Nevada into three latitudinal segments, recognizing shifts in species composition from north to south along the 650-kilometer north-south extent of the largest single mountain range in the contiguous United States.

Today, 493 terrestrial vertebrate species (California Department of Fish and Game 2003), 61 fish species and subspecies (Moyle and others 1996, USDA Forest Service 2001), and more than 2000 plant species (Storer and Usinger 1963) have portions or all of their geographic ranges within the bounds of the Sierra Nevada ecoregion. High levels of endemism contribute to the Sierra Nevada's biotic wealth: 13 terrestrial vertebrates (Graber 1996), 11 fish (Moyle and others 1996), and 405 vascular plant (Shevock 1996) species that are endemic to California occur only in the Sierra Nevada, and many more of the State's endemics have some part of their ranges in the Sierra Nevada. Concerns are mounting for the fate of biological diversity in the Sierra Nevada (Sierra Nevada Ecosystem Project (SNEP) 1996, USDA Forest Service 1998, California Legacy Project 2003). Although few vertebrate species are known to have been extirpated from the Sierra Nevada (Graber 1996), present-day species composition and richness may be misleading reflections of ecosystem conditions because of the time lag that often exists in measurable population response to changing environmental conditions.

Managing for sustainability in any type of system (ecological, social, or economic) requires maintaining diversity, variability, and redundancy (Berkes and others 2003). Biological diversity affects ecosystem processes, functions, and responses to disturbances (for example, fire), including the degree to which ecosystem services (for example, water yields and nutrient cycling) will be altered (for example, Lamotte 1983, Risser 1995, Kinzig and others 2001, Loreau and others 2002, Symstad and others 2003). In ecological systems, maintaining biological diversity at all levels of biological organization is an important step toward meeting the goal of sustainability.

Myriad past and present change agents, or stressors, have shaped Sierra Nevada ecosystems, including fire and fire suppression, grazing, logging, dams, development, recreation, air pollution, and climate change (Beesley 1996, Cahill and others 1996, Chang 1996, Duane 1996, McBride and others 1996, Momsen 1996, Stine 1996, Elliott-Fisk and others 1997, Lindström 2000, Millar this volume). Our understanding of the individual effects of these stressors on subsets of biota is growing (for example, Chang 1996); however, their combined

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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effects on natural systems are virtually unknown. Human response to changing ecosystem conditions and services brings another level of complexity and uncertainty into the sustainability equation. In short, ecosystem response to stressors and the reciprocal response of people to changes in the ecosystem constitute coupled dynamic systems that are likely to exhibit new and adaptive behaviors (Gunderson and others 1995, Gunderson and Holling 2002).

A recent assessment of population trends over the past 50 years of vertebrate species in the Sierra Nevada (USDA Forest Service 2001a) found that approximately 50 percent ($n = 210$ species) of all terrestrial vertebrates and approximately 60 percent ($n = 37$ species) of all fish species were considered moderately to highly vulnerable to population loss, extirpation, or extinction. Such a large proportion of species with a precarious future suggests that the composition of biota in the Sierra Nevada, particularly vertebrates, may be unstable and susceptible to a change in state or may have already crossed a sustainability threshold. When environmental conditions change rapidly, as they have in the Sierra Nevada, populations of species can fall into a non-equilibrium state or “debt of extinctions” scenario (Hanski 1994, Tilman and others 1994, Hanski 1997). In such cases, even though environmental conditions can no longer support sustainable populations, populations of longer lived species will persist but decline steadily toward extinction as mortality exceeds recruitment. It is possible, even likely, that environmental conditions in the Sierra Nevada are approaching or have exceeded a threshold of sustainability for some species, and the extirpation of species from some or all of their ranges in the Sierra Nevada could affect substantive change in ecosystem dynamics and services (*fig. 1*). Insights into profitable approaches to maintaining biological diversity in the Sierra Nevada can be gained by examining the interaction of humans and nature in detail at a smaller spatial scale. The Lake Tahoe basin presents just such an opportunity.

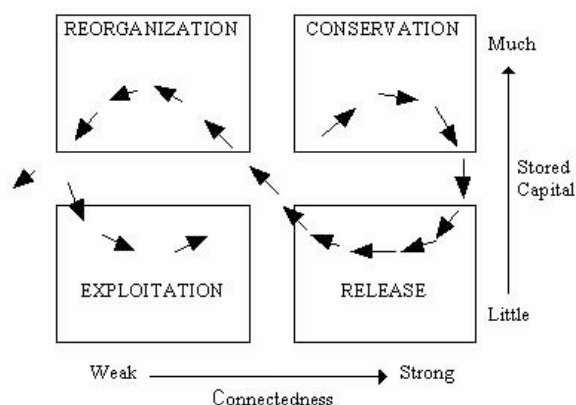


Figure 1— Holling's Cycle

Lake Tahoe as the Sentinel for Future Biodiversity

The same types and patterns of ecosystem degradation and alteration that are playing out throughout the Sierra Nevada are occurring in the Lake Tahoe basin. Coupled with high social value of the basin, Lake Tahoe can be viewed as a valuable portent for the fate of the Sierra Nevada. A recent Lake Tahoe Case study (Elliott-Fisk and others 1997) noted that the Lake Tahoe basin could serve in the discovery of solutions to conservation challenges facing the Sierra Nevada. Declining clarity in Lake Tahoe and a desire to maintain high environmental quality in the Lake Tahoe basin have summoned increasing attention to the fate of this area and resulted in many substantive actions, including the completion of multiple scientific assessments (Western Federal Regional Council Interagency Task Force 1979, Elliott-Fisk and others 1997, Murphy and Knopp 2000). A pivotal question is whether

ecological knowledge and institutional commitment are sufficient to take effective action to sustain biological diversity and ecosystem integrity in the Lake Tahoe basin. If biodiversity cannot be sustained in the Lake Tahoe basin, perhaps it cannot be done in the Sierra Nevada. A closer look at a few of the ecological and social players in the Lake Tahoe theater will illustrate how we can study and learn from efforts to “save the lake.”

Biological Diversity at Lake Tahoe

The 880-square-kilometer (88,000 hectares) Lake Tahoe basin cradles the largest alpine lake in North America, bounded by the Sierra Nevada crest on the west and the Carson Range on the east (Whitney 1979, Landauer 1996, Schaffer 1998). The Lake Tahoe basin has a high diversity of species, in part because of its location at the nexus of two major biogeographic provinces (the Sierra Nevada and the Great Basin; Udvardy 1969). The fault-block origin of the basin and its steep elevational gradient further diversifies the suite of ecosystems occurring in the basin, including a variety of ecologically significant areas, such as Pope Marsh, once a marsh of substantial extent in the Sierra Nevada; Grass Lake, Osgood Swamp, and Hell Hole, rare examples of bogs in the Sierra Nevada; the cushion plant community, an uncommon high-elevation shrub community adapted to alpine conditions; and deep-water plant beds in Lake Tahoe, a globally rare symbiotic plant community (Manley and others 2000). In addition to these exceptional ecosystem types, the basin also contains an array of more commonly occurring terrestrial and aquatic systems characteristic of lower montane, upper montane, subalpine, and alpine environments.

Human Disturbance: Recent Past and Present

The Lake Tahoe basin sustained perhaps the most intensive land use of any watershed in the Sierra Nevada during the height of commercial land uses that occurred throughout much of the range in the late 1800s and early 1900s. Past activities in the Lake Tahoe basin included clearcut logging of more than 50 percent of the basin and extensive grazing by sheep and cattle (Elliott-Fisk and others 1997, Lindström 2000). Intensive commercial use was followed by a century of fire exclusion, and, as throughout the Sierra Nevada, created an excess of dense, single-aged white fir stands with suppressed growth and high levels of mortality (Macomber and Woodcock 1994, McKelvey and others 1996, Elliott-Fisk and others 1997, Barbour and others 2002). Today, many stressors continue to shape the landscape (such as development, forest management, fire suppression, recreational use, declining air quality, and climate change), with fuel-reduction treatments becoming a prominent management activity (USDA Forest Service 2004) and recreation becoming a primary use of public lands in the basin, as throughout the Sierra Nevada. For example, National Forests in California host 28.7 million annual visitors (Anonymous 2002), and 3.1 million (13 percent) of them come to the Lake Tahoe basin (Kosis and others 2002)—the highest per annual visitation per unit area of any National Forest in California. Accordingly, Stewart (1996) identified Lake Tahoe as the single most important recreation component of the Sierra Nevada economy.

Plant and Animal Populations

Manley and others (2000) examined historical changes in the composition of vertebrate species in the Lake Tahoe basin. Their findings revealed ecologically significant changes in species composition that echo those experienced throughout the Sierra Nevada. Changes in habitat and populations were evaluated across the span of four major time periods: Prehistoric Era (pre-1860), Comstock Era (from 1860 to 1900), Post-Comstock Era (from 1900 to 1960), and Urbanization Era (from 1960 to the present) (Lindström 2000). Terrestrial vertebrate species apparently lost over this time period include four bird, seven mammal, and one amphibian species, with four top carnivores among them (grizzly bear

[*Ursus arctos*], wolverine [*Gulo gulo*], Sierra Nevada red fox [*Vulpes vulpes necator*] and peregrine falcon [*Falco peregrinus*]). Nine bird, two mammal, and one amphibian species appear to have moved into the basin over the past 50 to 100 years, including one carnivore (California spotted owl, *Strix occidentalis occidentalis*), and five exotic species: wild turkey (*Meleagris gallopavo*), European starling (*Sturnus vulgaris*), rock dove (*Columba livia*), house sparrow (*Passer domesticus*), and bullfrog (*Rana catesbeiana*).

Although lack of data precluded Manley and others (2000) from conducting a complete analysis of changes in fish, invertebrate, and vascular plant species, the 102 exotic species from these three groups (16 fish, 2 invertebrate, and 84 vascular plant species) that are now known to occupy the basin have had demonstrated impacts on aquatic ecosystem diversity and integrity. For example, most fish species in the basin are exotic, and the introduction of exotic, predator lake trout (*Salvelinus namaycush*) contributed significantly, along with fishing pressure and habitat degradation, to the extirpation of the once prolific Lahonton cutthroat trout (*Onchorhynchus clarki henshawii*) (Reuter and Miller 2000). Some changes in species composition in the basin reflect Sierra Nevada-wide extirpations, but undoubtedly basin-specific ecosystem alterations contributed substantially to observed changes in species composition.

Forest Ecosystems

The ecological significance of vegetation changes invoked by past activities has not been fully examined, but it must be considerable given altered tree species composition, reduced vegetation complexity, decreased extent of old-growth forests, degraded biological diversity, increased risk of high-intensity wildfires, and altered ecosystem functions, such as water uptake, fuels, tree longevity, and decay characteristics. Historically, 2,100 to 8,000 acres burned annually in the basin through a combination of human and natural ignitions compared with fewer than 500 acres burned annually today through prescribed fire and wildfire (Manley and others 2000). Similarly, before intensive land use, an estimated 55 percent of the conifer forests in the basin were old growth (large-diameter trees, snags, and logs, and characteristic canopy cover and vertical layering [Franklin and Fites-Kaufman 1996]) in contrast to today's 5 percent old growth (Manley and others 2000, Barbour and others 2002). Today, old-growth forests in the basin differ from the uncut forests in the mid 1800s in that they have approximately four times the understory tree species density, which is composed of 200 to 300 percent more white fir and incense cedar, 50 percent less Jeffrey pine, and a 100- to 300-percent greater incidence of tree disease and mortality (Manley and others 2000, Barbour and others 2002). The younger age and simplified structure of these second-growth forests have a reduced diversity of habitat conditions to support populations of plants and animals, particularly species associated with old-growth forests.

Restoration of forest integrity in the Lake Tahoe basin will require managing forests to increase the proportion of the landscape in old-growth condition, mimicking historic fire regimes to the extent possible, and managing development, disturbance, and exotic species to restore biological diversity and ecological function. This challenge exists throughout the Sierra Nevada, and successful implementation will test the resolve of all involved on two fronts: it will require close collaboration between scientists and managers to create a vision of sustainable forest conditions and then design treatments to achieve them, and it will require the support of local communities to take on the burdens of short-term reductions in air quality, changes in esthetics, and risks of escaped fire.

Aquatic Ecosystems

Aquatic and associated riparian ecosystems provide resources that support a large number and wide variety of rare and common species (Graber 1996, Manley and others 2000), especially in areas with dry climates, such as the Lake Tahoe basin (Naiman and others

1993, Kondolf and others 1996). The basin also has a high diversity of aquatic ecosystem types; 17 aquatic ecosystems were identified in the Lake Tahoe basin by Manley and others (2000), including eight lentic types (lakes, ponds, bogs, wet meadows) and nine lotic types (streams, marshes, springs). Some of the rarest aquatic types, such as Lake Tahoe itself, the three bogs, Pope Marsh, and the Upper Truckee River, are considered ecologically significant areas and are considered keystone contributors to biological diversity in the basin.

In the Sierra Nevada and the Lake Tahoe basin, aquatic and riparian environments have been highly altered over the past 150 years as a result of mining, dams, grazing, recreation, the introduction of exotic species, and urbanization (Kondolf and others 1996, Moyle 1996a, Elliott-Fisk and others 1997). A high and growing number of recreationists in the Lake Tahoe basin (Kosis and others 2002) may pose the most significant current and future risk to aquatic ecosystems. Recreational use can have numerous negative effects on the ecological integrity of aquatic ecosystems, such as bank erosion and compaction, loss of ground cover, pollution, introduction of exotic species, and harvest of native species.

Although aquatic ecosystems are currently managed with the intent of protection and restoration in the basin (TRPA 1982, TRPA 1986, USDA Forest Service 1988), the effects of past activities combined with increasing urbanization and recreation use have put aquatic and riparian ecosystems at risk of degradation. An evaluation of the status of aquatic ecosystems by Manley and others (2000) determined that most lentic ecosystems were at risk, primarily because of their rarity, and that protection from degradation of ecological integrity was not strong for any aquatic ecosystem in the basin. Aquatic conservation strategies can be an effective means of identifying problems and crafting solutions for large landscapes (for example, Forest Service 2003, 2004), and although their development and implementation have been proposed, they have not been adopted for the Sierra Nevada (Forest Service 1995, Moyle 1996b) and the Lake Tahoe basin (Murphy 2000).

Significant collaboration between scientists and managers is required to design, implement, and monitor aquatic conservation strategies (for example, Reese and others 2003). In the basin, conservation of aquatic and riparian biodiversity is complicated by a recent discovery that different taxa appear to exhibit different patterns of richness in riparian ecosystems (Manley 2000, Manley and others 2000). Specifically, Manley and others (2000) found that bird diversity was greatest at low elevations, mammal diversity was greatest at high elevations on the east side of the basin, and plant diversity was greatest at high elevations on the west side. It is likely that divergent spatial patterns of richness exist among taxonomic groups throughout the Sierra Nevada and that if concepts like aquatic diversity management areas (Moyle 1996b) are employed, they will need to encompass the broad taxonomic heterogeneity in diversity that exists across the larger landscape. The upcoming revision of the Tahoe Regional Plan by the Tahoe Regional Planning Agency and the Forest Service's Lake Tahoe Basin Management Unit may provide the momentum needed for the basin to design and implement the first aquatic conservation strategy in the Sierra Nevada.

Climate Change

In addition to direct anthropogenic and intrinsic processes at work in the Sierra Nevada, extrinsic factors are also acting on its ecosystems, with climate change being among the most significant (Millar this volume). Mountain ecosystems are key areas for monitoring and studying the effects of climate change on ecosystem composition, structure, and function (for example, Reasoner and others 2004). The extensive elevational range (greater than 1,000 meters) within the Lake Tahoe basin makes it a model laboratory for tracking environmental changes precipitated by climate change. Warming trends have the potential to change the distributions and interactions of many species in the basin. For example, species with limited elevational ranges in the basin, such as the western gray squirrel (*Sciurus*

griseus; low-elevation associate), golden-mantled ground squirrel (*Spermophilus lateralis*; mid- to high-elevation associate), western meadowlark (*Sturnella neglecta*, low elevation associate), and winter wren (*Troglodytes troglodytes*; high-precipitation associate) are likely to be sensitive and respond measurably to changes in temperature and precipitation (Manley 2000).

Climate change has and will significantly shape ecosystems in the Sierra Nevada, with discernable effects within the short span of 150 years (Cahill and others 1996, Stine 1996, MVZ 2004, Millar this volume). Management plans and actions may need to have longer time frames to consider and account for changes in species distributions and populations that are at risk solely as a result of climate change. Broad-scale monitoring programs, such as the Forest Service's Multiple Species Inventory and Monitoring Protocol (Manley and Roth 2004, Manley and others 2004), will greatly inform us of climate change effects on biota by providing data on the distributions and abundances of species and communities along multiple environmental gradients. Such monitoring programs will help differentiate change resulting from management from that precipitated by climate change and other factors.

A Weave of Wildland and Human Ecosystems

The role of local communities and society in the conservation of biological diversity is significant. Urban and wildland ecosystems are interwoven throughout much of the Sierra Nevada (for example, McBride and others 1996), including Lake Tahoe (Nechodom and others 2000), with various environmental effects, such as reduced tree density, lower canopy cover, and increased incidence of exotic plant species in forested environments (McBride and others 1996). The Lake Tahoe basin has acute urban-wildland interface challenges because of concordance of landscape complexity, high visitor/resident ratio, demand for outdoor recreational opportunities, risk of high-intensity fire, and socioeconomic stakes given high property values and regional dependence on tourism (Elliott-Fisk and others 1997, Nechodom and others 2000). Highly enmeshed wildland and human-dominated environments can stymie the use of some effective forest management tools that are needed to maintain and restore ecosystem integrity. For example, the reintroduction of fire has been identified as essential to restoring forest health in all recent assessments of the Lake Tahoe basin (Elliott-Fisk and others 1997, Manley and others 2000), as well as throughout the Sierra Nevada (Weatherspoon 1996, USDA Forest Service 2001c, USDA Forest Service 2004); however, smoke from prescribed fires obscures the basin's world-class views and can be a health concern for some individuals. Similarly, domestic dogs, both on- and off-leash, can affect the reproductive success and survivorship of many wildlife species (Knight and Cole 1995); yet, walking and running with dogs on- and off-leash is so common in the basin that it is considered part of the Lake Tahoe "lifestyle." Thus, although Lake Tahoe resources are valued by many, it will be likely difficult to garner local support for inconveniences associated with some critical conservation and management activities.

Concomitant with the allochthonous human-nature interactions occurring in the basin are also complex feedback loops operating between the basin and surrounding communities. As land prices climb in the basin, surrounding areas, such as Truckee and the Carson Valley, are experiencing rapid population growth, and these populations are increasing visitation and human impacts in the basin (Elliott-Fisk and others 1997). Similarly, as the Sacramento metropolitan area grows, so does the population of the adjacent foothills of the Sierra Nevada (Duane 1996), forming a burgeoning recreating public just one hour's drive from Lake Tahoe. The complex, adaptive nature of ecosystems (Levin 1998) presents challenges in meeting sustainability objectives in light of increasing human pressures that, if ignored or underestimated, put the future of biological diversity and sustainability in the Lake Tahoe basin and the Sierra Nevada in peril. Levin (1999a) offers eight commandments for environmental management that recognize the pivotal interplay between human and natural systems: (1) reduce uncertainty, (2) expect surprise, (3) maintain heterogeneity, (4) sustain

modularity, (5) preserve redundancy, (6) tighten feedback loops, (7) build trust, and (8) do unto others as you would have them do unto you. Revision of the Tahoe Regional Plan in 2007 will serve as an important benchmark to discern whether incentives to conserve and restore terrestrial and aquatic ecosystems are great enough to overcome information gaps, institutional barriers, and competing social values.

The Path Ahead for Biological Diversity in the Sierra Nevada

The Lake Tahoe basin has to contend with every primary stressor that currently acts on the Sierra Nevada resources, and in many cases, they are present in the extreme. The effects of past activities in the Sierra Nevada are now part of the fabric of current-day ecosystems. The gauntlet of successes and failures to understand and manifest sustainable, resilient ecosystem conditions in the Lake Tahoe basin will inform a course toward sustainability throughout the Sierra Nevada. Management approaches, including narratives of desired conditions, should reflect the fact that, as Levin (1992) articulated, “Ecosystems are assemblages of interacting components.... The essential constant is change: the balance of Nature describes a system far from equilibrium, alternating between periods of relative stasis and dramatic change.” Thus, our vision of biological diversity for the Sierra Nevada must be as dynamic as the factors acting on it, and management actions intended to achieve or maintain desired conditions for biological diversity need to recognize all agents of change as part of the management equation.

Experimentation, learning, and adaptation are the keys to sustainability (Holling 1978, Lee 1993, Janssen and Carpenter 1999). Institutions play an important role in the success of efforts to achieve ecosystem sustainability. Levin (1999b) argues that, “[we] need to build flexible, adaptive institutions, and recognizing the essential hegemony of individual decisions as cornerstones of effective management plans.” “Command-and-control” approaches to management that neglect intrinsic cycles of natural and social systems (Holling and Meffe 1996, Carpenter and others 1999) are inadequate to the task of achieving ecological sustainability and biodiversity conservation. Exploratory and adaptive approaches to management have the greatest potential to generate solutions for harmonizing management with natural forces and for maintaining ecosystem resiliency, biological diversity, and the services they provide (Carpenter and others 1999, Levin 1999b, Yorque and others 2002).

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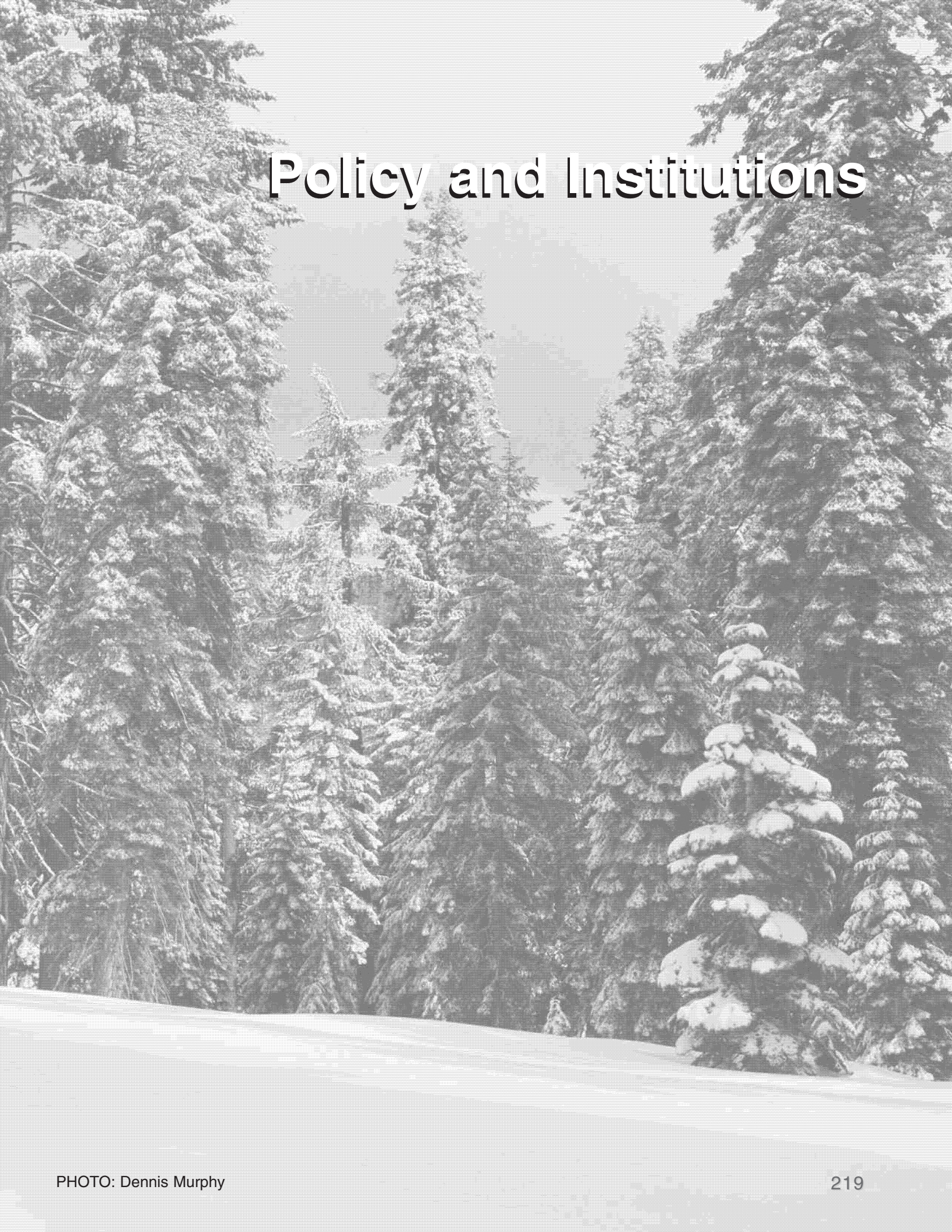
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Policy and Institutions

Sierra Nevada Science Symposium: Policy and Institutions Synthesis¹

Mark Nechodom,² Larry Ruth,³ and Jim Quinn⁴

The policy and institutional dimensions addressed in this symposium were diverse and somewhat diffuse. Each panel was developed to include a political, policy, and institutional perspective. Some of these perspectives were shared from a policy-maker's point of view, others from the view of scientific and technical managers with responsibility for integrating science into planning and management. Others represented a science practitioner's view on how and under what conditions the policy world might absorb, integrate, and respond to new information.

In this short synthesis, we draw from several of the themes expressed in the symposium concerning the nether margins between science and policy, in which science shies away from oversimplifications and policy fears the arcane and complex. We do not claim to represent accurately or to summarize the individual presentations given by Baggett, Murphy, Nechodom, Ruth, Stewart, or any of the various keynote speakers. In fact, what we do say below may even run counter to the intentions of the other policy and institutions speakers. For that, we apologize and hope we have correctly captured the dominant themes. Our purpose is to summarize the perspectives and responses that managers and policy-makers have presented to the natural sciences at this symposium and to explore themes that come from the common threads presented by the policy and institutions speakers.

On Wickedness

Hal Salwasser's keynote address framed the ongoing conflict in the Sierra Nevada as part of a more general problem of "wickedness" in conservation policy and management. To be clear, "wickedness" does not refer to nasty or intransigent agencies or interests. The term has become virtually a technical term, born in the public policy arena in the 1970s, during which some specialists in the political and policy sciences were trying to comprehend the repeated failures of a broad range of public policies similar to those of the seemingly endless revisions and amendments to the Sierra Nevada Framework.

In their seminal article, "Dilemmas in a General Theory of Planning," Rittel and Webber (1973) identified 10 characteristics of problems that seemed to elude successful solutions in public policy and planning. Although we will not repeat them in detail here, the underlying characteristic of wicked problems is that "problems" seem to elude "solutions," according to Rittel and Webber, "because there is no consensus on what the problems are, let alone how to resolve them." In other words, those who hold power and prerogative or actively pursue their interests through political processes do not agree on the very characterization of the problem at hand.

¹ This paper summarizes policy and institutional dimensions addressed at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Whereas Rittel and Webber were focused on public policy problem-solving, during the same period, Alvin Weinberg was interested in the ways the utility of science itself became limited by debates about underlying values. Coining the term “trans-scientific,” Weinberg (1972) called into question the ability of science to resolve key conflicts on its own terms, because those trans-scientific problems were fraught with the kinds of value conflicts on which science must necessarily remain silent.

Salwasser cited several authors who have recently carried the concept of wickedness forward into conservation planning and decisionmaking. And he accurately, we believe, captured how wickedness manifests itself along the long, arduous, and circuitous path of Sierra Nevada land and resource management decisions. However, we wish to suggest that the wickedness Salwasser identified is complicated and compounded by some deeper currents. We classify the deeper currents into two themes: resource valuation and institutional capacity. Each theme has notable manifestations in the Sierra Nevada region, which we will briefly discuss below.

It is arguable that the United States enjoyed a brief period of non-wickedness in its forestry and public land management policies. This is not to say that public land management has ever been very easy. We are only suggesting that, at some time in our history, there was a broad “social consensus” about the purposes and disposition of the Federal estate. The beginning of this period might be marked roughly by the early days of the Progressive Conservation era and the establishment of the Forest Service under the Department of Agriculture. It probably came to a gradual, sliding halt after passage of the National Environmental Policy Act, the National Forest Management Act, and the 1983 amendments to the Endangered Species Act. In that three-quarters of a century, forestry, mining, water development, and other resource management concerns were underpinned by a broad consensus (again, we emphasize, not perfect agreement) about the public benefits that were to accrue to society by resource exploitation at unprecedentedly large scales. It is also soundly arguable that, in fact, those benefits had accrued to the public, perhaps in orders of magnitude greater than Gifford Pinchot, Teddy Roosevelt, or even William Mulholland ever imagined.

This is not an apologia for development in general, nor do we mean to excuse public agency intransigence or failure. The fundamental consensus that defined public land management through extraction and commodity production has profoundly and irrevocably changed its direction. Therein arises the new era of decisionmaking and problem solving in the Sierra Nevada and elsewhere—without the ability to define problems correctly or establish a common range of risk and uncertainty, it is impossible to pursue solutions that will “take” politically. We argue that the profound shift in public trust—not in the public trust doctrine itself, but in its focus and content—has contributed to a long chain of frustrated decision processes, which reflect primarily and relentlessly on the judgments of the trustees (Sax 1984; Sax 1993).

One can interpret the repeated conflicts between public land beneficiaries and trustees as a public and private renegotiation of the dynamic balance between two major social needs. On the one hand, property rights and the limited private capture of public values are built into our constitutional understanding of the relationship between private property and citizenship. On the other hand, resource management agencies have a fundamental obligation to maintain ecological integrity (and other non-market public values) as a public trust responsibility. In practice, these two requirements are often at odds with one another.

We would argue that this fundamental tension is irresolvable; further, it is designed to be irresolvable under our current form of government. To resolve this tension in favor of private property rights would condemn our Sierra Nevada region to a massive “tragedy of the commons.” To resolve in the direction of a complete “locking up” of the public lands would likely leave us with long-term ecological and economic consequences that many would find intolerable. Therefore, we have placed ourselves in a position in the Sierra

Nevada region where we cannot *not* manage. Much of the region is sufficiently altered from an ecological perspective that to “walk away” would invite wholly unwelcome consequences. This dilemma forces the trustees into a serious discussion about how much to manage and for what purposes, rather than *whether* to manage at all (and, it is well known that some interests think the risks of any management are higher than the risks associated with not managing at all). To recognize the need for some kind of management, we must also be prepared to answer the following questions: What are the desired future conditions of the region and its landscapes? And, who should be held accountable and responsible for achieving those conditions?

Resource Values

Inherent in the struggle to define a “desired future condition” in the Sierra Nevada is a more fundamental conflict over values. By “values” we do not intend a vague definition of ethics or preferences. We mean to focus on what people and interests actually value, how they go about expressing those values, and how they try to ensure that those values are captured in assets to be preserved through public trust doctrine by public trustees. In shorter terms: What is it? What is it worth? and Who is responsible for protecting it?

The resource valuation problem in the Sierra Nevada is an institutional mis-match between wealth-generating and asset-protecting activities and how current institutions focus their resources. Much is made about the declining timber industry and the deleterious economic and social impacts of the dramatic fall-off in board-foot production during the 1990s. But as Stewart (1996) points out, the more significant sources of economic wealth in the Sierra Nevada have little to do with, and may actually be impaired by, timber production. Most higher-value economic activities in the region come from impounding water and providing recreational opportunities. Hydroelectric generation, developed water delivery, and a wide range of recreational and amenity activities contribute billions of dollars to California’s Gross Domestic Product (GDP) and far outstrip the contributions of the forest products industry. (This is not to say that forestry and forest products are not important or appropriate. In fact, there is a need for a very critical discussion regarding the forest products processing infrastructure needed to deal with the waste products from millions of acres of hazardous fuels reduction treatments. However, we leave that discussion to another venue.)

The point here is simply that we do not have methods or mechanisms through which we can adequately reflect the relative values of assets that we *de facto* consider of very high value. In perhaps the most technically sophisticated and intellectually honest attempt to date, the California Fire Plan (California Department of Forestry and Fire Protection 2004) has captured, in the Sierra Nevada region, the relationship between assets and values at risk from wildfire compared with the levels of protection allocated to them. Combining spatial analysis of land use and asset value data with local involvement, the Fire Plan compares what people say is valuable with what they actually allocate to protect those values, in terms of fire protection. Whereas “level of service” (that is, how many engines and initial-attack resources) in the Fire Plan may be a narrow reflection of how the public values its assets, in concept it is right on target. If we put a high value on these homes, watersheds, cell phone towers, transportation routes, sensitive habitats, and so forth, we will put resources in place to protect them from wildfire. This ignores, of course, the political problem inherent in any allocation of burdens and benefits. In several California wildland and resource protection cases, urban constituents often question the equity of having to pay for all their own fire services at home, while also being tapped to subsidize fire protection for rural and exurban dwellers elsewhere in the state.

A key problem that must be overcome is to select methodologies that allow public participants to recognize what they value and to compare their relative values under different trade-off scenarios. Not only do well-managed forests produce a variety of non-timber

products valued by the public, including predictable and clean runoff, trapping of pollutants, and recreational amenities, they also provide quality-of-life amenities—the classic “non-market values”—including open space, uncluttered viewsheds, and wildlife. The public is willing to pay huge, if difficult-to-measure, sums to secure many of these amenities, and they produce genuine markets that foster economic growth, including travel and tourism, restoration and wildlife protection, water marketing, and potentially carbon sequestration and other forms of individually transferable quota markets. There are several ways to establish common measures of value of non-market amenities. Some methods require fairly sophisticated research tools, such as contingent valuation surveys, in which respondents are prompted to reveal comparative values, willingness to pay, and willingness to accept. Very few studies of this nature have been conducted in the Sierra Nevada.

In another context, dozens of Sierra Nevadan hydropower facilities will go through relicensing procedures over the next decade, involving hundreds of millions of dollars in operational and non-power values. In every recent major relicensing process, several million dollars worth of studies have been ordered. Very few of them have included a full accounting of environmental and social values, particularly non-power or non-market values.

How might we account for the broader public interests in valuing Sierra Nevadan resources? Resource mobilization theory (RMT), a common method of analysis in the policy sciences, is an effective way to measure *de facto* public choice and values. Although the RMT analytical methods grew from attempts to understand the development and efficacy of social movements (McAdam and others 1996, McCarthy and Zald 1987), the approach is useful in examining how multiple interests use a range of resources to achieve political and economic goals. When applied in the Sierra Nevada context, an analysis of the resources mobilized to protect and enhance amenity and public safety values reveals an enormous investment landscape. We have not completed the analysis necessary to present precise numbers, but a thumbnail estimate puts the values of the resources mobilized in the billions of dollars.

How does this square with the mere millions of dollars invested by public agencies in forest and ecosystem management? Fairly poorly, in our estimation. Although the Forest Service is constantly harangued to manage vegetation in the Wildland Urban Intermix (WUI), urban and exurban development proceed apace, with attendant expectations that services are to follow and amenity values will be protected by someone. Current projections show the resident population in the Sierra Nevada growing from approximately 660,000 in 1990 to more than 1.3 million by 2020 and to more than 2 million by 2040.⁵ These conservative estimates are based on *existing permitted development* and are therefore not at all speculative. The demand for emergency response, transportation of goods and services, water, electricity, fire protection, and so forth will only continue to grow in the next few decades, creating additional pressure to manage the public lands in the Sierra Nevada in accordance with exurban demands for amenity and safety values. All this is occurring within a context of a landscape that historically burned every 10 to 15 years. Fires of the past were generally of moderate to low intensity. As we have seen at this symposium, current fire conditions, with higher risks of severe and extensive fires, pose significant challenges to future managers and service providers.

One way to understand the demand for services is through a “public markets” lens. Quinn and Quinn (2000) maintain that simply looking at actual market exchanges (in other words, payments for goods and services) misses the more important picture. The trading of goods

⁵ Population estimates vary widely for the region. Some of the larger variances come from counting total population in the 23 California and Nevada counties in which the Sierra Nevada range lies. This method renders projections of up to 6.8 million residents “in” the Sierra Nevada region by 2040. A more conservative estimate uses the regional boundary established for the purposes of the Sierra Nevada Ecosystem Project (SNEP 1996) at 1,000 feet above sea level, excluding much of the valley and low foothill development. These projections foresee approximately 2 million residents by 2040 (see Duane 1996; Duane 1999).

and services falls into the category of “tradable property rights.” The most obvious form of tradable property is simply buying something like real estate. Property values are relatively easy to establish (generally what the market will bear); however, creating markets for environmental goods is more challenging. Good examples would be “cap-and-trade” or pollution trading mechanisms for criteria air pollutants in some air basins. A power plant in Arizona, for example, may find it more economical to continue to put several tons of SO₄ into the atmosphere by purchasing SO₄ credits from someone who has “banked” the pollution rights in California by SO₄ reductions, rather than invest in additional scrubbers on their stacks. Conservation easements function in largely the same way: a value is placed on the ecosystem services provided by not developing the land and keeping it in a condition closer to a natural habitat. Dozens of land trust transactions are negotiated annually on precisely this premise, wherein a landowner is paid a negotiated amount for leaving a given portion of his or her land in an undeveloped condition for a predetermined period of time. In many cases, conservation easements play critical roles in development mitigation banking, further emphasizing their roles in markets for goods and services.

Three other mechanisms for the expression of value are not generally analyzed to understand how the public values its common assets. First, there are regulatory mechanisms, such as any number of environmental quality requirements that are mobilized on behalf of the public or narrower private interests. For example, if one were to pay 15 lawyers to intervene in a procedure to relicense a hydropower dam, in order to realize non-power benefits from the impoundment of water, one would be investing in the protection and enhancement of a certain suite of values inherent in the water and its uses. Similarly, mobilizing resources to achieve the listing of a given species is an expression of value through regulatory mechanisms.

Insurance-like mechanisms are a second form of pursuing values. These mechanisms structure trade-offs under uncertain circumstances, such as a Habitat Conservation Plan (HCP) under section 10 of the Endangered Species Act. Negotiating “incidental take” of a species is a way of hedging impacts. If, for example, a developer can specify a given level of risk he or she is willing to take in order to derive wealth from a new resort, an HCP enables public and private interests to negotiate a trade-off value for the species in question and hedge each others’ risks. These hedging strategies can be monetized, although one needs to proceed with caution in this regard. One may be able only to establish differences in monetary equivalents at orders of magnitude, but they are still potentially significant indicators.

Finally, “targeted taxation” functions as another indicator of value. This mechanism is used frequently to express public value or protect public goods and is different from taxation in that it creates general revenues (such as an income or a property tax), unit fees, or charges that are designed to offset the externalities or impacts associated with a given activity. This is an effective way to aggregate demand for a service or good that cannot be sold or traded at a specific level. For example, allowing biomass power plants to reduce their Federal tax rate by using forest thinnings for fuel to offset wildfire occurrence has been under legislative consideration for some time. Governments are uniquely positioned to encourage or discourage certain behaviors by creating tax incentives to achieve public purposes. As Quinn and Quinn observe:

Unit charges set at a level where total revenues just offset total externalities make the total market more efficient and provide added incentives for producer innovations and voluntary consumer choices of more cost-effective products or services. Assessing fees or taxes on those who are currently or potentially charging the society for their support (for example, energy, water, fertilizer, or gasoline consumers) makes more economic sense than do general sales or income taxes, which affect those selling services or products at full cost.

In the Sierra Nevada context, all four of these mechanisms are already used to shape the landscape and decision spaces of public agencies and private interests. Using this lens, we find a tangled web of values, each expressed through multiple lines of interventions and market-like mechanisms, at varying scales. A comprehensive analysis of public choices and competition for benefits would reveal clear separation among actors and interests in pursuing a broad range of resource exploitation and conservation goals. Nechodom and Quinn have attempted to capture this by mapping the broad categories of commodities and amenities against the scale at which a range of interests pursues their goals. This mapping exercise is still under development and is presented here to suggest ways the configuration of institutions and policy in the Sierra Nevada might change to respond to actual pressures in the human and ecological systems in the region.

Figure 1 illustrates ways in which purchasers (a general term for consumers, investors, and voters) act on their interests from entirely different scales of concern. The global purchaser, for example, may be more interested in where carbon sequestration credits can be procured most efficiently and has very little interest in locational amenities. His or her interest is substitutable and can highly complement other consumers' interests (for example, carbon sequestration is potentially very efficient in many parts of the world and can contribute substantially to locational amenity values while creating local employment). In contrast, if a purchaser's primary interest is in locational amenities, substitutability is limited (for example, one seeking a parcel in an eastside pine forest for a retirement home is unlikely to be equally satisfied with a parcel in sagebrush steppe). We believe that understanding the system in which values trade-offs occur at various scales, using the above measures of value-seeking, will help explain where there are high degrees of complementarity and low levels of conflict among purchasers seeking amenities. This approach will also help identify where conflicts are likely because of lack of substitutability or complementarity among purchasers and amenities. The thickness of the lines in the diagram (fig. 1) suggests the extent to which these pathways are currently implemented in the Sierra Nevada region.

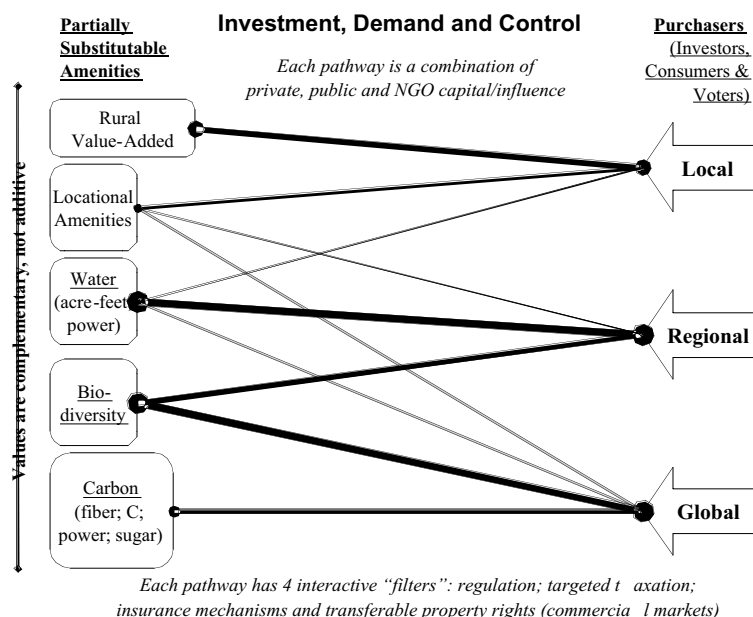


Figure 1— Mapping amenities, demand and investment at local, regional and global scales. NGO, nongovernmental organization.

Each of these forms of expressing value is preceded by political processes. One cannot simply create a new tax or monetize the value of a species by fiat. A political process must take place by which the premises and the values are negotiated. This naturally begs the question of access, transparency, and power. Who gets to determine what combination of market-like mechanisms to use? Who participates in placing values on a given asset? The power to participate, influence, and derive benefit depends largely on capacity among institutional and individual actors. Political science and sociology have long focused on measuring institutional capacity and human capital. The literature is too broad to cite here. We focus on institutional capacity in our summary below to highlight how appropriate venues might be established for negotiation among conflicting values in the context of conservation and natural resources decision making.

Capacity

We define capacity as the ability to respond to opportunities or to accomplish something. Institutional capacity refers to the ability of any given organization or institution to respond to demands and mandates through use of its authorities, resources, and prerogatives.

Where and how humans derive wealth and benefit from Sierra Nevada ecosystems do not “map” adequately onto how institutional prerogatives and jurisdictions are arranged. Duane (1996, 1999) has shown that patterns of development and the demographics that follow are likely to be more important drivers of institutional investment than any other force in the Sierra Nevada. As exurban populations begin to populate the region, demands for roads, schools, sewers, water, fire protection, and a whole host of amenities increase dramatically.

The jurisdictional “footprint” that controls development patterns (largely land-use planning at the county level and transportation planning at the State level) is not well equipped to deal with the landscape-scale impacts of housing, water, transportation, and other infrastructure development. The California Environmental Quality Act (CEQA) focuses on the project level, and rarely does a case require mitigation or even analysis beyond immediate environmental or transportation impacts (despite a requirement in the language of CEQA that cumulative impacts be examined). This piecemeal pattern is parallel to the “nibbled to death by NEPA” problem described by Federal land managers in the Sierra Nevada. From the interim California spotted owl (CASPO) guidelines through the Sierra Nevada Framework, decisions have been driven by an increasing need to focus analysis and decisionmaking at the landscape level. The scale of planning and analysis is expanding, whether the concern has been driven by a concern for metapopulations of a given species or for meeting the challenges posed by wildfire at manageable geographic scales. Institutional resources have been slow in catching up. Although analytical technology may have improved by leaps and bounds, the decision space has not caught up with the scale of the problems to be addressed. Nechodom and Leisz (2000) found in a study of county capacity that local planning organizations have neither the mandate, the resources, nor the will to participate in planning and decisionmaking beyond the immediate confines of CEQA scale projects (Nechodom and Leisz 2001).

Who Is Minding the Landscape?

Landscape-level planning and management are required to achieve desired results for fire behavior, species conservation, and watershed protection. However, the institutional constellations of mandates, prerogatives, authorities, and responsibilities are not well suited to accomplish those goals. Institutions are rewarded for accomplishing goals and solving problems that fall largely within their own jurisdictions. Many of the landscape-level problems that are driving decisionmaking are multidisciplinary and multijurisdictional. This fundamental problem has become increasingly manifest in the Sierra Nevada region.

Wildland fire suppression is probably the most highly developed form of interagency planning and management. The incident command system, on the whole, works extremely well to integrate Federal, State, and local fire suppression resources. And yet, wildfire suppression is roughly the equivalent of martial law: many rules are suspended, or exigency rules take over. The goal is to put the fire out (notwithstanding the occasional “wildland fire use” burn, which in itself requires enormous planning and suppression capability). The efficiencies of the incident command system and wildland fire-fighting techniques do not translate well to preventative management strategies or long-range planning requirements.

The most important differences between the rarified atmosphere of fire fighting and the complexities of planning and management lie in how we assess, plan, and act under conditions of risk and uncertainty. Clearly, wildfire is rife with high risk and uncertainty. But in the wildfire situation, risk, and uncertainty are managed under relatively strict protocols: protect life and property; preserve ecological assets where possible; and do as little damage as possible in the course of suppression. Very little time and energy are spent wondering about stochastic ecological processes or whether strategically placed thinning operations change fire behavior at the landscape level while the fire is burning. The more difficult questions arise between occurrences of fire (for there will always be fires on Sierra Nevada landscapes). Addressing the more difficult questions of where and how much to thin, what impacts are acceptable (or desirable) on select suites of species and their habitats, or the economic impacts of different management regimes requires appropriate and constructive venues of discussion, analysis, and decisionmaking.

Adaptive management has been the answer of choice to the question of appropriate venues and processes for addressing complex landscape-scale problems. Although there is considerable debate over whether adaptive management can be implemented at large scales, we leave the discussion of design and efficiency to other investigations. However, the institutional capacities to host, convene, oversee, and implement adaptive management are of key concern. Adaptive management, even in its most rudimentary forms, requires consensus on relative risk and uncertainty. For example, pesticide impacts on mountain yellow-legged frogs might be deemed to be of such high risk and uncertainty that adaptive management of Sierra Nevada grazing allotments and Central Valley pesticide use over a 10-year period is warranted. Immediately, one sees the likely points of controversy in this example: Who decided that survival of mountain yellow-legged frogs represented high risk or management uncertainty? Who is responsible for ensuring that monitoring is correctly designed and implemented? Who interprets the monitoring data? Who is obligated to do anything if the data show increased risk or harm?

In their very form and nature, these are political and institutional questions. Who decides? Who is responsible and accountable? In short, to perhaps misappropriate Robert Dahl’s classic study of democracy: Who governs? (Dahl 1961). Adaptive management is an essentially political process, despite the fact that a high degree of technical and scientific knowledge must be engaged for it to work. If one of the intended outcomes of adaptive management is to require an obligatory response to new information, there must be adequate transparency, accountability, and political will in the system to ensure that it does not stop dead when unpleasant facts are found.

When well executed, adaptive management represents a form of institutional learning and equips managers to use the outcomes of past and present decisions made under conditions of uncertainty to decrease uncertainty in future decisionmaking. However, in order to do so, both experimental design and follow-up monitoring need to be sufficiently coordinated so that analysis can be conducted. This requires a certain degree of institutional control. In reality, because most ecosystem level problems occur across multiple jurisdictional lines, institutional control of the adaptive management process requires a high degree of inter-institutional collaboration; therefore, reducing management uncertainty over large landscapes through transparently accessible analysis and adaptation necessarily means that a

number of institutions and agencies have to work closely together. They must create meta-institutions among several disparate institutions.

To our knowledge, no institutions are currently in place, with processes currently under way, that are capable of taking on anything more than the narrowest problems under an adaptive management regime in the Sierra Nevada region. It is highly unlikely that any one institution is capable of or willing to take on system-wide issues. And yet, these kinds of issues are currently considered impediments to active public land and resource management in the Sierra Nevada region.

In this light, if our assumptions are correct, we propose that adaptive management offers three key opportunities. First, if the adaptive management regime is designed with openness and transparency, it is highly likely to offer legitimate seats at the table for those who will otherwise pursue their interests by other means. In other words, will we deal with our conflicts in a court before a judge or across a table covered with maps and flipcharts? This is the structural dimension of adaptive management that is still yet to be confronted by Sierra Nevada institutions and actors.

Second, adaptive management gives dissenters an opportunity to collect information to assess the outcomes and, therefore, the future appropriateness of management decisions with which they disagree. Although it is not a risk-free strategy, adaptive management processes can increase the likelihood that decisions will be based on facts and not brute political force. Of course, it is important to acknowledge that the dissenters may be just plain wrong.

Finally, adaptive management offers a powerful vehicle for moving past wickedness. If limited experimental management actions are taken and monitored by legitimate, peer-reviewed protocols, the results become available to all. We assume that, over time, a “library” of collective experience focused on implementation of vegetation, fire, and habitat management experiments will lend itself to greater and greater public confidence in the public trust agencies. But that is a superficially political result. On a deeper level, adaptive management can be a way of resolving endemic and persistent wickedness for the reasons we describe below.

Conclusion: Whither Wickedness?

Wickedness, we recall, is characterized by not being able to agree on the very premises or definition of the problem—all solutions are confounded by interminable conflict. In the Sierra Nevada context, the inability to agree on the nature of the problem arises, as we argue above, from fundamental differences of opinion and perception about the disposition of the Federal estate. Salwasser argues that wickedness can often be resolved by better science. We propose that wickedness is not resolved simply by better science, but in the way science is linked to deeper political processes. Good politics, generally speaking, takes conflict seriously enough to place facts and values on an equal footing and ensures sufficient exposure of assumptions and positions. It is one of the ways that trans-scientific problems can be addressed.

If adaptive management regimes are designed as if politics mattered, they will naturally cause the participants to visit the first principles that lie behind their assumptions. Adaptive management becomes, therefore, a venue of political negotiation of incommensurable values in a controlled, rule-bound environment whose purpose is to accomplish management outcomes.

Our conclusion, if somewhat speculative, is that we will find new purposes and an emergent social consensus by reverse engineering adaptive management. Conducted in a transparent and scientifically informed way, adaptive management will produce a series of outcomes that will focus us on our fundamental purposes. We will eventually be forced to agree, even if the common decision space is initially quite narrow, on the nature of the problems we are

trying to solve. Without adaptive management, as we have described it, the alternative is clearly visible. The default position of any public trust agency is to act according to its own interpretation of the mandate or charter given to the trustees. Without some kind of democratic checks on the interpretation of the agency's charter, agencies will tend to confuse their charter with the operational imperatives that keep them in business. Eventually the need to survive will merge with the public trust mandate, resulting in a circular mandate simply to survive.

We believe that adaptive management in the Sierra Nevada could break that endless loop and encourage a political environment adequate for the ecological environment. One might even posit that, if the Sierra Nevada's ecological health is worth fighting to save, perhaps its political ecology is equally worthy of struggle and sacrifice to ensure its health and integrity.

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A black and white photograph of a grassy hillside. The terrain is covered with low-lying vegetation, including grasses and small shrubs. Several large, smooth, rounded rocks are scattered across the slope. The lighting creates strong shadows, highlighting the textures of the plants and the shapes of the rocks. The overall scene is a natural, undisturbed landscape.

Poster Session Abstracts

Extreme Variability in Tree-Ring Chronologies from Different Physical Settings¹

Andrew G. Bunn,² Lindsey A. Waggoner,² and Lisa J. Graumlich²

Long chronologies of annually resolved past-climate proxies derived from tree rings are key to assessing the role of temperature and precipitation variability and trends on subalpine forests. Especially important contributors to the time-series data are tree-ring records from high-elevation, long-lived conifers in western North America. Although high-elevation trees are generally considered good recorders of past climate, little research has investigated the influence of kilometer-scale physical setting on the sensitivity of tree-ring chronologies. Using proxies for soil moisture and radiation derived from a digital elevation model, increment cores were systematically collected for 12 tree-ring chronologies in extreme biophysical settings from three sites in the Sierra Nevada Mountains of California. A multivariate analysis of the chronologies is presented, which illustrates the importance of considering the physical template, especially as it relates to soil moisture, as a patterning agent of this key paleoclimatic resource. Preliminary results indicate that soil moisture affects chronology sensitivity, pointing to the need to account for physical setting when sampling.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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The Sierra Nevada Global Change Research Program¹

Nathan L. Stephenson,² Jon E. Keeley,² Jan W. van Wagtendonk,³ Dean L. Urban,⁴ Thomas W. Swetnam,⁵ and Lisa J. Graumlich⁶

The Sierra Nevada Global Change Research Program began in 1991 as a component of the National Park Service's (now U.S. Geological Survey's) Global Change Research Program. The program's core study areas are Sequoia, Kings Canyon, and Yosemite National Parks. The goal is to understand and predict the effects of environmental changes on montane forests. To reach this end, the program consists of integrated studies organized around three themes: paleoecology, contemporary ecology, and modeling. The paleoecological theme takes advantage of the Sierra Nevada's rich endowment of tree-ring and palynological resources to develop an understanding of past climatic changes and the consequent responses of fire regimes and forests. The contemporary ecology theme takes advantage of the Sierra Nevada's substantive climatic gradients as "natural experiments," allowing researchers to evaluate climatic mechanisms controlling forest structure, composition, and dynamics. The modeling theme integrates findings from paleoecological and contemporary studies; it is a vehicle for scaling up the program's mechanistic findings to regional landscapes and predicting which parts of montane landscapes may be most sensitive to future environmental changes. To date, the program has produced several results both of broad interest to biologists and useful to land managers.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Climate Change and the Bay-Delta Watershed¹

Noah Knowles,² Dan Cayan,² and Mike Dettinger²

California's primary hydrologic system, the San Francisco estuary and its upstream watershed, is vulnerable to the regional hydrologic consequences of projected global climate change. Projected temperature anomalies from a global climate model are used to drive a combined model of watershed hydrology and estuarine dynamics. This poster presents computer animations representing these projections at several spatial scales over the coming century. By 2090, a projected temperature increase of 2.1 degrees Celsius results in a loss of about half of the average April snowpack storage, with greatest losses in the northern headwaters. Consequently, spring runoff is reduced by 5.6 km³, with associated increases in winter flood peaks. The smaller spring flows yield spring and summer salinity increases of up to 9 psu in the delta, with larger increases in wet years. This poster uses animations to provide a powerful means of communicating the broad scope of these hydrologic and estuarine impacts of climate change in California.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Climate Change as an Ecosystem Architect: Examples from High-Elevation Pine Forests¹

Constance Millar,² Diane Delany,² Robert Westfall,² and John King³

Advances in ecology and conservation during the 20th century motivated a shift from viewing nature as static and typological to dynamic and processual. Static concepts, however, still constrain our understanding of natural dynamism and limit our conservation successes. Recent advances in earth system sciences, which characterize recurrent climate change as a central physical force on earth, have not been well incorporated into evolutionary and ecological theory nor yet translated into regional conservation and management practice.

Preliminary results from several studies of pine ecosystems in the high Sierra Nevada and adjacent Great Basin ranges provide examples of forest response to historic climate change. In all studies, standard tree-ring and ecological plot analysis methods were used. Correlated growth response and meadow/snowfield invasions of whitebark pine and lodgepole pine during four multidecadal climate periods in the 20th century are documented as well as decadal cycles in limber pine growth related to dry and wet periods over the past two centuries. Century-scale growth variability of limber pine forests over the past 4,000 years correlates with major temperature and precipitation cycles as derived from independent climate indicators. Major demographic shifts of limber pine include cyclic extirpation and recolonization events that appear correlated to multidecadal climate phases. Such natural variability has not been figured into conservation baselines and planning.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Sagebrush Expansion in Meadows of the Kern Plateau, Southern Sierra Nevada¹

Heather Swartz,² Eric Berlow,³ and Carla D'Antonio⁴

Over the last century, significant vegetation change and stream incision have occurred in meadows of the Kern Plateau in the southern Sierra Nevada. Rothrock's sagebrush, *Artemisia rothrockii*, has expanded extensively into areas of wet meadow vegetation. Lowered water tables as a result of stream incision contribute to shrub expansion; however, sagebrush also invades unincised areas. This research project examines rates and spatial patterns of sagebrush expansion and factors correlated with local changes in sagebrush distribution.

Using Geographic Information Systems, repeat aerial photographs were rectified to identify changes in sagebrush distributions. The initial comparison of time points shows many new areas of sagebrush as well as isolated local recovery of wet meadow vegetation.

To characterize areas of sagebrush expansion, environmental and landscape variables were measured in sites with and without recent expansion. Preliminary results show that areas of new sagebrush are intermediate in soil moisture, relative elevation, and sagebrush density between intact herbaceous vegetation and older sagebrush. They occur on all geomorphic surfaces including floodplains, newly incised terraces, and older terraces. The authors are now using classification trees to identify combinations of variables that best predict conditions for sagebrush expansion. These classification trees can provide a management tool to reduce further sagebrush expansion.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Thermodynamics of Snowpack at Gin Flat, Yosemite National Park, during Winter and Spring 2002¹

Michael D. Dettinger² and Frank Gehrke³

The Gin Flat automated snow-telemetry site, at 7,050 feet in elevation in Yosemite National Park, has been augmented during the past 2 years to measure components of the water and radiation budgets of the snowpack, in addition to the precipitation, temperatures, and snow-water content measurements typical of such sites. New measurements at Gin Flat include snow thickness, incoming solar radiation, and net radiation to the snow surface. Together, these measurements characterize gross water and radiative heat budgets of the winter snowpack, as well as snow density. During 2002, temperatures within the (6-foot) snowpack were monitored at 1-foot vertical intervals as indicators of the time- and depth-varying thermodynamics of the snowpack. The measurements at Gin Flat, taken together, illustrate multiday downwelling of cold into the Sierra Nevada snowpack during two prolonged cold snaps; however, for the most part, the snowpack remained essentially at 0 °C throughout the winter and spring. Additional instrumentation, such as that operated at Gin Flat, is proving to be robust to the elements and provides new insights into the workings of Sierra Nevada snowpacks. Augmentations have now been included at several more sites, including Tuolumne Meadows and Dana Flat in Yosemite National Park.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Snow, Topography, and the Diurnal Cycle in Streamflow¹

Jessica Lundquist,² Michael Dettinger,³ Daniel Cayan,² and Noah Knowles²

Hourly measurements of river discharge provide a widely available, but as yet underutilized, source of information about snowmelt processes, providing direct information on basin output at a fine temporal scale. The timing of streamflow variation within each day reflects the daily timing of snowmelt maxima and minima, modulated by travel times through the snowpack, hillslopes, and stream channels to the gauging stations where they are measured. The daily timing of the diurnal cycle consequently reflects the seasonal evolution of travel times and, by extension, the evolution of snowpack and snow cover conditions within contributing watersheds.

Traditional theories, based on numerical models and localized, small-basin observations, report that the hour of day of maximum flow becomes earlier as the snowpack thins, reflecting shorter travel times for surface melt to reach the base of the snowpack. However, an examination of hourly discharge from 100 basins in the western United States, ranging in size from 1 square kilometer to 10,812 square kilometers, reveals a more complex situation. Depending on basin size and topography, diurnal timing often depends strongly on the discharge magnitude and on the snowmelt location.

In most of the basins examined, at the end of the melt season, the hour of maximum discharge shifts to later in the day, reflecting increased travel times as the snowline retreats to higher elevations. The rate of this retreat is more rapid in dry years than in wet years and may provide a measure of how basin snow cover and soil moisture respond to interannual climate variations.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Historic Variability of Vegetation in Glass Creek Meadow, Inyo National Forest, California, and Its Role in Resource Management Planning¹

Wallace Woolfenden²

The study of past variability of ecosystems is important for understanding ecosystem dynamics that occur at time scales greater than the time scale at which they are usually observed, for evaluating present ecosystem conditions and for planning for their sustainability. The history of Glass Creek Meadow vegetation was interpreted from a 3,000-year pollen sequence extracted from radiocarbon-dated sediment cores in order to examine the value of historic reference conditions in managing this type of ecosystem. In the top section of the sequence, an interval of low pollen concentration above a volcanic ash bed and mixed with volcanic tephra marks the effect of the Glass Creek eruption of about 600 years ago. An increase in willow pollen followed by an increase in aster and saltbush pollen is the major indicator of vegetation change during and after the eruption. A large spike of sedimentary charcoal and a decrease in fir and buttercup pollen between 100 and 225 years ago indicate a fire effect on the meadow and surrounding pine-fir forest. A decrease in willow pollen to low levels by 300 years ago to the present, along with fairly stable proportions of forb, grass, and sedge pollen, contradicts the assessment of the meadow as having been overgrazed.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Effects of Altered Summer Precipitation on Sierra Nevada Shrubs¹

Michael E. Loik²

Current global climate models predict a 25 to 50 percent increase in precipitation for California by 2095. The effects of spatial and temporal patterns of precipitation change on plants are uncertain. An increase in summer monsoon activity is considered likely for the eastern Sierra Nevada. Although increased precipitation could be beneficial for plants, not all species can equally utilize summer rain.

The author tested hypotheses regarding increased summer precipitation on photosynthesis for *Artemisia tridentata* and *Purshia tridentata*. Supplemental water was added over the range of 0 to 200 percent of average precipitation, over 1 to 14 days, and at three elevations; water relations, photosynthesis, and stress within PSII were measured. Photosynthesis as a function of added water increased more for *A. tridentata* than for *P. tridentata*. Both species responded maximally at 2 days following addition. Several small additions elicited more of a response than did one large addition. Photosynthesis was greater for plants at higher elevations. Future patterns of photosynthesis in response to increased summer rainfall will be species-specific and will depend on the timing, magnitude, and spatial scale of actual precipitation changes. Results of this study will contribute to the development of restoration plans for recovery of damaged habitats.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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High Temperature Tolerance for *Purshia tridentata* Exposed to Increased Summer Precipitation Across an Elevation Gradient¹

Gitane L. Royce² and Michael E. Loik³

Current global climate models predict increased precipitation for California by the year 2050. This research focused on the impacts of climate change on the arid shrub *Purshia tridentata* (Rosaceae). Three sites spanning a total of 1,400 meters in elevation were chosen. The authors tested the hypotheses that (1) *P. tridentata* at low elevation is better able to survive high temperatures than it is at high elevation and (2) increased precipitation will enhance its tolerance of high temperatures. *In situ* watering manipulations were used to determine the potential impact of increased precipitation on *P. tridentata*. Thermal stress was assessed by measuring damage to cell and chloroplast membranes, as well as the ability to uptake CO₂. At 45 °C, CO₂ flux was -0.104 mol m⁻² s⁻¹ for plants at 1,725 meters and -3.056 mol m⁻² s⁻¹ for plants at 3,070 meters. FV/FM was enhanced by 5.5 percent for 1,725 meters, 10.3 percent for 2,600 meters, and 24.8 percent for 3,070 meters when compared with untreated plants at 45 °C (P < 0.0409). Based on electrolyte leakage, the LT50 was 56 °C at 1,725 meters, 54 °C at 2,600 meters, and 49 °C at 3,070 meters. These results indicate that plants at lower-elevation sites are better able to withstand extreme high temperatures and that enhanced tolerance to high temperatures due to increased precipitation will be most prominent for upper elevations.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Climate, Snow, Water, and Chemistry Observations in Yosemite National Park: A Monitoring Network for Environmental Change¹

Daniel Cayan,² Jessica Lundquist,² Mike Dettinger,³ Dave Clow,⁴ Frank Gehrke,⁵ Steve Hager,⁶ David Peterson,⁶ Richard Smith,⁶ and Mark Butler⁷

Yosemite National Park sits astride the high Sierra Nevada and encompasses the watersheds of two important rivers, the Merced and Tuolumne. Its pristine conditions, together with the access that park roads and trails provide to the high country, make it a unique setting for scientific studies of the Sierra Nevada Range. During the 2001 Yosemite National Park research-planning workshop, the park was identified as having a special role in the earth sciences as a locus for trans-Sierra Nevada studies and studies about how natural systems respond to global and regional climate change. Park environs also have the potential to be a barometer for hydrologic variations at spatial scales spanning the Sierra Nevada to the whole of western North America and at time scales ranging from hours to decades.

The presence of meteorological stations and streamflow gauging stations established almost a century ago in the Merced River basin have provided much of the incentive for studies that have demonstrated the remarkable potential of the park for earth science investigations. However, these relatively few observation sites now need to be augmented with more monitoring sites and additional parameters in both the Merced and Tuolumne River basins. To fulfill this need, meteorological, snowpack, and hydrologic conditions within the park are being monitored in more detail and greater consistency than in the past or elsewhere (at this scale) in the range.

The ability to interpret and predict streamflow, snowpack, flood, geochemical, and related ecological processes in Yosemite National Park has grown as a result of recent scientific research within its boundaries. With this increased ability comes the increased need for data, and particularly for real-time data, if this growing understanding is to be adequately translated into useful information for use by the Park, region, and Nation. Reaching the required level of monitoring is likely to be an incremental process as support, methods, and a track history of monitoring successes are developed that will justify the ultimate goals.

The initial components that will form the core of this monitoring effort include data on meteorology, hydrology, snow dynamics, and stream chemistry. In the near term, better communications are needed to harvest these data in real time. Presently they are transmitted via scheduled bursts of GOES telemetry or during infrequent manual downloads from memory contained in self-recording instruments. Ultimately, the aim is to embed many of these instruments into a near-continuous real-time network that will be ported to the Internet. Whereas the initial suite of physically based observations are those being implemented immediately or in the near future, the envisioned communications and other infrastructure will be designed to accommodate other physical or biological sensors and their data streams.

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Climate and Wildfire in California and the Western United States¹

Anthony Westerling,² Alexander Gershunov,² Daniel Cayan,² Michael Dettinger,² Tim Barnett,² and Thomas Swetnam³

It is well known that climate influences are pervasive in wildfire regimes in the western United States. In this research, wildfire histories and reconstructions for a variety of temporal and spatial scales are used to describe climate-wildfire relationships on annual to decadal time scales for California and the western United States. A 21-year gridded 1 x 1 degree monthly fire history compiled from Federal agency fire reports recreates the seasonality and interannual variability of wildfire in the western United States. A 75-year record of area burned aggregated by state for years 1916 through 1990 and regional fire scar indices for years 1700 to 1900 indicates strong links between variability in climate and wildfire regimes on decadal scales. Correlations between anomalous wildfire frequency and extent and the Palmer Drought Severity Index (PDSI) illustrate the importance of prior and accumulated precipitation anomalies for future wildfire season severity. Links to moisture conditions from the current and antecedent seasons' moisture conditions vary widely with differences in predominant fuel type, and can be exploited to estimate statistical models of seasonal wildfire area burned. The authors present statistical models reconstructing 18th- and 19th-century wildfire area burned using PDSI reconstructed from tree rings, which correlate strongly with regional fire scar indices for the same period, and a statistical forecast model for predicting area burned by ecosystem province in the western United States a season in advance.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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The Southern Sierra Repeat Photography Project: Vegetation Changes over the Past 125 Years¹

Monica M. Bueno,² Nathan Stephenson,² Jon E. Keeley,² and Anne Pfaff²

In this project, repeat photography was used to reconstruct historical changes in southern Sierra Nevada plant communities over the past 125 years. The study area encompassed foothill and forest plant communities from the Stanislaus River south to the Kern River. The primary focus was a comparison of vegetation changes in ponderosa pine forests and oak-chaparral communities of Kings Canyon with those already documented for Yosemite Valley. These two valleys share similar geologic and human histories, although Yosemite Valley has undergone extreme changes in drainage not experienced by Kings Canyon. In addition to qualitatively describing each of the photo pairs, some pairs were quantitatively analyzed using a simple, dot-grid-overlay counting method. The authors conclude that density and cover increases in the plant communities seen in Kings Canyon are not as dramatic as those documented for Yosemite Valley, raising questions about the roles of fire suppression versus hydrology in affecting vegetation changes in the latter.

Other, less detailed areas of inquiry included a look at changes in foothill chaparral communities and the chaparral-conifer ecotone and an examination of early vegetation conditions and subsequent change in giant sequoia groves. Landscape-level vegetation changes were evident in many of the photo comparisons.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Measuring the Effectiveness of Fuel Treatments in Changing Fire Behavior and Fire Effects during Wildfires¹

Jo Ann Fites-Kaufman,² Dave Sapsis,³ Sue Husari,⁴ Larry Hood,⁵ Berni Bahro,⁶ Christie Neill,⁶ Danny C. Lee,⁷ and Bret Butler⁸

Direct observation and measurement of fire behavior as it passes through fuel treatment areas are the most direct ways to evaluate the effectiveness of fuel treatments. Concordant measurement of fuel conditions before the fire and fire behavior during the fire provide a means of evaluating which fuel metrics best relate to wildland fire behavior and improve fire behavior predictions. A rapid response team has been established to measure pre- and post-fire fuel conditions and fire behavior during wildland fire in areas with various fuel treatments and other past land management activities. During the fire season of 2002, the team is prototyping techniques for such research. For each fire event, the team: (1) rapidly obtains vegetation management history information; (2) obtains pre-fire aerial photographs; (3) collects data on pre-fire fuels condition; (4) measures fire behavior through sites where fuels have been measured; and (5) measures select immediate-post-fire effects and indirect measures of fire behavior. All information on weather, fire behavior, topography, fuels, fire suppression actions, and other pertinent information is captured and recorded, providing an overall context for the pattern of the fire. Preliminary results from one to three fires in 2002 will be available.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Ecological Impacts of Season of Prescribed Fire in a Sierra Nevadan Mixed Conifer Forest¹

Eric E. Knapp,² Jon E. Keeley,² and Nathan L. Stephenson²

Prescribed fire is an important tool for reducing fuels and restoring structure and function to forested ecosystems of the Sierra Nevada. Only a fraction of the acreage necessary for maintaining a natural fire return interval typically gets burned each year because of air-quality concerns in adjacent populated areas and the limited time before winter snows. Most prescribed burning is currently conducted in the fall to coincide with the normal historical fire period. This is also the time of year with the poorest air quality. Expanding the prescribed fire window to include early-season burns might reduce air-quality conflicts and allow more acres to be treated. However, the impact of early-season burning on many important ecosystem components is poorly understood.

Nine 15-hectare plots were established in Sequoia National Park in 2001. Three plots were burned in fall 2001, three plots were burned in June 2002, and three remained unburned (controls). Data on fuels, overstory tree density and composition, understory vegetation, small mammal and bird populations, bark beetles, root pathogens, and soil nutrient cycling were collected by researchers from the U.S. Geological Survey and other collaborators before the prescribed burns and are being collected post-burn. Initial data indicate a great deal of heterogeneity in fire intensity and subsequent tree mortality within both the early-season and late-season burn units. Multiple regression analysis showed that the proportion of the tree basal area composed of pines, together with the total basal area of all trees, explained 26 percent of the variation in crown scorch height in late-season burn plots. Areas with a high abundance of pines and more trees burned with the greatest intensity, whereas areas dominated by fir trees and having fewer trees burned with lower intensity. Data on tree mortality, fire damage, and area burned are presently being collected in the early-season burn plots. These data and comparisons between the early-and late-season burn treatments will be reported. Preliminary data indicate that early-season burns resulted in less fuel reduction and left more of the area unburned. These islands of unburned habitat may be important for post-fire recolonization by some plant and animal species.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Preliminary Results from Hazardous Fuel Reduction at Yosemite National Park¹

Kara J. Paintner² and Monica Buhler²

Monitoring of mechanical fuel reduction paired with prescribed fires began at Yosemite National Park in 1996. Resource objectives include targets for total fuel loads and tree density. Ten plots have been installed using the National Park Service's Fire Monitoring Handbook. Each two-phase treatment starts with mechanical removal and piling of all ponderosa pine, incense cedar, and white fir smaller than 6 inches diameter at breast height (dbh) and burning of the piles. The treated area is then burned within 2 years. Seven plots have been thinned and had piles burned, and two plots have been burned. One- and ten-hour fuels increased after thinning and pile burning. Although the total fuel load was reduced, it remained well above target levels. The two burned plots showed significant fuel load reduction. Changes in fire behavior and tree mortality were modeled at the high end of burn prescription before and after thinning using crown mass. Before thinning, a stand could have surface and active crown fire, whereas after thinning, fire behavior changed to surface fire alone. Canopy base heights increased with thinning, whereas scorch height and mortality of larger trees decreased. This information is helping to refine project prescriptions, targets, and field evaluations for future work.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Spatial Considerations in Fire Management: Importance of Heterogeneity for Maintaining Diversity in a Mixed Conifer Forest¹

Monique E. Rocca,² Dean L. Urban,³ and Jon E. Keeley⁴

This study examines factors controlling fine-scale distributions of herbs, shrubs, and tree seedlings in Sierra Nevada mixed conifer forests. The goals of this project are to (1) determine the importance of within-fire heterogeneity in fire effects to maintaining plant diversity and (2) compare alternative fire-restoration strategies (spring prescribed fire, fall prescribed fire, and prescribed natural fire) in terms of their ability to create a heterogeneous environment that allows diverse suites of species to coexist. High resolution (1 meter) botanical and environmental data have been collected along 256-meter transects in the fire/fire surrogates plots and recent prescribed natural fires at Sequoia National Park. This study introduces a novel spatial statistical approach, wavelet analysis, to identify relationships between species and their environment while accounting for the fact that different environmental variables exert their influence on plants at different spatial scales. Preliminary results show that, in the absence of fire, understory species distributions are controlled by local variability in topography and soil moisture at scales greater than 64 meters. The authors are testing whether variability in fire effects leads to finer scale patterning of species distributions after fire. Once identified, the types and scales of fire-generated environmental variability that matter to plants can be incorporated into fire restoration plans.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Response to Management Strategies in Young-Growth Giant Sequoia Stands at Mountain Home State Forest¹

Gary Roller ² and Douglas D. Piirto³

Young-growth giant sequoia stands at Mountain Home State Forest were remeasured in 2001 to evaluate growth response to three silvicultural treatments: thinning, thinning followed by an underburn, and control. This is the third measurement in a continuing study that began in 1989. The California Department of Forestry and Fire Protection is providing funding for this Cal Poly study.

The current study is specifically evaluating (1) overall growth performance of treated giant sequoia stands, (2) understory plant response to the silvicultural treatments, and (3) fuel accumulations over the 12 years since the study stands were treated. All plots were precisely mapped using GPS technology, and photographs were taken from identified photo points during this third remeasurement effort.

Preliminary findings of this current Cal Poly study are available. This study is unique because very little research has been done to comparatively track the overstory and understory growth response of giant sequoia and associated flora following mechanical treatment and prescribed burning. The data and conclusions drawn from this study will be invaluable given the high level of interest in managing giant sequoia stands.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Thermally Driven Wind Systems and Boundary Layer Structure in Yosemite National Park¹

Craig B. Clements²

Thermally driven wind systems are a common phenomenon in mountainous regions and are important in the transport of pollutants within the mountain boundary layer. Because population increases are expected in California's Central Valley, there is a need for a better understanding of the boundary layer structure in the Sierra Nevada. This will have important practical implications and provide improved forecasting of air pollution episodes that may lead to adverse health and visibility degradation in the region's national parks.

Observations of the wind and temperature structure made in two major valleys of Yosemite National Park are presented. Measurements were made during multiple campaigns from 1994 to 1998 using standard meteorological towers, an atmospheric profiling system, and pilot balloons. Results have shown that the atmospheric structure in the Yosemite region is complex and is rarely decoupled from the prevailing synoptic-scale flows. Vertical profiles of temperature in Yosemite Valley showed a strong and shallow inversion developing in the lowest 40 meters by morning. Above this layer, the valley atmosphere was nearly isothermal up to approximately ~700 m. above ground level. Winds within the inversion were extremely weak, but down-valley flows (approximately ~4-6 m s⁻¹) persisted through the entire valley depth, suggesting that pollutants are easily transported from outside the region into the valley.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Fire and Invasive Plants in the Mixed Coniferous Forest¹

Jon E. Keeley ²

In the coniferous forests of Sequoia and Kings Canyon National Parks, species diversity is a function of fire severity and time period since fire. High-intensity fires create gaps that decrease canopy cover and increase light levels and nutrients for an ephemeral successional flora. Few species have persistent seed banks, so the time period since fire is an important determinant of colonization success. Complicating the picture of post-fire response is a highly significant interaction between fire severity and time period since fire for understory cover, species richness, and alien plant species richness and cover. Time was consistently a significant factor for these parameters, whereas fire severity was a significant factor only for species richness parameters. In general, understory was sparse the first year after fire, particularly in low-severity burns, and increased substantially several years after fire, particularly on high-severity burns. Both fire severity and time period since fire affected alien species richness and dominance. Coniferous forests had approximately one-third as many alien species as foothill oak savannas, and fewer than half of the species were shared between these communities. Some sites were largely free of alien species, whereas others had a significant alien presence that would present a challenge for fire restoration of these forests.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Impacts of Fuel Breaks on Alien Plant Invasion into Wildlands¹

Jon E. Keeley ² and Kyle Merriam²

This project addresses impacts of fuel breaks or defensible fuel-reduction zones on invasion by alien plant species into wildland areas that represent diverse fuel types, including shrublands, woodlands, and conifer forests. The authors are investigating this potential impact on Federal (Bureau of Land Management, National Park Service, and Forest Service), State (California Department of Forestry and Fire Protection), and local jurisdictions throughout California with multi-agency cooperation and support. The project has three objectives: (1) to inventory current floristic composition of fuel breaks in southern California, the central coast, the north coast, and Sierra Nevada and relate patterns of alien plant distribution to fuel break parameters, including construction age, past maintenance, vegetation modification treatment, proximity to roads, and other environmental variables; (2) to sample intensively belt transects perpendicular from fuel breaks into surrounding vegetation to determine the extent to which fuel breaks may act as source populations for the invasion of wildland areas (this sampling focuses on areas that have experienced fires within the past decade, because this is the time ecosystems are most vulnerable to invasion), and (3) to educate resource managers about the potential problems of invasive plants, both in terms of how they displace native vegetation and alter fire regimes and how fuel manipulations may be planned to minimize these impacts on natural landscapes.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Avian Response to Prescribed Burning in the Spring¹

Karen Bagne,² John Rotenberry,³ and Kathryn Purcell⁴

Fire is an important abiotic component in maintaining a diverse landscape in many regions including the Sierra Nevada. Exclusion of fire during the last century has altered natural systems, but in the past two decades, fire has been reintroduced through prescribed burning. Although prescribed fire returns an important natural process to the landscape, fire under human control can have features that are not consistent with fire regimes of the past. In particular, prescribed fires are often initiated during moist periods, such as spring, when many bird species are actively breeding. Preliminary findings from two years of data collected over 2 years in the Sierra National Forest are presented. Fires were set in early April and burned patchily on three of nine study sites. Territories of Hutton's Vireo were mapped and their breeding attempts monitored. Other target bird species were monitored as well. Tentative findings suggest that response to burning is similar to that during inclement weather events that can occur in the spring, and unburned patches within treated areas support habitat features required by specific species that could be otherwise be negatively affected. Other habitat features, such as snags, were monitored for changes in distribution and abundance resulting from prescribed fire as well as for use by cavity-nesting species.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Improving Fire Hazard Assessment at the Urban Wildland Interface: Case Study in South Lake Tahoe, California¹

Lisa de Jong ²

A fire hazard assessment was conducted on private, developed lots in South Lake Tahoe, a high-fire-hazard urban-wildland interface community in northern California. Fire hazard was assessed in terms of the minimum standards in the National Fire Protection Association's (NFPA) Standard 299 and homeowner choices relative to compliance with fire safety laws, construction of the home, and irrigation practices. In addition, researchers assessed the influence of noncompliant neighbors on a parcel's fire hazard. Results indicate that the overall fire hazard rating for the city is relatively low because of its good infrastructure: good roads, water, signage, and level of service. However, the citywide noncompliance rate for maintenance is 66 percent, the citywide noncompliance rate for defensible space is 86 percent when adjusted for small parcel size, and 57 percent of the parcels are noncompliant for both defensible space and maintenance. This study strongly suggests that homeowners in South Lake Tahoe rarely choose fire safety even though the city's fire infrastructure is effective. Furthermore, individual fire hazard will be underestimated if small lot size and homeowner actions are not taken into account. Analysis of compliance rates and homeowner choices will provide a more accurate estimate of individual lot fire hazard.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Landscape Patterns of Pre-20th-Century Fire in the Kaweah Watershed, Sequoia and Kings Canyon National Parks¹

Anthony C. Caprio²

Knowledge of the spatial and temporal attributes of fire that occurred before Euro-American settlement (1700 to 1900), including fire size, is important for understanding ecosystem processes and for developing ecologically sound fire management objectives. Over the past decade, dendrochronology has been used to reconstruct fire histories for a network of sites in the Kaweah watershed on the west slope of the Sierra Nevada. This information provides a better understanding of fire across large spatial scales before Euro-American settlement within a complex landscape.

Sites extend from low-elevation conifer patches embedded in chaparral vegetation to high-elevation subalpine conifer forests. Striking differences in the fire regime between north and south aspects have been found, particularly at low- to mid-elevation conifer sites. Fire frequency on north aspects was less than half that observed on south aspects, with occurrence strongly linked to climate on north aspects. Reconstructions of fire size also show considerable variability. Some burns extended over much of the drainage and into adjacent watersheds. Fire size was also related to climatic variability, with large fires, particularly on north aspects, occurring more often during dry years. Such differences must have had significant influence on the biotic components and past dynamics of Sierra Nevada landscapes. This baseline information is being used in assessing the role of fire as an ecosystem process.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Restoring Mixed Conifer Forests with Prescribed Fire: Monitoring to Assess Fuel Reduction and Stand Structure Objectives¹

Mary Beth Keifer,² Jeff Manley,² and Karen Webster²

Similar to wildlands throughout the Sierra Nevada, Sequoia and Kings Canyon National Parks experienced a disruption of the fire regime over the last century that altered forest conditions. Heavy surface fuels accumulated, stand density increased, and species composition shifted as a result of fire exclusion in forests where frequent fires had historically burned. Over the last 35 years, park managers and scientists have attempted to restore fuel and forest conditions using prescribed fire. A long-term fire effects monitoring program has documented changes in fuel load, stand structure and composition, and shrub and herbaceous vegetation composition before and after following prescribed fire treatment. Fuel-reduction objectives for initial prescribed fire treatment are met in all mixed conifer forest types. In the giant sequoia-mixed conifer forest, stand-structure-restoration objectives are met within 5 years after initial treatment; however, other mixed conifer forest types may need a second treatment with prescribed fire before restoration objectives are achieved. Once structural restoration objectives are met, process-related objectives for maintaining the natural fire regime become the standard for determining the success of the long-term prescribed fire program success.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Forest Litter Densities under Different Dominant Tree Species: A Factor Affecting Ground Fire Spread¹

Kurt M. Menning,² John J. Battles,² Tracy L. Benning,³ and Nathan L. Stephenson⁴

Long-lived conifer and several hardwood species dominate the mixed conifer forest in the southern Sierra Nevada. Historically, this forest experienced frequent, low-severity fires. The link between canopy species variability and fire behavior in a mixed forest is not well understood, however. Forest litter was sampled across 10,000 hectares in the Mineral King watershed to determine how dominant species affect litter density and fire behavior. Samples were sorted by canopy dominance. Litter under red fir (*Abies magnifica*) was the densest at 95 kilograms per cubic meter (kg/m³), followed by pine (*Pinus ponderosa*, *P. jeffreyi*, *P. monticola*, *P. contorta*: 76 kg/m³), white fir (*A. concolor*: 72 kg/m³), and the least dense, sequoia and cedar (*Sequoiadendron giganteum* and *Calocedrus decurrens*: 67 kg/m³). Density differences observed between red fir and both white fir and sequoia/cedar are significant. Fire spread rates and intensity have been calculated for the different litter densities given standard conditions. For example, white fir fire-spread rates (0.23 m/min) are more than double that of red fir (0.09 m/min). Intensity in white fir litter (38 J/m²min) is more than seven times that in red fir (5.3 J/m²min). Dominant canopy species appear to dramatically affect fire behavior in the mixed conifer forest.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Fire History of the Chaparral Zone in the Southern Sierra Nevada¹

Jon E. Keeley,² Anne Pfaff,² and Pat Lineback³

Chaparral dominates a significant portion of the southern Sierra Nevada foothills, yet relatively little attention has been given to historical patterns of burning in these shrublands. Burning patterns for the 20th century were evaluated using a fire history database for the national parks; national forests; and lands administered by the Bureau of Land Management, California Department of Forestry and Fire Protection, and other jurisdictions in the foothills. Roughly half of the chaparral area has not recorded a fire during this time period, whereas some areas have experienced repeated fires. Spatial and temporal patterns of burning are presented. From these and other studies, there is reason to believe that, unlike southern California chaparral, these ecosystems may be at risk from fire exclusion.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Soil Moisture and Tree Seedling Distributions in a Mature Mixed Conifer Forest¹

Andrew Gray,² Harold Zald,³ and Malcolm North⁴

Distribution and abundance of tree seedlings and soil moisture in relation to stand structure were examined in an old-growth, Sierra Nevada mixed conifer forest. These measurements served as pre-treatment measurements for the forest-restoration experiment at the Teakettle Experimental Forest. Tree seedlings of the following species were found in declining order of abundance: white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), black oak (*Quercus kelloggii*), bitter cherry (*Prunus emarginata*), red fir (*Abies magnifica*), sugar pine (*Pinus lambertiana*), and Jeffrey pine (*Pinus jeffreyi*). Most species declined in abundance from closed-canopy areas to open areas to whitethorn ceanothus (*Ceanothus cordulatus*)-dominated areas. The exceptions were bitter cherry, which was most abundant in ceanothus patches, Jeffrey pine, which was most abundant in open areas, and black oak, which was most abundant in bedrock-dominated areas. For most tree species, areas with seedlings tended to have greater soil moisture than did areas without seedlings. Soil moisture declined steadily in the top 45 cm of soil during the growing season. Volumetric moisture values soon after snowmelt (mid-May) averaged 18 percent (ranging from 12 to 33 percent), and declined to 14 percent (ranging from 6 to 47 percent) by early July and 10 percent (ranging from 5 to 28 percent) by October. The high variability in soil moisture was associated with differences in topography and soil depth, and will likely be an important factor in determining the location and speed of vegetation response to disturbance.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Soil Nutrient Pools and Fluxes within a Mixed Conifer Forest: Implications for Ecological Restoration¹

Heather E. Erickson,² Dale Johnson,³ Patricia Soto,⁴ and Carolyn Hunsaker⁵

Forest burning and thinning have obvious aboveground effects, yet effects on soil nutrient pools and fluxes are less apparent. As part of a large-scale forest-restoration experiment, baseline differences in soil resources were assessed for three dominant patch types (closed canopy, open canopy, and *Ceanothus*) within a mixed conifer forest. Organic and surface mineral horizon soils (0-15 cm) were collected from 54 patches (18 each for closed canopy, open canopy, and *Ceanothus*) and used to determine inorganic nitrogen (N), net N mineralization using laboratory incubations, and total pools of carbon (C) and N. *In-situ* fluxes of inorganic N and ortho-phosphorus (P) were also measured using resin lysimeters. For more than 2 years, *Ceanothus* showed greater nitrate-N and net N mineralization in organic horizons and ammonium-N and net N mineralization in mineral horizons than the other patch types. In contrast, the N and P fluxes measured by resin lysimeters did not differ significantly among the patches. In organic horizons, N pools were equally high in closed canopy and *Ceanothus* patch types, whereas C pools were greater under closed canopy. In mineral soils, N and C pools were greater under *Ceanothus* and open canopy than under closed canopy. Thus, restoration activities will likely affect the patch types uniquely.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Edge Effects in Mixed-Conifer Group Selection Openings: Tree Height Response to Resource Gradients¹

Robert York,² John Battles,³ and Robert Heald⁴

The group selection method of regenerating forests has been proposed as an alternative to clearcutting that potentially maintains economic viability while preserving ecosystem integrity. However, questions remain about the appropriate size of group-selection openings and the subsequent effects of edges on tree performance. In addition, there are questions about what resources may limit seedling growth within edge zones. To address these uncertainties in Sierra Nevadan mixed conifer forests, replicated circular openings, ranging from 0.1 to 1 hectares (ha), were cleared in 1996 at the Blodgett Forest Research Station and planted with seedlings of six native tree species. After 3 years of growth, heights of all trees were measured and analyzed according to species, opening size, and location within the opening. To assess edge influences on tree height, differences in extension growth, predawn water potential, and light availability were measured along north-south transects for three species: giant sequoia (*Sequoiadendron giganteum*), ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*).

The sequence of mean height from tallest to shortest on the basis of species was giant sequoia, incense cedar, Douglas-fir, ponderosa pine, white fir, and sugar pine. For all species combined, a tenfold increase in the area of the opening corresponded to a 34 percent increase in mean height. Trees were tallest on average in the north rows and shortest in the south rows. There was no difference in height between trees in the east and west rows. As expected, resource availability was greatest near the center and least near the edges, with northern edges receiving significantly more light than southern edges. In general, observed edge effects on sapling height growth were correlated with light and water supply. However, there were important differences between species in the nature of the co-limitation. Giant sequoia growth was most sensitive to light and water availability; together these variables explained more than 47 percent of the observed variation in giant sequoia height. In contrast, only light was a significant predictor of ponderosa pine performance. Douglas-fir heights were significantly related to both light and water, but there was more unexplained variability in the Douglas-fir model than in the other species. These highly controlled experimental group openings provide a standard reference for silviculturalists using the group-selection method of regeneration.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Mapping Sierra Nevada Vegetation Structure with Radar, Lidar, and Multispectral Fusion of Remote Sensors¹

Jo Ann Fites-Kaufman,² Carolyn Hunsaker,³ Peter Hyde,⁴ Ralph Dubaya,⁴ Leland Pierce,⁵ Wayne Walker,⁵ Birgit Peterson,⁴ Bryan Blair,⁴ Holly Hyde,² and Michelle Hofton⁴

At the present time, different subregions of the Sierra Nevada are mapped during different years and with different methods, contributing to inconsistent assessments of wildlife habitat, old-growth forest conditions, and fuel mapping and fire behavior analysis. The objective of this project is to develop a reliable, cost-effective process to evaluate and monitor wildlife habitat, old-growth forests, fuels, and potential fire behavior. Structural attributes evaluated have been large tree density (for old growth); tree height, crown base height, and crown bulk density (for crown fuels); and canopy cover and layering (for wildlife habitat). Remote sensors include radar, lidar, and Landsat™. Lidar and radar have been successful in mapping biomass, tree heights, canopy cover, large tree density, and canopy layering in other parts of the country but have not been tested in the diverse forests of the Sierra Nevada. Results to date show that lidar can map canopy heights well in the Sierra Nevada ($R^2 = 0.75$, SE 8.2 m), with increasing accuracy away from plot edges ($R^2 = 0.93$, SE 4.8 m). Canopy cover was estimated within 8 percent of measured values ($R^2 = 0.81$). Biomass was also estimated successfully, with a RMSD of 251 Mg/ha ($R^2 = 0.83$). Work with radar and fusion is under way.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Throughfall Deposition of Nitrogen in the Sierra Nevada as Determined by Ion Exchange Resin Columns¹

Mark Fenn²

Nitrogen (N) deposition rates are high in some areas of California as a result of emissions from motor vehicles and agricultural activities. Total N deposition inputs are not known for most Sierra Nevada sites, largely because of the costs and technical difficulties of measuring the array of physical and chemical forms of nitrogenous pollutants. Recent studies demonstrate that monitoring throughfall N deposition using “passive” throughfall collectors is a viable method for estimating N deposition inputs at a large number of sites and is more practical than other techniques. This method uses ion-exchange resin columns that absorb inorganic N ions from throughfall or bulk deposition solutions. Throughfall deposition has been measured with passive collectors at 11 sites along a north-south transect in the Sierra Nevada. The importance of NH_x emissions from agriculture in the Central Valley is evident from these data. The usefulness of this modified throughfall collection method is being evaluated, and the potential ecological impacts of N deposition will be discussed. It is proposed that ion exchange throughfall collectors can be used to determine N deposition thresholds at which key ecological effects, including water quality impacts, may occur in the Sierra Nevada.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Hydrologic Characterization and Implications of Forest Soil Disturbance at a Plot Scale: A Case Study in the California Sierra Nevada Mixed Conifer Zone¹

Lucas W. Paz²

Physical and chemical environmental parameters were monitored in efforts to describe soil hydrology and plant characteristics on an artificially disturbed forest soil in the western Sierra Nevada Mountains. Disturbance treatment plots in the USDA Forest Service's Long Term Soil Productivity (LTSP) Research Program were assessed to characterize the impacts of forest removal, soil compaction, and removal of organic residue on soil moisture characteristics and related physiological processes related to soil water uptake and site hydrology. The primary investigation (1997–1999) assessed a broad range of soil parameters to determine the relative influence of organic residue and soil compaction on soil permeability and moisture capacity. *In-situ* volumetric soil moisture content was monitored throughout the 1998 growing season, and soil moisture characteristics were developed in the laboratory from data on soil water retention.

The results demonstrate how soil disturbance, typified by compaction and organic matter removal, can decisively alter the seasonal soil moisture regime and plant-available water. Significant changes in soil porosity and depth of organic residue were found to directly affect infiltration potential, soil water content, soil water potential and availability, soil temperature, soil aeration, and leaf water potential. A soil moisture balance for five soil disturbance treatments— (1) control/reference, (2) stem removal only, (3) whole tree and forest floor removal, (4) stem removal and soil compaction, and (5) whole tree removal, forest floor removal and soil compaction— was modeled using available soil moisture parameters established during the 1998 sampling period. Soil disturbance typified by a loss in porosity reduced soil moisture available to plants late in the growing season and resulted in reduced potential for translocation of moisture to deeper subsurface zones.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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California Land Cover Mapping and Monitoring: Creating and Maintaining Systematic and Accurate Land Cover Maps¹

Chris S. Fischer,² Mark Rosenberg,² Lisa M. Levien,³ and Brian D. Schwind³

An accurate depiction of the spatial distribution of habitat types within California is required for a variety of land management planning purposes. The relative extent of vegetation or habitat types in different ownerships, watersheds, and counties has major implications for policies and strategies that can be ownership specific. To conduct the "Forest and Range 2002 Assessment," vegetation extent, composition, and structure information from numerous sources were combined into a format compatible for use within a Geographic Information System (GIS), which allows statistical analysis as well as numerous spatial modeling efforts to address timber, range, fire, development impacts, and wildlife habitat issues.

The California Land Cover Mapping and Monitoring Program (LCMMP), a cooperative program between the USDA Forest Service and the California Department of Forestry and Fire Protection, creates seamless data from Landsat Thematic Mapper™ satellite imagery. Vegetation data establish existing conditions from which impacts of changes over time are assessed. Data are captured using automated, systematic procedures that can efficiently and consistently map large areas at low cost. Regionally, monitoring can identify patterns and critical causes of change. Locally, monitoring can assess county land-use policies, identify areas of insects or disease problems, or assess the extent and impact of timber harvest in a watershed.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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The Response of Cheatgrass (*Bromus tectorum* L.) and Native Flora to Ecological Manipulations in the Yellow Pine–Mixed Conifer Forest¹

Thomas W. McGinnis,² Jon E. Keeley,² Matt Brooks,³ Robert Sanford,⁴ and Jayne Belnap⁵

The earliest settlers brought weeds with them to the West; one of the most persistent weeds to arrive on western rangelands is cheatgrass. Burned areas are quickly colonized by cheatgrass as isolated satellite populations, which then spread their seeds into these newly disturbed lands. Although areas west of the Sierra Nevada have long been converted to non-native annual grasses, such as *Bromus* and *Avena*, cheatgrass commonly invades east of these mountains in the Great Basin; the forests in between were once thought to be immune to annual grass invasions. Although cheatgrass has been known to exist along roads and trails in the Sierra Nevada for some time, widespread invasions in the yellow pine forest were unknown. Today, large expanses of these forests are becoming carpeted by cheatgrass. One such area of widespread invasion is the Cedar Grove area of Kings Canyon National Park, where this study takes place.

Because the disturbance factors that trigger cheatgrass invasions in these forests are unknown, measures to prevent its invasion are also unknown. In 408 randomly assigned five-by-five-meter test plots (six replicate sites), researchers are intensifying several disturbance factors to determine how each affects cheatgrass and native plant cover. Plots either remain unburned or are burned in one of three burning seasons. Before and after each burning season, soils are tested to see how temperatures affect soil nutrients. Temperatures are monitored above- and below-ground using six thermocouples per plot. Plots are assigned one of the following manipulations: no addition, pine litter addition, 50 percent shade, added or reduced nitrogen, added or reduced phosphorus, cheatgrass seed addition, or native seed addition. Although no manipulation following the low-intensity burns in fall 2001 resulted in the elimination of cheatgrass, it is expected (after observing the unmanipulated forest surrounding these plots) that the addition of five centimeters of pine needles, a treatment added in 2002, will eradicate cheatgrass. Other plant cover changes will be assessed relative to each disturbance factor.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Reconstruction of Historical Vegetation Distributions in the Sierra Nevada Using Government Land Office Survey Records¹

Holly Hyde,² Jo Ann Fites-Kaufman,² Michael Barbour,³ and Dave Weixelman²

Most reconstructions of historical vegetation in the Sierra Nevada have focused at the site scale. The objective of this study was to reconstruct patterns of tree species composition at the landscape scale. Historical relationships of composition with environmental gradients were of specific interest. This study utilized government General Land Office (GLO) survey records, which represent a systematic grid of points at section corners, collected in the late 1800s. At each section corner, data were recorded in a manner that resembles the point-center-quarter procedure. GLO data were examined across three elevational gradients in the central and southern Sierra Nevada, encompassing modern foothill, ponderosa pine, mixed conifer, and red fir forests. A community classification (TWINSPAN-based) resulted in 15 community types. Based on canonical correspondence analysis, elevation was the primary environmental influence (80 percent of variance), followed by topographic position and aspect. At elevations below 1,000 meters, oak was dominant (78 percent frequency), but pine comprised 24 percent of the basal area. Pine species represented 60 percent and 49 percent of the total basal area in low elevation (1,000 to 1,500 meters) and mid-elevation (1,500 to 2,000 meters) areas. At low elevations, oaks shared dominance (37 percent frequency) with pines, whereas at mid-elevations white fir comprised 16 percent of the basal area and 26 percent of the stems.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Continuous Forest Inventory in California: New Design Provides Rich and Timely Data for a Variety of Applications¹

Karen Waddell² and Sally Campbell³

The Pacific Northwest Research Station's Forest Inventory and Analysis (PNW-FIA) program inventories public and private forestlands in California, Oregon, Washington, Alaska, and the Pacific Islands. In the past few years, PNW-FIA has implemented a new nationally consistent, four-point design across all ownerships. Inventory plots are now sampled on an annual basis, instead of on the traditional 10-year cycle. PNW-FIA databases contain a diverse array of unbiased estimates for many attributes of California's forest ecosystems. PNW-FIA staff and collaborators are actively working on a variety of summary reports, analyses, and research studies, and many projects either focus on or are relevant to forests in the Sierra Nevada. Examples of ongoing projects include a study of California's hardwoods, sudden oak death, fuel treatment feasibility and acceptance, and an update of forestland statistics. This poster highlights details of the new inventory design, summarizes the type of data being collected and calculated, and describes some of the projects that use either current or past inventory information.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Characterizing the Light Regime of Different Mature Forest Stand Structures¹

Rolf Gersonde² and Kevin L. O'Hara³

Successful regeneration of mixed conifer forests depends on conditions suitable for survival and growth of all desired species. The light regime under the forest canopy strongly influences the competitive interaction of regenerating species and can be manipulated by the forest manager through density management of the overstory. The light model tRAYci was used to calculate light transmission through canopies of different densities, overstory species, and spatial structure: seed tree, shelterwood, small group selection, and closed canopy.

Average light intensity at the forest floor was lowest in the closed canopy stand (basal area of 125 square feet per acre), followed by the shelterwood (basal area of 75 square feet per acre), small group selection (0.25-acre opening) and was highest in the seed tree stand (basal area of 17.4 square feet per acre). Light intensity was significantly lower at the forest floor when the overstory was composed of white fir (*Abies concolor*) than when it was composed of ponderosa pine (*Pinus ponderosa*). Variability of incident light in the transition zone increased with stand density. Variation in aspect caused a small but significant change (2.7 percent) in average light intensity at the forest floor. Data from this study showed differences in the vertical profile of light transmission through the canopy. Light profiles in all stands showed a homogeneous light regime below the foliated crown space (dim light zone, 0–15 meters) and rapidly increasing light transmission in the transition zone (15–30 meters).

Light intensity and vertical position of the light gradient have consequences for the availability of light to understory trees. Characterizing the available light resources under various overstory structures can facilitate development of management guidelines for regeneration of mixed conifer stands.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Tree Growth and Death in the Sierra Nevada¹

Nathan L. Stephenson,² Phillip J. van Mantgem,³ and Peggy E. Moore⁴

Models suggest that forest characteristics are profoundly affected by the relationship between tree growth rate and probability of death. Yet little is known about the relationship, or how environmental changes might affect it. In particular, “gap” models of forest dynamics rely on two untested assumptions: (1) causes of tree death fall into two groups: those independent of and those dependent on growth rate, and (2) the only way environmental changes affect probability of death is indirectly, by altering growth rate. These assumptions were examined by tracking the growth and survival of 10,691 trees, recording 775 deaths by cause. Contrary to assumptions, no specific cause of death was independent of growth rate. However, the strength of the relationship between growth and death differed significantly among causes. White pine blister rust was found to increase probability of death in *Pinus lambertiana* growing at all rates, demonstrating that changes in probability of death can be either growth mediated, as assumed in gap models, or direct, resulting from a change in the nature of the relationship between growth rate and probability of death. The findings from this study have implications for understanding and predicting the potential effects of environmental changes on tree mortality.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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A Contrast in Vital Rates: Life Table Projections for *Abies concolor* and *Pinus lambertiana* in a Sierra Nevada Mixed Conifer Forest¹

John J. Battles² and Frieder G. Schurr³

The demography of *Abies concolor* (ABCO) and *Pinus lambertiana* (PILA) was examined in a mature mixed conifer forest in the Sierra Nevada. Size-classified matrix models were constructed and then elasticity analysis applied to determine which vital rates (survival, growth, and fecundity) were the most important determinants of population change. Survival of canopy-sized ABCO averaged 0.985 per year for the past 30 years. Fecundity (measured as the number of germinants produced) over the past 5 years averaged 154 germinants per canopy tree year. The projected population growth rate for ABCO was 1.007, indicative of a slowly growing population. In contrast, PILA, was projected to decline, with a growth rate equal to 0.985. Adult survival, particularly in the codominant size class, was much lower for PILA than for ABCO (0.939). PILA fecundity averaged less than 10 germinants per tree year. Changes in the PILA population were extraordinarily sensitive to the survival rate of canopy trees (elasticity = 0.856). The ABCO population was also dependent on adult survival (elasticity = 0.506), but understory tree survival was another important component (elasticity = 0.371). These projections support the contention that the Sierra Nevada conifer forests are communities currently ruled by nonequilibrium dynamics. Both fire suppression and an introduced pathogen contribute to the uncertain future of these forests.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Overview of the Kings River Project¹

Carolyn Hunsaker² and Nancy Fleenor³

The Kings River Project seeks to determine whether desired landscape conditions that create forest stand structures that mimic historic forest conditions and processes can sustain wildlife populations and stream ecosystems while providing forest products. The Sierra National Forest and the Pacific Southwest Research Station are working together on design, implementation, and analyses for the Kings River Project. Since 1994, the Kings River Project has been implementing a management system of uneven-aged group selection and a program of prescribed fire within two adjacent watersheds comprising 150,000 acres. Current research studies include stream ecosystems and watershed condition, demography of the California spotted owl, variations in the abundance and productivity of forest birds, occurrence and distribution of fishers, and long-term soil productivity. The project is examining the response of these ecosystem elements to timber harvest and prescribed fire.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Edge Effects of Group-Selection Harvest on an Old-Growth Forest in the Sierra Nevada¹

Zachary E. Kayler,² Lucas B. Fortini,² and John J. Battles²

Potential edge effects associated with group-selection harvest were measured on the northern border of an old-growth Sierra Nevada conifer forest. Changes in resource availability (light, water, and seedbed) and plant composition (abundance and richness) were quantified across transects that spanned from the interior of old-growth forest through group-selection openings. Researchers found a steep change in resource availability: plots in old-growth forests and on edges of the group opening were shadier (8 percent versus 50 percent full sun), had more water in the top 20 cm of soil, and had less exposed mineral soil. These three environmental variables explained more than one-third of the observed variation in species composition. Both parametric and non-parametric multivariate analyses confirmed that there are two distinct plant communities, old-growth and group selection, with no indication of an ecotonal community along the edge. Understory plant species richness normalized to a total area sampled of 0.25 hectare was significantly greater in the group-selection (59 species) than in the old-growth forest (42 species). Non-native plant species accounted for a similar proportion of total species richness in both community types (four percent). *Chimaphila umbellata* was a reliable indicator species of old-growth forest conditions.

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A Comparison of Ectomycorrhizal Response to Group-Selection Cutting on Two Mixed Conifer Species, *Pseudotsuga menziesii* and *Pinus ponderosa*¹

Anna L. Levin,² John J. Battles,² and Thomas D. Bruns²

Group selection has been proposed as an alternative to clearcutting, but the impact on a crucial component of seedling health, ectomycorrhizal fungi (EMF), has not been examined. Seedlings of *Pseudotsuga menziesii* (PSME) and *Pinus ponderosa* (PIPO) were planted in one-hectare groups along a gradient from intact forest to opening at Blodgett Forest to (1) determine whether EMF colonization rates and species richness decrease with increasing distance from forest edge and (2) examine whether patterns in EMF communities differ between the two conifer hosts. For PSME, a significant reduction in EMF colonization and richness occurred with distance from the edge. The colonization rate for PSME seedlings in the forest was nearly 100 percent, with 4.8 EMF species per seedling, but decreased to an average of 58 percent colonization and 3.2 species per seedlings in the opening. In contrast, there were no edge-related differences in EMF colonization or richness for PIPO: the colonization rate was 90 percent, with approximately four EMF species per seedling, regardless of distance from forest edge. The reduction in EMF colonization and richness found on PSME in the opening suggest that establishment problems observed for PSME in large clearcuts may be related to the mycorrhizal status of seedlings.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Growth of Conifers Planted under a Shelterwood¹

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This study compares the survival and growth of conifer seedlings planted in various forest floor conditions under a shelterwood. Planting under a shelterwood is indicated when some desirable seed trees are not available, for example sugar pine (*Pinus lambertiana*) resistant (Rr) to white pine blister rust (*Cronartium ribicola*). At Blodgett Forest Research Station, a shelterwood harvest retained 12 seed trees per acre. Tractor-pile site preparation left burned piles as far away from shelterwood trees as possible. These locations become the best potential growth sites and the least likely to be stocked by natural seed fall. Fifty burn piles were planted with Rr sugar pine, Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), giant sequoia (*Sequoiadendron giganteum*), and incense cedar (*Calocedrus decurrens*) in ash, burn pile edge, and adjacent unburned area. After 5 years, diameter and height of each planted seedling were recorded. Shrub species, percent cover, and height were measured on mil-acre plots at each planted tree. Average diameter and height of both giant sequoia and ponderosa pine were greater than that of sugar pine, incense cedar, and Douglas-fir. Shrubs grew more vigorously along the edge of burned piles than in either ash or mineral soil, whereas trees grew faster when planted in ash.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Sequoia Pruning Timing Study¹

Robert C. Heald² and Wm. David Rambeau²

Young-growth giant sequoias (*Sequoiadendron giganteum*) have potential to produce high-value clear redwood products but exhibit virtually no self-pruning. Average branch diameters at age 10 years range from 1 to 3 centimeters as spacing increases from 2 to 6 meters. Whereas planting density affects stem diameter and height, branch sizes remain well within the range that can easily be pruned using standard tools. Little is known about the effects of pruning on growth, epicormic branching, heartwood formation, and stem taper of giant sequoias.

This study was located in an existing sequoia density study at Blodgett Forest Research Station. Sequoia trees were pruned over a wide range of tree sizes and pruning intensities throughout a calendar year. Measurements of 500 pruned and control trees included tree height, stem diameter at several heights, existing epicormics, heartwood, branch recession, crown radius, and branch diameters. After pruning, sequoia trees produced epicormic branches only at pruned branch collars. Sequoia trees pruned from October through May frequently developed epicormic branches. These sprouts first appeared in conjunction with new leaf development the following June. Sequoia trees pruned from June through September rarely developed epicormic branches. Frequency, quantity, and length of epicormic branches produced increased as pruning intensity increased.

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Mixed Conifer Plantation Growth¹

Robert C. Heald² and Nadia Hamey²

Although little information is available, some observers have speculated that mixed species plantations provide greater wood productivity, increased visual quality, and more wildlife species diversity than single species plantings. This study examined a variety of cultural treatments in native mixed conifer plantations at Blodgett Forest Research Station. For site preparation, all woody material other than sawlogs was masticated and left in place following harvest. The sites were planted in April 1992 with an equal mix of *Pinus ponderosa*, *Pinus lambertiana*, *Calocedrus decurrens*, *Abies concolor*, *Pseudotsuga menziesii*, and *Sequoiadendron giganteum* on 2.5-meter square spacing. The stumps of harvested *Quercus kelloggii* sprouted vigorously the same spring. In a random block design, six replications each of hand weeding, herbicide, and a no-treatment control were applied during the second growing season. An additional 18 similar treatment areas were exposed to grazing by range cattle. All treatments were thinned after the 5th-year measurement to a residual density averaging 800 trees per hectare. Seasonal range cattle grazing (and the exclosures) continued throughout the study. After 10 years, tree heights and diameters varied significantly by species, treatment type, and total shrub cover. Combined grazing and weeding or grazing and herbicide plots developed the least shrub cover and largest trees.

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Effects of Planting Density on Early Growth of Giant Sequoia (*Sequoiadendron giganteum*)¹

Robert C. Heald²

This study measured 2,086 giant sequoia seedlings planted at spacings of 7 to 20 feet. Giant sequoia show remarkably early and extensive effects of competition. Spacing substantially affects early height growth of sequoias. By 10 years, trees at wide spacing distance were showing 60 percent wider annual diameter growth and 50 percent higher annual height growth than trees at half each respective spacing. During the 9th and 10th growing seasons, 27 trees were carefully measured every 2 weeks from April through October. Total season height and diameter growth generally increased with increasing spacing. Trees at wide spacings added approximately 1 inch in diameter and 2.6 feet in height, approximately 40 percent more growth than trees at half their respective spacings. One explanation for the unusual response is that both height and diameter growth are limited by soil moisture depletion during the late growing season. Sequoia trees at all spacings had observable diameter growth by mid-May. New leaf development and branch and height growth were not visible until mid-June. Both height and diameter growth simultaneously ceased by September. This contrasts with typical conifer patterns of an early spring start and short duration of height growth followed by more gradual and longer-duration secondary growth of the cambium.

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The Kings River Project: Small Stream Ecosystem Variability and Response to Fire¹

Carolyn Hunsaker² and Sean Eagan²

The quality of aquatic and riparian ecosystems is a function of their condition and the integrity of adjacent uplands in their watershed. Although small streams make up a large proportion of the overall stream network, our knowledge of how they function is still limited. The Kings River Experimental Watershed Project was initiated in 2000 to quantify the variability in characteristics of small-stream ecosystems and their associated watersheds. Forest managers want to understand the effects of fire and fuel reduction treatments on riparian and stream physical, chemical, and biological conditions. Two mixed conifer study sites are being developed at elevations of 1,700 to 2,400 meters. Data will be gathered for at least a 3-year reference period, and then fire and harvesting treatments will be applied. After the treatments, data will be gathered for at least 7 years. Each site will have a control watershed that receives no treatments, a watershed that is burned, a watershed that is harvested, and a watershed that is both burned and harvested. The watersheds range from 80 to 150 hectares, a size that can be consistently treated. Data relative to stream discharge, water chemistry, sediment loads, and invertebrate composition have been collected for water years 2000 and 2001.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Seed Fall and Seedling Recruitment in Mixed Conifer Forests of the Sierra Nevada¹

Jon E. Keeley² and Philip van Mantgem²

Forest regeneration is likely a sensitive indicator of global change perhaps evident in patterns of cone initiation, seed production, and seedling recruitment. Regeneration, however, is complicated by a limited understanding of how current conditions control these parameters. Seedling recruitment strategies are poorly understood because of marked limitations in the temporal and spatial scale of study. The Sierra Nevada Global Change Project can contribute significantly because of its long-term focus across a broad elevational range, from 1,500 to 3,000 meters, in the southern and central Sierra Nevada. Analysis along this gradient shows that elevation is an important predictor of conifer seedling density, best illustrated by a simple exponential decay model. Elevational effects are only weakly evident in firs but prominent in pines. Not surprisingly, in these largely undisturbed forests, white fir (*Abies concolor*) dominates the recruitment, and ponderosa pine (*Pinus ponderosa*) is barely represented. Incense cedar (*Calocedrus decurrens*) and sugar pine (*P. lambertiana*) recruitment patterns are broadly similar to that of white fir. Evidence of successful understory recruitment and establishment in the understory by sugar pine suggests limited fire dependence in this pine species. Although white fir is capable of successful recruitment in the understory of undisturbed forests, it also recruits heavily into burned sites, suggesting that the often-used term “fire-intolerant species” may be inappropriate.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Influence of Light and Soil Moisture on Sierra Nevada Mixed Conifer Forest Understory Community¹

Malcolm North,² Brian Oakley,³ Rob Figener,⁴ Andrew Gray,⁵ and Michael Barbour⁴

Site conditions affecting herb and shrub dynamics in Sierra Nevada forests have not been well studied. In an old-growth, mixed conifer forest, the understory community and its distribution in relation to microsite conditions was examined. Canopy cover was also measured using three common field methods to compare the assessment of conditions influencing herb and shrub cover. The objectives of this study were to (1) ordinate the understory plots to assess indirect environmental gradients influencing community structure; (2) test for significant differences in soil moisture, light, canopy cover, and coarse woody-debris or litter-depth conditions between associations, (3) identify individual herbs and shrubs strongly correlated with specific site conditions; and (4) identify which measure of canopy cover is most strongly correlated with understory cover. Communities in the mixed conifer understory were strongly influenced by soil moisture, coarse woody debris, litter depth, and intensity of understory light. There appear to be threshold soil-moisture and canopy-cover levels below which herbs are rare or absent. Spherical densiometer and moosehorn canopy cover measurements were found to be poor indicators of understory conditions because they did not account for canopy openings and sun angle. In the southern Sierra Nevada, hemispherical photographs are needed to predict understory dynamics in response to fire and thinning disturbances.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Differences in Stand Structure and Pattern of Sierra Nevada and Pacific Northwest Old-Growth Forests¹

Malcolm North,² Jiquan Chen,³ and Brian Oakley⁴

Species composition, structure, spatial pattern, light, and soil moisture were compared between two old-growth forests: closed-canopy Pacific Northwest western hemlock/Douglas-fir at the Wind River Canopy Crane Facility and patchy Sierra Nevada mixed conifer at the Teakettle Experimental Forest. The Teakettle forest exhibits a lower basal area than Wind River forest. Basal area at Teakettle is concentrated in tree groups, 30 to 50 meters in diameter, with these groups having a similar basal area and higher density than at Wind River. At Wind River, large trees are regularly spaced from 0 to 15 meters, and shade-tolerant and intolerant species are “repelled,” whereas at Teakettle, large trees are randomly distributed from 0 to 80 meters, and shade-tolerant and shade-intolerant species are “attracted.” Average understory light is 15 times higher at Teakettle than at Wind River. At Teakettle, there is no canopy stratification by shade tolerance, and light in openings may inhibit horizontal stem pattern, producing persistent gaps. This suggests that mixed conifer forests may have a minimum canopy cover threshold for tree survival. Higher cover needed for tree establishment and growth may override stem repulsion produced by tree competition for growing resources. These findings indicate that stand management that reduces canopy cover to release regeneration should be applied with caution in the southern Sierra Nevada.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Effects of Logging and Prescribed Fire on Fecundity and Seed Dispersal of Sierra Nevada Conifers¹

Ruth Ann Kern²

Seed rain is being monitored in experimental-forest treatment plots to investigate the effects of thinning and prescribed fire on seed production and seed dispersal distances of Sierra Nevada conifers. Eighteen 1-hectare forest research plots, established in the Teakettle Experimental Watershed in the Sierra National Forest, have been manipulated in a 2×3 factorial design (fire or no fire; shelterwood thinning prescription, California spotted-owl thinning prescription, or no thinning) with three replicates of each treatment. Twenty-five seed traps (0.25 m²) have been installed on a 25-meter grid in each of the 18 plots. Logging and prescribed fire treatments were completed in 2001, and seed traps were installed in early summer 2002. Data from this long-term study will be used to understand individual and cumulative effects of thinning and prescribed burning on seed production and seed dispersal distances of white fir, red fir, sugar pine, Jeffrey pine, and incense cedar.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Effects of Fire on Soil Nitrogen and *Frankia* Associated with Patches of the Actinorhizal Shrub *Ceanothus cordulatus*¹

Brian Oakley,² Malcolm North,³ Brian P. Hedlund,⁴ James T. Staley,⁴ and Jerry F. Franklin⁵

The largest inputs of nitrogen (N) occur via symbiotic N-fixation, yet N-fixing plants are usually limited to the early stages of post-disturbance succession. Sierra Nevada forests, however, are an interesting exception because N-fixing *Ceanothus* spp. can dominate the understory even in mature and old-growth forests, possibly because of fire maintaining an open canopy. This study focused on two key questions: (1) are soil N levels associated with patches of *Ceanothus* significantly enriched relative to surrounding areas, and if so, does this effect persist after fire? And (2) does fire reduce the number of *Frankia* in the soil or select for particular strains of *Frankia*?

A burn experiment was conducted to determine whether soil beneath *C. cordulatus* patches represents N “resource islands” and whether any N enrichment persists after fire to potentially influence forest regeneration and spatial patterning. *Ceanothus* patches are enriched relative to other patch types in total and mineral N before fire, and this effect largely persists after fire. Vigorous resprouting (particularly in plots burned at low intensity) and lower C:N ratios in *Ceanothus* patches will likely continue this trend into the future. Fire appears to have little effect on *Frankia*, and regional *Frankia* diversity is low; however, distinct strains can be found at the scale of major biogeographic divisions.

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Fire and Fuels Management, Landscape Dynamics, and Fish and Wildlife Resources: An Integrated Research Plan on the Plumas and Lassen National Forests¹

Peter Stine,² John Keane,² Malcolm North,² Scott Stephens,³ Doug Kelt,⁴ Dirk Van Vuren,⁴ Michael Johnson,⁵ Geoff Geupel,⁶ and Mary Chase⁶

An integrated series of studies is intended to evaluate land management strategies that have been designed to reduce wildland fire hazard, promote forest health and ecosystem stability, and provide economic benefits across managed forest landscapes, such as those found on the Plumas and Lassen National Forests. The research program is organized around four principal issues: (1) efficacy of selected combinations of defensible fuel profile zones (DFPZs) and area fuel treatments to reduce the extent and severity of wildland fires; (2) effects of group selection as a silvicultural tool on various forest elements and conditions; (3) cumulative effects of management regimes on landscape dynamics, such as forest structure, composition and succession across time and space; and (4) species-specific responses to landscape changes resulting from different forest management regimes. At the most basic level, the objective of the proposed research is to address, in a coordinated effort, an array of related ecological questions, and thereby provide empirical data to inform future management decisions.

At this time, the research program is focusing on five “modules” of response variables. These include (1) vegetation; (2) fire and fuels; (3) density, reproductive success, and diet of the California spotted owl; (4) small mammal distribution, abundance, and habitat relations; and (5) landbird distribution, abundance, and habitat relations. The critical interplay of space and time, particularly over larger, longer, and more diverse frames of reference than most ecological research programs have attempted in the past, is a major objective of this research program. The program is designed to assess the integrated response of key variables across broad landscapes over relatively long periods of time. Although some questions can be addressed by substituting space for time or by inductive reasoning from short-term, small-scale studies to broader landscapes, other questions unavoidably require a longer-term research commitment over large landscapes.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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The Kings River Project: Historic Stand Structures, Forest Processes, and Vegetation Manipulation¹

Carolyn Ballard² and Ramiro Rojas²

The Kings River Project is intended to create an experimental framework at a watershed scale to examine the response of an array of ecosystem elements to uneven-aged, small group selection and prescribed fire. Structural variation caused by timber harvest or mechanical thinning is designed to be fine grained, mimicking small-scale natural disturbances, such as those caused by a few acres of high-intensity crown fires within a matrix of frequent low-intensity fires. The systems initiated for the study minimize the use of forest zoning, emphasize multi-resource objective management on homogenous areas in a watershed, and utilize the uneven-aged management system to program vegetation manipulation. Group selection and silvicultural practices are used to mimic effects of frequent, low-intensity fire. Fuels treatments are concurrent with silvicultural activities, and harvest practices followed by slash piling, mastication, and prescribed burning are used to create openings. Defensible fuel profile zones are used within the wildland urban intermix to aid wildfire suppression. Prescribed fires, alone or in conjunction with silvicultural treatments, are being conducted to improve ecosystem condition and return fire to the forest as a natural disturbance process.

The Kings River Project defines desired forest conditions as those stand structures and processes found in the area in the 1850s. Historic forest structures and processes were investigated to determine the range of variability found within the project watersheds. A vision of desired stand structures and processes was developed from historic photos, descriptions from trained observers from the early 1900s, literature from similar neighboring forests, data collected from the early 1900s, and examinations conducted within the project area. This analysis determined that although stand structures were variable, generalizations can be made on the basis of on forest type, aspect, and slope. Frequent low-intensity fire resulted in uneven-aged structures across the ponderosa pine and mixed conifer types. High variability existed between and within stands. Understory fuel loading was low. Regeneration occurred episodically rather than continuously. Stand density was characterized by widely spaced crowns. Many forest stands within the project area were characterized by unoccupied growing space. In contrast, high crown density and infrequent fires characterized the true fir stands. Fire often caused stand replacement along the transition from pine-dominated stands to fir-dominated stands. Forest exams for 1912 and 1917 found little evidence of insect mortality.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Inventory and Risk Assessment of Aspen on the Eagle Lake Ranger District, Lassen National Forest¹

Bobette E. Jones² and Tom H. Rickman²

An aspen (*Populus tremuloides* Michx.) inventory and risk assessment project is being conducted on the Eagle Lake Ranger District, Lassen National Forest. This project was initiated in response to observed declines in health and distribution of aspen stands on the Eagle Lake Ranger District. Objectives of this project are to (1) produce a complete inventory of aspen on the Eagle Lake Ranger District by 2003 and (2) develop stand-specific management recommendations and include these recommendations as actions analyzed in site-specific environmental documents under the National Environmental Policy Act (NEPA) so that the required restoration activities can take place.

Each aspen stand is delineated using Global Positioning Systems and assessed on the basis of risk factors identified by Bartos and Campbell (*Decline of quaking aspen in the interior West, examples from Utah*, 1998). Management recommendations are based on observed stand conditions. To date, 312 stands totaling 592 hectares, with a mean stand size of 1.9 hectares, have been inventoried. Eighty-seven percent of the stands have received a high or highest priority rating, indicating that aspen are at risk. Aspen is considered a keystone species, and aspen communities are critical for maintaining biodiversity in Western landscapes. Loss of aspen can be attributed primarily to successional processes that occur in the absence of natural fire regimes and with excessive browsing. Continuation of the current successional trend, which has existed for the past 100–140 years on the Eagle Lake Ranger District, will result in the eventual loss of most aspen stands. The District's extensive inventory and restoration efforts are an attempt to avoid this loss.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Monitoring Changes in Channel Morphology to Evaluate Management Actions Concerning the Merced River in Yosemite Valley¹

C. Marie Denn²

Stream channel morphology alters in accordance with changes in riverbank and floodplain land use and can measurably respond to land use changes on 4- to 10-year time scales. Yosemite National Park is continuing a long-term channel morphology monitoring program, initiated in 1989, to evaluate effects of development, recreation, restoration, dam removal, and natural disturbance events on the Merced Wild and Scenic River in Yosemite Valley. This monitoring program has revealed effects of development and intensive riverbank restoration on the river and provided better understanding of the 100-year flood of 1997. In the future, this study will show alterations in the river channel structure due to post-flood policy and land use changes.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Modeling Ozone Uptake in Ponderosa Pine throughout the Sierra Nevada¹

Jeanne A. Panek,² Laurent Misson,² and Allen H. Goldstein²

Tropospheric ozone is a pollutant responsible for forest injury worldwide. It is a strong oxidant that invades foliage through stomatal pores and impairs normal physiological function. In the Sierra Nevada, ozone uptake can be unrelated to ozone concentrations. Peak ozone concentrations occur in the late summer, but uptake then is low because of stomatal closure in response to moisture stress. Thus, concentration-based indices of ozone exposure do not accurately reflect the ozone “seen” by plants. To estimate ozone uptake in ponderosa pine (the most ozone-sensitive Sierra Nevadan conifer) throughout the Sierra Nevada, gas exchange/physiology was directly measured at four sites along an ozone gradient for three growing seasons and one winter. From these data, a model was developed and validated. This model was then used to estimate ozone flux (ozone concentration relative to canopy conductance to ozone) across the Sierra Nevada through time. This approach can be used to develop cause-effect relationships between ozone stress and forest injury in pine. The uptake-modeling method is being adopted across Europe to replace concentration-based indices. This is one of the very few studies attempting to model ozone flux to forests in the United States, and it will contribute to improvements in monitoring of Sierra Nevada forest health in response to ozone pollution.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Evaporation from Lake Tahoe, California¹

Gayle L. Dana,² James C. Trask,³ and David McGraw²

Accurate measurements of evaporation are important to management of water storage as well as to understanding turnover and nutrient storage in lakes. Evaporation has been a poorly constrained component in past water budget studies of Lake Tahoe, California, and is the last major unknown for effective management of the Truckee River Basin under the Truckee River Operating Agreement (TROA). To obtain evaporation rates from Lake Tahoe, two studies of evaporation were conducted from September 1999 to December 2000. The first study was designed to obtain the best possible and first year-round measurements of evaporation using the eddy correlation technique. The second study was designed to determine the accuracy of evaporation estimates obtained from the historical Tahoe City evaporation pan, which are suspect as a result of progressive shading over time. In this second study, evaporation was measured with a class-A standard evaporation pan placed in a location with minimal shading and wind obstruction at the U.S. Coast Guard (USCG) station a few miles from Tahoe City.

Annual evaporation measured by eddy correlation was 672 millimeters (mm), compared to 674 to 1,099 mm estimated in previous studies. Annual evaporation estimated using meteorological methods (for example, modified Penman) varied sevenfold, indicating that calibration to the eddy correlation measurements would be necessary to use these methods to accurately represent annual evaporation. Pan evaporation measured at the USCG site was 1.5 to 2 times higher than at the Tahoe City site, and evaporation at both sites was higher than that measured with eddy correlation. These results demonstrate that selection of a site-specific pan coefficient is essential to obtaining reliable evaporation estimates.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Wildfire Burn Patterns and Riparian Vegetation Response along Two Northern Sierra Nevada Creeks¹

Leda N. Kobziar² and Joe R. McBride²

Although the role of fire in forested ecosystems of the Sierra Nevada has been the subject of considerable research, little is known about how fire affects the riparian zones of these forests. This study compares the effects of wildfire on riparian vegetation characteristics along two small creeks in the northern Sierra Nevada mixed conifer forest type of the Plumas National Forest. The behavior and severity of the fire are addressed in relation to the physical characteristics of the two creeks, and the vegetation response patterns are analyzed. Where fire appeared to have burned more quickly through transects on Fourth Water Creek, more of the remaining plants sprouted than did along Third Water Creek. The predominant regeneration mechanisms of the two creeks also differed. More seedlings were found on Fourth Water Creek transects, whereas plant response along Third Water Creek was mostly vegetative. For both creeks, the percent of burned hardwoods that sprouted increased with proximity to the water's edge. The interplay between fire occurrence and proximity to the water table and the influence of these factors on abundance and composition of riparian vegetation are explored. The results can help guide management strategies aimed at restoring resilience to riparian corridors in disturbance-prone ecosystems.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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In-situ Overland Flow Collection System for Sierra Nevada Watersheds¹

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A versatile intermediate-scale in-situ overland flow collection system of 50 to 100 square meters (m²) or more has been developed to capture surface runoff during natural events. This design is readily applied to a wide range of terrain common to natural watershed settings, including areas that receive considerable amounts of winter snowfall. Cumulative runoff from 13 Sierra Nevada study sites over a 7-month period ranged from a low of 3.9 liters (0.08 L m⁻²) to a high of 21.6 L (0.43 L m⁻²) on slopes less than 10 percent in areas of no visible erosion or surface runoff during both snowmelt and summer precipitation. Importantly, this approach may be useful in directly linking nutrient loading from surface runoff to tributary and lake water quality; NH₄⁺-N concentrations as high as 86.2 milligrams per liter (mg L⁻¹) and ortho-PO₄ as high as 28.7 mg L⁻¹ P were found in the surface runoff. Soil solution extracts and snowmelt were greater than 3 and 2.5 orders of magnitude lower, respectively. These findings are highly pertinent to hydrologic and nutrient transport models in the Lake Tahoe basin and likely pertinent to other watersheds having similar topographic, biological, and climatic characteristics.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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High Natural Rates of Nutrient Loading to a Montane Reservoir (Crowley Lake, California)¹

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Crowley Lake in Mono County, California (with an area of 17 square kilometers [km²] and mean depth of 9 meters), lies in the Long Valley caldera and is a valuable aquatic resource. It is the premier trout fishery in the eastern Sierra Nevada and the largest reservoir in the Los Angeles aqueduct system. In summer, large cyanophyte blooms impair recreational uses and water quality. Nutrient inputs were measured via seven tributary streams originating in alpine and subalpine catchments (total area of 985 km²) and passing through grazed lands and light urban development. On two of the tributaries, large natural spring systems contain high concentrations of nitrogen (N), phosphorus (P), and arsenic and constitute the major source of stream loading (greater than 90 percent of P). Measured stream inputs of phosphorus are approximately in balance with reservoir exports, in contrast to those of nitrogen for which exports are nearly three times the measured inputs. Thus, nitrogen fixation is a likely additional source of N.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Correlating Biological Indicators of Stress with Ecological Disturbance in Sierra Nevada Lakes¹

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Low levels of ecological degradation are difficult to observe but are important in defining alpine lakes that have low resistance to and long recovery from stress. The technique of categorizing ecological health of a lake, as applied in the eastern United States by the U.S. Environmental Protection Agency, was applied to lakes surrounding the Lake Tahoe basin in the Sierra Nevada. Lake chemistry, littoral and riparian zone content, and human recreational activity were recorded for each of 16 lake sites: Angora, Castle, Donner, Eagle, Fallen Leaf, Gold, Jackson Meadows, Marlette, Prosser Creek, Sand Harbor, Stampede, Spaulding, Tahoe City, Tahoe Keys, Twin, and Topaz. In addition, juvenile rainbow trout (n = 25) were exposed for 48 hours at each site (5 subsites around lake perimeter) in cages submerged at 2.5 meters. Five genes were analyzed for mRNA levels in trout gill and liver: CYP1A1, metallothionein, vitellogenin, activin, and multiple xenobiotic resistance (MXR). Gene expression was statistically analyzed with principle component analysis and correlated with the most important ecological parameters of lake stress. Preliminary conclusions show a wide range of disturbance with specific chemical contact at several sites. This study suggests that inputs to lake water (runoff and motorized watercraft) can be monitored with this assessment regime and that vertebrate stress levels can help to characterize local ecological disturbance.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Effects of Prescribed Burning on Stream and Riparian Ecosystems¹

Leah A. Rogers,² Vincent H. Resh,² and Scott L. Stephens³

In areas where wildfire has been suppressed, prescribed burning can be an efficient forest management tool for fuel reduction and ecosystem restoration. However, concerns about the effects of fire on sensitive habitats, such as streams and riparian areas, have limited its use in management. Though wildfires can have long-lasting effects on physical and biological features of streams and riparian areas, little is known about the effects of prescribed fire. In September 2002, an upland and riparian plot will be burned using prescribed fire at the University of California's Blodgett Forest Research Station in the central Sierra Nevada. Changes in water quality, channel morphology, hydrology, aquatic macroinvertebrates, algal biomass, large woody debris, and riparian forest community dynamics will be documented in burned and unburned first-order catchments before and after the prescribed fire (beyond-BACI design). Multiple control and impact sites are being used to compare pre-fire and post-fire results to provide information on: (1) effects of prescribed burning on streams and riparian zones, (2) effects of fuel reduction in riparian zones, and (3) recovery of streams following disturbance. Pre-fire data and results on immediate effects of the riparian/upland prescribed fire of September 2002 are presented.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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High-Resolution River Chemistry in the Sierra Nevada¹

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Linking variations in large-scale atmospheric circulation patterns (climate) to variations in snowmelt discharge and riverine chemistry is a relatively new science. Three important elements of this research are to: (1) establish a hydroclimate monitoring network, (2) monitor riverine chemistry at rates compatible with hydroclimate variables (hourly, daily), and (3) exploit the remarkable synchronism in spring snowmelt discharge variations between watersheds in the Sierra Nevada. The third element simplifies interpretation of multi-watershed variations in river chemistry. This problem is further simplified here by focusing on the variations in water conductivity, a conservative property measuring total dissolved solids (TDS) or salts.

First year (2001) interbasin results from the Merced and Stanislaus rivers are available. Historically, the correlation of daily discharge of these two rivers has been strong ($r = +0.98$, from 1951 to 1993). (The Stanislaus River discharge gauge was discontinued in 1993.) During 2001, a measure of discharge, water pressure or elevation, also showed a strong interbasin correlation at the hourly time scale ($r = +0.96$ for calendar days 1 to 160). Despite this strong correlation in discharge, the conductivity variations in the two rivers were different. During low river flow, in both rivers, the diurnal peaks of conductivity occurred after the diurnal peak in discharge. Following the onset of snowmelt discharge, this pattern remained the same in the Stanislaus River; however, in the Merced River, the conductivity peak shifted, within 5 days of rising discharge, to occur before the discharge peak. Thus, after snowmelt began, the diurnal conductivity cycles in the two rivers were 180 degrees out of phase. A preliminary explanation for this difference is that the rate of dilution of TDS (dissolved salts) is greater in the Merced than in the Stanislaus watershed (above the gauges).

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Using Ecosystem Types as Predictors of Variation in the Effects of Riparian Zones on Water Quality¹

Amy G. Merrill²

The Sierra Nevada is experiencing increasingly high rates of nitrogen (N) deposition (for example, 15 kilograms per hectare per year). Expected increases in California's population and fossil fuel use indicate that this trend is likely to continue, possibly endangering water quality and aquatic ecosystem health. Riparian zones and other wetlands are known to remove N from ground and surface waters before they enter aquatic systems. However, variation in N-filtering abilities among different riparian zones is poorly quantified, particularly in mountainous landscapes. This study tested the hypothesis that different riparian ecosystem types are associated with different rates of microbial N uptake, retention, and input to ground and surface water. Twenty plots, four each of five ecosystem types, were randomly selected along a tributary to Lake Tahoe. Throughout the snow-free season, N transformations under background and elevated N conditions were measured. Significant differences in denitrification, net mineralization, and net nitrification were found among ecosystem types under background N conditions. Under elevated N conditions, ecosystem type differences in denitrification and ground water N flux were also significant. These results suggest that classification of riparian ecosystem types can be useful in predicting and accurately modeling landscape scale patterns of riparian zone influence on ground and stream water N.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Automated Hourly Measurements of Concentrations of Nitrate plus Nitrite and Dissolved Silica at Happy Isles Bridge, Yosemite National Park¹

Stephen W. Hager,² Richard E. Smith,² and David H. Peterson²

Linking variations in climate to variations in river chemistry requires monitoring chemical variations at rates similar to those of hydro-climate variables. Hourly measurements of nitrate plus nitrite (N+N) and dissolved silica (DSi) are now being made in the Merced River at Happy Isles Bridge in Yosemite National Park. The instruments (NAS-2E and AutoLAB; W.S. Envirotech, U.K.) are user-programmable colorimetric analyzers. Stable analytical routines, capable of observing the small hourly variations seen in snowmelt, have been developed. Precision (two standard deviations on the blank) is typically better than 0.1 micromoles per liter for N+N and 0.8 micromoles per liter for DSi. Although the NAS-2E is submergible, deployment of the analyzers on the bank of the river allows more elaborate analytical routines, larger reagent quantities, and renewable (solar) power, while ensuring the lowest possible chance of contamination of the river. Deployments of up to 12 weeks have been made with the N+N analyzer.

Data obtained demonstrate the utility of hourly sampling toward understanding the pathways that snowmelt water goes through on its way to the gauge. Concentrations of N+N undergo regular diel cycles during snowmelt. At the beginning of snowmelt season, concentrations increase as flows do: the “first flush” phenomenon. Later in the year, comparison with hourly conductivity measurements reveals the relative timing of at least two pathways. Rain events following periods of dry weather also have distinct signatures. Concentrations of DSi show a progressive decrease through the spring. Possible explanations include depletion of DSi in soils, changes in source areas, and biological uptake.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Magnitude and Interannual Variability of Sediment Production from Forest Roads in the Sierra Nevada¹

Drew Coe² and Lee H. MacDonald²

In many forested catchments, roads are the primary source of sediment. However, little is known about sediment production from forest roads in the Sierra Nevada. The objectives of this study were to: (1) measure sediment production and site variables from native surface and rocked roads, respectively, and (2) develop models to predict road surface sediment production. Sediment production rates were measured at the road segment scale by constructing 70 sediment fences and monitoring sediment production rates for 1 to 3 years. The road segments were in the American and Cosumnes river drainages at elevations of 900 to 2,000 meters and included both public and private roads.

For the 1999–2000 wet season, the mean sediment production rate for native surface roads was 7.6 metric tons per hectare per year ($\text{t ha}^{-1} \text{ yr}^{-1}$), and the range was 0.4 to 33 $\text{t ha}^{-1} \text{ yr}^{-1}$. For the 2000–2001 wet season, the same road segments averaged only 1.4 $\text{t ha}^{-1} \text{ yr}^{-1}$, and the range of values was correspondingly reduced to 0.03–4.9 $\text{t ha}^{-1} \text{ yr}^{-1}$. On average, recently graded road segments produced twice as much sediment as comparable segments that had not been recently regraded. Rocked roads produced only 2 to 4 percent as much sediment as comparable native surface roads. The distribution of sediment production rates is highly skewed because a few road segments generated most of the sediment. Preliminary data from the 2001–2002 wet season indicate that sediment production rates were intermediate to the values from the first and second wet seasons.

The large interannual variability in sediment production rates is probably due to differences in the magnitude and character of precipitation. The more persistent snow cover in 2000–2001 appears to have protected the road surface and reduced sediment production rates per unit of precipitation. Approximately 50 percent of the variability in sediment production rates for ungraded native surface roads can be explained by the product of road surface area and road gradient. The largest sediment production rates were from road segments downslope of areas with impermeable bedrock, and this may be attributed to higher runoff rates and the interception of more subsurface stormflow. Older roads with inadequate drainage produced much more sediment per unit area than roads that follow current specifications. In the absence of rocking or paving, improved drainage and road placement are the best means to reduce erosion from native surface roads.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Developing a Spatially Explicit Model to Predict Changes in Runoff and Sediment Yields in the Central Sierra Nevada¹

Lee H. MacDonald,² Sandra E. Litschert,² and Drew Coe²

A lumped conceptual model is currently being used to assess cumulative watershed effects (CWEs) on national forest lands in California. This model converts the estimated effects of different management activities to Equivalent Roaded Acres (ERAs), sums the ERAs for the watershed of concern, and then compares the area-adjusted ERA value to an empirical threshold of concern. Key limitations to this approach include (1) lack of any spatial considerations (for example, a road near the stream generally has the same ERA as a ridgetop road), (2) absence of different coefficients and recovery rates for changes in runoff as compared to changes in erosion, and (3) limited validation at both the site and watershed scale.

Recent increases in geographic information systems, corporate databases, computing power, and field data are facilitating the development of a spatially explicit, quasi-physically based model to more accurately assess CWEs in the central Sierra Nevada. The goal is to develop a modular set of procedures that allows resource specialists to predict changes in runoff and sediment yields for watersheds ranging in scale from approximately 10 to 100 square kilometers.

In its initial phase, the model will predict catchment-scale changes in runoff and erosion due to forest harvest, roads, and fires. The lack of paired-watershed studies in the Sierra Nevada means that management-induced changes in low flows, annual water yields, and peak flows will be estimated from published values. Background and management-induced erosion rates are being obtained from a combination of literature values and field data collected by the authors from 1999 to 2002. The predicted changes in runoff will simply be summed over the catchment being modeled, whereas the sediment model will have procedures to deliver sediment from the hillslope to the channel network as a function of hillslope gradient and distance from the channel. Sediment will be routed through the stream network as a function of stream gradient, drainage area, and particle size. Users will be able to change the suggested default values for calculating changes in runoff and erosion rates, as well as altering the suggested recovery curves and algorithms for sediment delivery.

The model and user interface will be a stand-alone program in Visual Basic that uses ArcObjects and MapObjects. Standard ArcInfo coverages provide the underlying spatial data. The design criteria are to produce a model that (1) is relatively easy to use, (2) allows users to readily change input values and thereby evaluate the sensitivity of the model output to the assumed values, (3) can be readily expanded to accommodate other land management activities or improved predictive algorithms, and (4) will encourage the collection of additional field data by allowing users to input locally derived values.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Geology and Landslides in Latour Demonstration State Forest¹

John P. Schlosser,² William R. Short,³ and Michael A. Wopat⁴

The Department of Conservation's California Geological Survey (CGS) provides technical information about landslides, erosion, sedimentation, and other geologic hazards to agencies making land use decisions in watersheds where proposed activities may affect public safety, water quality, and fish habitat. At the request of the California Department of Forestry and Fire Protection, CGS conducted a study of geologic and geomorphic features related to landsliding for use in the 1994 Latour Demonstration State Forest (Shasta County) Sustained Yield Plan (SYP). The results of the study were portrayed on 1:24,000 scale maps in contiguous parts of the Miller Mountain, Hagaman Gulch, Jacks Backbone, and Manzanita Lake 7.5-minute quadrangles, which include the headwaters of South Cow Creek and Old Cow Creek. Landslide susceptibility categories were also identified. In anticipation of the 10-year update of the SYP, CGS digitized the 1994 maps using an ArcInfo Geographic Information System, with associated data attributes and metadata compiled into an ArcInfo database. Geology and landslide features on the digitized maps will be updated through field surveys, review of existing publications and air photos, and use of selected landslide-related models. Landslide potential will be recalculated so that information on both sets of maps will be consistent with methods currently being used by CGS for mapping landslides on California's north coast.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Potential Impacts of Sudden Oak Death in the Sierra Nevada¹

Doug McCreary²

Sudden Oak Death, or SOD, is a new type of mortality that affects oaks in coastal areas. It is caused by a recently named fungus-like pathogen, *Phytophthora ramorum*, that kills trees by causing stem lesions. It has currently been confirmed in 12 coastal counties ranging from Monterey to Humboldt. In addition to oaks, this pathogen also infects about a dozen other plant species that may harbor the pathogen but are not necessarily killed by it. As of this writing (August 2002), this disease has not yet been confirmed in any Sierra Nevada counties; however, there is concern that it could spread to these areas. Several confirmed hosts, including California black oak, big leaf maple, madrone, and manzanita, grow in the Sierra Nevada, and environmental conditions in the mid-elevation foothills are not that different from those in infested coastal regions.

If SOD were to become established in the Sierra Nevada, it could have serious negative impacts, including increased risk of wildfires, adverse effects on wildlife habitat and associated wildlife species, increased potential for erosion and resulting degradation in water quality, and a dramatic alteration in the visual landscape. It is therefore critical that efforts be taken to minimize the risk of spread from coastal areas to the Sierra Nevada.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Decline of Sugar Pine in the Sierra Nevada¹

Phillip J. van Mantgem² and Nathan L. Stephenson²

Throughout the Sierra Nevada, sugar pine is under attack from an exotic pathogen, white pine blister rust (*Cronartium ribicola*). Although the range and severity of infection are relatively well known, long-term demographic data that document the actual impact of the disease are lacking. Population trends have been estimated based on data collected from observations of 1,668 individual sugar pines over 5 to 15 years at four different sites in Sequoia and Yosemite National Parks. Populations are declining at most sites (lambda range: 1.01 to -0.82), and no site presents unequivocal evidence for population growth or stability as indicated by bootstrapped confidence intervals. Sensitivity analysis demonstrates that population growth rates are most closely tied to large tree survivorship. A retrospective analysis of the data shows, however, that poor recruitment is the primary cause of among-site differences with respect to the rate of population decline. Population change occurs very slowly for most tree species, and stochastic projections of this study's population models suggest that sugar pine will not become locally extinct at any of the study sites within the next 50 years. Nevertheless, local extinctions are likely within a generation, and additional stressors, such as fire, increased pathogen virulence, or climate change, may accelerate the rate of decline.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Amphibian Disease Dynamics in a Fragmented Landscape¹

Cheryl Briggs,² Lara Rachowicz,³ Vance Vredenburg,³ John Taylor,³ John Parker,³ Craig Moritz,³ Martha Hoopes,³ Rob Bingham,³ and Roland Knapp⁴

Impacts of a newly identified chytrid fungal pathogen, *Batrachochytrium dendrobatidis*, on populations of mountain yellow-legged frogs, *Rana muscosa*, are being studied. The chytrid fungus was first described in 1998 but has already been implicated in declines of amphibian populations worldwide. Reports of *R. muscosa* die-offs in the Sierra Nevada associated with the presence of the disease have been accumulating over the past 5 years. Laboratory and field experiments are being conducted to quantify the transmission process and understand effects of the disease on individual tadpoles and frogs. Results indicate that individuals infected as tadpoles die from the disease within days after metamorphosis. Field surveys and resurveys are documenting spread of the disease through the Sierra Nevada and impacts of the disease on *R. muscosa* populations. Information from transmission experiments, field surveys, and detailed studies of frog movement patterns will be used to establish parameters for spatially explicit models of the frog-chytrid relationship. The models will be used to help understand the host-disease interaction and suggest management strategies.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Ecology of an Arboreal Forage Lichen in Sierra Nevada Red Fir and Mixed Conifer Forests¹

Tom Rambo²

Bryoria fremontii is an arboreal lichen with important ecological linkages in Sierra Nevada forests. It is primary winter forage and nesting material for the northern flying squirrel, which itself serves as important prey for several sensitive species, including the California spotted owl, northern goshawk, marten, and fisher. Little is known about the effects of dispersed versus aggregated live-tree retention on the viability of arboreal lichens, and overall ecological knowledge of lichen epiphytes in these forests is limited. However, lichens are highly susceptible to forest thinning and environmental disturbances, especially those that produce changes in microclimate.

Bryoria distribution appears to be highly positively associated with red fir. This ongoing study will quantify the degree of this association, explore its nature, and assess the effect of overstory versus understory thinning treatments on *Bryoria* transplants in conjunction with the Teakettle Ecosystem Experiment. Overstory thinning produces a pattern of dispersed live-tree retention, whereas understory thinning is more apt to leave trees aggregated in groups. Results will provide forest managers with information on which thinning pattern, tree species, and habitat conditions are more favorable for fostering *Bryoria* populations. Conservation of *Bryoria*, in turn, has broad implications for the conservation of sensitive species and biodiversity in Sierra Nevada forests.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Meadow Fragmentation in Yosemite National Park as Indicated by Invertebrate Distributions¹

Jeff G. Holmquist² and Jutta Schmidt-Gengenbach²

Fragmentation of meadow plant assemblages by trails is relatively apparent, but effects on mobile fauna are more difficult to discern. Disturbance to vegetation may reduce habitat available for fauna to a greater extent than would be suggested by damage to plants, because even narrow gaps can greatly change the ratio of “edge” to “core” habitat in the surviving vegetation. Meadow invertebrate fauna were sampled using transects that ran perpendicular to trails to assess functional fragmentation of the meadow assemblage. A secondary goal was to provide baseline data on this important terrestrial assemblage.

Five low-elevation sites (Yosemite Valley) and five high-elevation sites (Tuolumne Meadows) were sampled over a 2-year period. Each site was sampled during both early (high soil moisture) and late (low moisture) season. At each site, a sample was taken in the trail, in meadow vegetation at the trail edge, and at 2, 5, and 10 meters from the trail. A suction extraction technique was developed for collecting surface-dwelling invertebrates: a Craftsman 320 km/h gasoline vacuum modified with a mesh collecting chamber inserted in the two intake tubes. Before vacuuming, a 0.5-square-meter steel quadrat with a mesh covering was thrown onto a randomly-determined location along the transect and staked into place. The vacuum tube was then inserted through an elasticized hole in the mesh and worked through the vegetation to remove fauna.

The meadow invertebrate assemblage proved to be remarkably diverse, with relatively low dominance of any one form, even at the taxonomic level of order. Mites were the most abundant organisms (Acari, 24 percent of fauna), followed by ants (*Hymenoptera*, 23 percent), beetles (*Coleoptera*, 11 percent), leafhoppers (*Homoptera*, 11 percent), flies (*Diptera*, 10 percent), and substantial numbers of spiders, bristletails, true bugs, grasshoppers, caddisflies, moths, lacewings, and other insects. There were 178.4 arthropods per square meter in the early season versus only 24.4 per square meter in the late season, and low-elevation sites had 2.2 times the overall abundance of high-elevation sites (139 versus 64 animals per square meter).

The effects of trails extended further into the surrounding meadow habitat than would have been predicted on the basis of vegetation alone. Invertebrate assemblages in portions of meadows bordering trails had 24 percent of the abundance of “core” meadow areas across all species. Ants provide a good example of the extension of trail effects into intact meadow vegetation. There was an average of 1.6 ants per square meter in trails, and 5.0, 9.0, and 63.6 ants per square meter in vegetation next to trails, 2 meters from trails, and 5 to 10 meters from trails, respectively. Abundances on the trails were even lower than expected: there was a mean of only 10.2 invertebrates (of all types) per square meter of trail versus 157.5 animals per square meter of core meadow habitat.

Meadows harbor a diverse and sensitive assemblage of invertebrates that is not readily visible. Trails negatively influence higher trophic levels, including both primary (for example, leafhoppers) and secondary (for example, spiders) consumers. Invertebrates are affected over an area that is 20 times greater than that of the removed vegetation; footpaths should be planned with the understanding that ecological “footprints” of trails extend beyond the limits of visible disturbance.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Pattern and Scale of Large Tree Distributions in the Sierra Nevada: Implications for Inventory, Monitoring, and Management¹

Jo Ann Fites-Kaufman,² Dave Weixelman,² Rand Knight,³ and Jerry Franklin³

The abundance and distribution of large trees is of primary importance in defining and measuring old forests in the Sierra Nevada. Most data used for old-forest and wildlife-habitat relations analysis and research is from small, sub-acre plots and low sampling intensities. Yet these data are often extrapolated to stand and even landscape scales. The accuracy and precision associated with different sampling intensities were evaluated in computer-simulated and actual old forest stands. Simulations of estimate precision with increasing sample area (0.1 to 25 percent) show that larger sample areas (greater than 5 percent) are needed when large tree densities are low—a common situation in the Sierra Nevada. Monte-Carlo permutations of 100 random selections of typical plots (0.10 to 1.6 acres) in stem-mapped old forest stands indicate that applied sample size areas are insufficient to accurately estimate large tree densities. This is partly due to the patchy distribution of large trees in stands in the Sierra Nevada. The most commonly used data set in the Sierra Nevada is the Forest Inventory and Analysis data, which represents less than 0.2 percent of a sample area. These results suggest that extrapolating small-plot data on large trees to stand or landscape scales may not only be inappropriate, but it also may be highly inaccurate.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Fisher Population Monitoring in the Kings River Adaptive Management Area¹

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Recent surveys have shown that fishers in the southern Sierra Nevada are isolated from other populations in the state by approximately 400 kilometers. Because of this isolation and because these populations occupy the southernmost extent of this species' range, managers are concerned about the conservation of fishers in California. To validate the regional surveys at a local scale, fisher population monitoring in the Kings River Adaptive Management Area is focused on the dynamics of a subpopulation using mark-recapture methods. In order to develop an efficient method for monitoring fisher populations at this scale, two recapture methods are being compared: re-sight of ear-tagged animals with automatically triggered cameras and DNA-based individual identification from hair samples. Preliminary surveys have been successful in identifying recaptured fishers using photo stations. Techniques for genotyping hair samples using microsatellites are being developed.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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The Importance of Riparian Habitat to Northern Flying Squirrels at the Teakettle Experimental Forest¹

Marc D. Meyer,² Douglas A. Kelt,² and Malcolm North³

The northern flying squirrel (*Glaucomys sabrinus*) is an important species for forest management in the Sierra Nevada because it is the principal prey of California spotted owls (*Strix occidentalis occidentalis*) and an agent of dispersal for hypogeous ectomycorrhizal fungi. Flying squirrels, hypogeous sporocarps (truffles), and several habitat factors were sampled in 18 separate old-growth forest stands in the southern Sierra Nevada to determine factors associated with flying squirrel abundance. Results demonstrated that creek area and distance were the only habitat factors significantly associated with flying squirrel abundance at the study site. Moreover, greater frequency, richness, and biomass of hypogeous fungi sporocarps were found in riparian areas relative to drier, upland sites. Flying squirrels may be strongly associated with perennial creeks at this study site because truffles have greater abundance and a longer fruiting season along creeks than the ephemeral truffle crop on upland sites. The results underscore the importance of perennial streams and creeks for wildlife in Sierra Nevada forest ecosystems.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Research Natural Areas in the Sierra Nevada Bioregion: Contribution to Biodiversity Conservation and Opportunities for Research¹

Constance Millar² and Hugh Safford³

The Research Natural Areas (RNA) program is a nationwide Federal network of public lands established to conserve biological diversity, provide baseline ecological information, and encourage scientific research. Areas selected are usually larger than 5,000 acres and exemplify minimally disturbed ecosystems representative of the range of terrestrial vegetation and habitat types administered by Federal land management agencies. The lands are strictly managed for biodiversity and environmental protection, but nonmanipulative research and monitoring are encouraged as primary objectives.

The Pacific Southwest Research Station and Pacific Southwest Region jointly manage the California program. In the Sierra Nevada, 22 RNAs have been established, and 20 more are pending establishment. RNAs range from low-elevation foothill grasslands on the west side and pinyon-juniper woodlands on the east side through the elevational zones to alpine fell-fields. Unpublished ecological surveys, which include detailed species lists, vegetation type maps, soils maps, and land use history exist for most of these areas. Many RNAs have long been sites of intensive research. The Hall RNA, for instance, on the Tioga Crest, was the location for pioneering genecological research by Clausen, Keck, and Hiesey in the 1940s. Current research by Schemske and colleagues continues the historic work at the molecular level.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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California Spotted Owl Demographics in the Southern Sierra Nevada, 1990-2001¹

Thomas E. Munton,² George N. Steger,² and William F. Laudenslayer, Jr.²

California spotted owl (*Strix occidentalis occidentalis*) demography has been examined at study areas in the Sierra National Forest (265 square miles) and Sequoia-Kings Canyon National Parks (132 square miles) for 12 consecutive years. The Sierra National Forest study area has been managed for multiple-use including timber harvest, whereas Sequoia-Kings Canyon National Parks has been managed as a National Park with removal of trees limited for decades. Standard spotted-owl study techniques were used to assess survival and reproductive success. The average fecundity for the Sierra National Forest study area for 1990 through 2001 was 0.2652 (se = 0.0690), estimated from an intercept only (means) model. Average fecundity for Sequoia-Kings Canyon National Parks from 1991 through 2001 was 0.2679 (se = 0.0703). On both study areas, fecundity rates varied substantially from year to year, whereas survival rates appeared less variable. Estimated adult apparent survival (F) was higher for Sequoia-Kings Canyon National Parks [F = 0.8774 (se = 0.0149)] than for Sierra National Forest [F = 0.8301 (se = 0.0154)]. The difference in forest management between study areas is only one of many possible explanations for the difference in survival. Further analyses that incorporate measures of vegetation structure and composition may provide insights into factors that may be causing this difference in survival.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Willow Flycatcher Meadow Habitat Parameters in the Sierra Nevada Bioregion¹

Rosemary A. Stefani²

Efforts to successfully model suitable habitat for the State endangered willow flycatcher (*Empidonax traillii*) across 11 million acres of the Sierra Nevada bioregion have been limited. Recent habitat selection modeling of this bird species in the north-central Sierra Nevada indicates that it is significantly more likely to be detected at sites with standing water or saturated soils and an abundance of riparian deciduous shrubs. In addition, site size often matters: more than 80 percent of willow flycatcher territories in the Sierra Nevada occur in meadows larger than 8 hectares. However, other features of known willow flycatcher sites in the north-central Sierra, such as dominant plant species, vegetation patch shape, amount and source of water, vary widely. This field study, which commenced in June 2002 and concluded at the end of September 2002, will assess and photo-document biotic, abiotic, and anthropogenic conditions in more than 100 known willow flycatcher sites as well as meadows that meet the general definition of potential willow flycatcher habitat (wet or moist meadows larger than 6 hectares with a riparian deciduous shrub component) in 11 national forests of the bioregion. These data will be used to determine whether there are any significant differences between known and potential site conditions that can be used to identify suitable willow flycatcher habitat model parameters for the bioregion. Summary statistics of condition assessment variables for known and potential willow flycatcher sites will be presented and future work identified.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Predator Abundance and Habitat Relationships in the Central Sierra Nevada¹

Andrew Hatch²

Forest ecosystems of the northern Sierra Nevada, between Lassen and Yosemite National Parks, have been subject to large-scale human alteration and management for hundreds of years. Predators with specific habitat requirements and rare predators, such as the Sierra Nevada red fox, California wolverine, and Pacific fisher, apparently are extirpated from this region. Since 1997, the Central Sierra Environmental Resource Center has placed more than 125 carnivore scent-stations throughout the Stanislaus National Forest. The low statistical power of the scent-station survey did not allow for population trends or estimates to be obtained from the data. The relationship between predator abundance and habitat type and quality does give an indication that large, undisturbed regions of high-quality habitat may be a limiting factor for rare predators within the central Sierra Nevada. Forest management practices that decrease fragmentation and increase forest interior could help provide corridors and habitat patches for the Pacific fisher if it is reintroduced or if as yet undiscovered remnant populations survive in the central Sierra Nevada.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Finding Core and Corridor Wildland Areas in the Sierra Nevada and Modoc Plateau Using GIS¹

Evan Girvetz² and Fraser Shilling²

The goals of the Wildlands Project are to maintain native species, habitat types, ecological and evolutionary processes, and the adaptive nature of North American ecosystems. To help meet these goals for the Sierra Nevada, the landscape was assessed for its ability to support a wildlands network, using a combination of focal species habitats, unfragmented landscapes, and essential connecting and ecologically critical areas. The ArcView extension program “Ecosystem Management Decision-Support” was used to combine these disparate elements and data sets for the Sierra Nevada, Modoc Plateau, and Cascade bioregions. Each 500-by-500 meter-grid cell of the landscape was scored for its contribution to conservation of biodiversity and “wildlands.” Then, using the annealing function of SITES ArcView extension, these grid cell values were gathered together to create “core areas.” Finally, the “Least Cost Path” extension of ArcView was used to create corridor connection among these core areas. This wildlands network was tested for its ability to represent particular plant communities within the network, the overlap between the network and focal species habitat maps, and the proportion of roadless areas and other areas of interest contained within the wildlands system.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Avian Biodiversity in the Sierra Nevada over an Elevational Gradient¹

Kathryn L. Purcell² and Douglas A. Drynan²

Conserving all species is essential for sustaining ecosystem patterns and processes, and the appropriate focus for wildlife conservation by the Forest Service is on maintaining native biodiversity. Conservation of biological diversity depends on availability of habitat conditions that sustain healthy populations of coexisting species. A closer look at the habitat needs of individual species will enable prediction of their responses to habitat change resulting from management practices.

Bird census and vegetation data were collected at 18 study sites from 1995 through 2002. The sites were distributed across an elevational gradient and occurred in four forest types: ponderosa pine (1,025 to 1,370 meters), mixed conifer (1,710 to 2,010 meters), true fir (2,170 to 2,350 meters), and lodgepole pine (2,470 to 2,775 meters). Species diversity was highest at the lowest elevation sites and decreased with increasing elevation. Abundance generally followed the same pattern and was highest in ponderosa pine and mixed conifer sites. Annual variability was high and related to weather conditions.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Snow-tracking American martins in the Lake Tahoe Basin: A Quantitative Method for Supporting Science-Based Management¹

Mary Cablk² and Susan Spaulding³

American martens (*Martes americana*) are forest carnivores that are known to occur in the Lake Tahoe Basin. In some cases, martens are found in proximity to recreational areas, including ski resorts, snowmobile routes, and campgrounds. Understanding relationships between martens and anthropogenic activities is critical for managing animal populations and their habitats. To address this issue using quantitative methods, research began in January 2002 at Heavenly Ski Resort as a joint effort between Heavenly Ski Resort, Desert Research Institute, and the USDA Forest Service. Methods that incorporate advanced GPS and GIS tools with snow-tracking have been developed. The method has advantages over telemetry in certain situations but also has its own caveats. Data collected directly from snow-tracking includes information on subnivean access, road and trail use or avoidance, and home range sizes. Snow-tracking data are easily incorporated with other data collected using different methods, such as remote cameras or track plate stations. Other analyses can also be conducted with these data, for example, by incorporating them with spatial habitat characteristics to assess habitat preferences. Snow-tracking data can be used to examine the habits of individual animals or to better understand dynamics at a population or landscape scale.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Native Bees in Sierra Nevada High Meadows¹

Richard G. Hatfield²

Montane meadows and wetlands, especially those with emergent vegetation, are some of the most productive wildlife habitats in California. The importance of high-elevation wetlands to biodiversity is nowhere more evident than on the arid eastern slope of the Sierra Nevada.

Native bees are the most important animal pollinators of flowering plants in the Sierra Nevada ecosystem. A two-pronged approach was used to examine whether local or regional factors determined native bee diversity in Sierra Nevada eastern slope meadows. First, the diversity of solitary and native bee populations was examined in wet and dry meadows with differing proportions of willow (*Salix* sp.) habitat. Second, the properties of eastern slope meadows that contribute to bumblebee (*Bombus* sp.) diversity were examined. Meadow characteristics compared included size, presence of grazing, grazing history, floral diversity, and proximity to other wet and dry meadows. As the Forest Service, Bureau of Land Management, The Nature Conservancy, and others are currently developing plans for northern Sierra Nevada meadow restoration, this study will provide useful information that can contribute to the management of these important and diverse habitats.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Bird Population Dynamics of Sierra Nevada Meadows¹

Mark D. Reynolds,² Julia I. Smith,³ and Gretchen LeBuhn⁴

Montane meadows of the Sierra Nevada are some of the most productive and imperiled habitats for breeding and migrating landbirds in western North America. The Nature Conservancy has recently established the Northern Sierra Project with the goal of preserving more than 55,000 acres of unprotected mountain meadow habitats. Understanding natural and human influences on the quality of montane meadow habitats for birds in the Sierra Nevada is critical to measuring the success of conservation actions: preservation, mitigation, and restoration. Livestock grazing is believed to be a primary threat.

Meadows in the northern Sierra Nevada vary in size, shape, elevation, hydrology, vegetation, and current and historical management. To understand effects of meadow condition and trend, including grazing, on bird populations, 50 meadows within the greater northern Sierra Nevada region (100-square-kilometer study area) have been sampled over the past several years using standard monitoring protocols (point counts, mist-netting, and nest searches). Meadows varied substantially in size and habitat heterogeneity. Large meadows generally had higher species richness ($r^2 = 0.44$) and diversity ($r^2 = 0.23$) and lower evenness ($r^2 = 0.17$). Meadows had unique species assemblages with low inter-meadow community similarity (mean Jaccard's index = 0.32 ± 0.04). Wet-meadows had significantly greater species richness than dry meadows. Wet meadow-dependent bird species were detected infrequently and were concentrated mostly in the northern-most part of the study area. Species richness decreased slightly with erosion pavement and stream incision effects associated with livestock grazing. Bird population metrics will be used as an index to calibrate habitat restoration and measure conservation success.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7-10, 2002, Kings Beach, California.

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Floristic Similarity of Meadows among National Forests in California¹

Dave Weixelman²

Meadow sites were studied in order to determine floristic similarity of meadows among national forests in California. During the summers of 1999 through 2001, 456 meadows were sampled across 16 national forests in California as part of the Forest Service's range monitoring program. The overall objective of the program was to establish permanent monitoring plots in meadows for recording meadow condition and trend. At each plot, percent frequency of occurrence for each plant species was recorded using 60 quadrat frames. An agglomerative, hierarchical clustering technique, using Euclidean distance measures, was applied to the data using the statistical package SPSS. For this analysis, 186 plant species were used, with sedges (*Cyperaceae*), rushes (*Juncaceae*), and grasses (*Poaceae*) being the main contributors. Only meadows with a water table of less than 100 centimeters were used in the analysis. Results indicate the presence of four significant geographical regions: (1) Sierra Nevada east side and southern Cascade/Sierra Nevada transition forests, (2) southern Cascade and northwestern California forests, (3) central and southern Sierra Nevada west side forests, and (4) southern forests of the transverse range. These results can be used to draw preliminary floristic boundaries for meadow classification work and provide ecological response units for meadow management.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Annual Variation and Geographic Patterns in Acorn Production by California Black Oak¹

Barrett A. Garrison² and Walter D. Koenig³

California black oak (*Quercus kelloggii*) is the predominant deciduous tree found in montane hardwood and coniferous forests in the Sierra Nevada. Recent assessments of the natural resources in the Sierra Nevada, including the Sierra Nevada Ecosystem Project and the Forest Service's Conservation Framework, have identified conservation issues with this tree species. Many species of birds and mammals feed on acorns produced by California black oak, and acorn production has considerable temporal and spatial variation that may have ecological implications to wildlife, oak recruitment, and forest attributes. Between 1994 and 2001, acorn production was measured at seven sites in California, including three in the Sierra Nevada and southern Cascades. Acorn production varied among years and locations, but production tended to be greatest for trees in southerly latitudes and western longitudes. Tree age and weather were additional factors influencing acorn production by California black oak.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Assessing Patterns of Vegetation Change in the Sierra Nevada Using Remotely Sensed Data¹

Lisa M. Levien,² Sean Parks,² Scott Shupe,² and JoAnn Fites³

As human and natural forces continue to alter the landscape, resource agencies, county planners, and local interest groups find it increasingly important to monitor and assess change. Under the Sierra Nevada Forest Plan Amendment Final Environmental Impact Statement (FEIS), old forest ecosystems are identified as needing urgent attention because they are one of the most altered ecosystems in the Sierra Nevada. Knowing the distribution of old forest ecosystems and patterns of vegetation change over time can provide critical information for planning and management processes and tools. Assessing patterns and levels of vegetation change within these ecosystems provides a tool for understanding the impacts that change agents have on the landscape. Vegetation-change data from the California Land Cover Mapping and Monitoring Program (LCMMP) are used to determine the distribution and patterns of change within the Sierra Nevada bioregion. Multi-temporal Landsat Thematic Mapper (TM) data are used to map changes in vegetation cover over an approximately 20-year span. Other geographic layers, including old forest ecosystems data, are used to assess patterns of change across the Sierra Nevada.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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A Systematic Approach to Assessing the Biodiversity of Bats in the Sierra Nevada¹

Patricia N. Manley,² Ted Weller,³ and Michelle McKenzie⁴

Bats play an important role in ecosystem function, as well as provide ecological services of unquantified economic value. The most basic information about distribution, abundance, and habitat association is lacking for many bat species, even as evidence suggests that some species are becoming less common and their populations may be declining. In the Sierra Nevada, 11 species of bats are of concern, and basic information gaps pose a barrier to their conservation. The majority of information about bats in the Sierra Nevada has been derived from surveys at non-random locations and known roosts. However, large-scale inventory and monitoring approaches based on a probabilistic sample have the greatest potential to generate reliable information for many species in a relatively short period of time. A second year of testing a systematic, landscape-scale approach to monitoring bat populations, which combines the use of mist-nets with state-of-the-art acoustic monitoring to survey species, is being completed. An analysis of sampling efficiency to describe site-specific species composition has been conducted. A model-based approach is used to estimate detection probabilities for individual species and species richness. Those probabilities are then used to calculate minimum sample size requirements to detect changes in species distribution and richness.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Patterns and Thresholds of Fragmentation in Urbanizing Landscapes¹

Patricia N. Manley² and Dennis D. Murphy³

Biological diversity is affected by a wide variety of environmental events and processes, including past evolutionary developments, biogeographic processes, extinctions, as well as ongoing ecological influences. In the Sierra Nevada fragmentation and anthropogenic disturbance are key factors that affect the biological diversity and integrity of forested ecosystems at multiple scales. However, the current understanding of the specific effects of fragmentation at multiple spatial and temporal scales and the interactive effects of anthropogenic disturbances is extremely limited.

In the Lake Tahoe Basin, researchers are studying species distribution, species diversity, and ecological integrity across fragmentation and disturbance gradients at the patch scale and interactive threshold effects of fragmentation at the landscape scale. Measures of biological diversity include the presence, abundance, and reproductive status of species most likely to be most affected by fragmentation and disturbance, including birds, small mammals, invertebrates, and vascular plants. Potential patch-scale effects include loss of native species, lower abundance and reproductive success of those species, presence of exotics, and changes in plant phenology that can affect plant-animal interactions. Potential landscape-scale effects of fragmentation include loss of native species, lower population sizes, and isolation of populations. Patch-scale predictive models will be developed and spatially explicit simulation modeling will be used to evaluate landscape-scale thresholds and predict the effects of potential future fragmentation scenarios.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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A New Inventory and Monitoring Program in Sierra Nevada National Parks¹

Linda S. Mutch²

The National Park Service has implemented an inventory and monitoring program to improve the quality and accessibility of natural resource information for park managers, Park Service policy makers, and the public. The first phase of the program is a biological inventory with the following goals: (1) to document the occurrence of at least 90 percent of vertebrate and vascular plant species estimated to occur in parks and (2) to describe the distribution and relative abundance of species of special management concern, which include listed species, invasive non-native species and other species of special management interest to parks. The second phase of the program will establish long-term monitoring of key indicators of ecosystem change.

To improve the efficiency of an inventory and monitoring program, the Park Service created networks of parks that are linked by geography and shared natural resource characteristics. The Sierra Nevada Network (SNN) includes Devils Postpile National Monument and Sequoia Kings Canyon, and Yosemite National Parks. The SNN is in the third year of a 5-year biological inventory program. Results of baseline inventories for bats, birds, vascular plants, slender salamanders, and invertebrates are available, as is a summary of data management priorities, upcoming inventories, and planning efforts for long-term monitoring.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Characterizing Fire Threats to Communities: Combining Regional and Project Planning Perspectives¹

Dave Sapsis² and William Stewart²

Characterizing the scale of the wildland-urban interface problem and improving site-specific responses to fire threats to communities involve different analytical procedures that often do not work well together. Two scales of analysis, regional and project, are used to characterize fire threats to communities in California. At the regional/statewide scale, a standardized procedure is used to combine fire hazard and modern-era fire occurrence into a composite index of fire threat. Housing-density data from the U.S. Census are used to characterize population densities into urban, interface, rural residential, and wildland housing densities. Density grids are then characterized by their maximal fire threat within a 1.5-mile buffer area. The resulting statewide map shows a combined density by proximal fire-threat class.

For project level analysis, spatial fire-growth modeling is used in conjunction with terrain, ownership, detailed housing information, and expected severe fire weather patterns to explore alternative patterns of landscape fuel treatments required for effective reductions in fire risk to communities. The use of strictly defined buffer distances from ownership boundaries will often not effectively modify fire behavior to reduce risk of house loss. Effective project level implementation requires assessing area-specific hazards and opportunities for mitigations, which invariably require flexibility in land allocations and collaboration across jurisdictions.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Decision Support for Road System Analysis and Modification on the Tahoe National Forest¹

Fraser Shilling² and Evan Girvetz²

The USDA Forest Service is required to analyze road systems on each National Forest to assess potential environmental impacts. The authors have developed a novel and inexpensive way to do this using the Ecosystem Management Decision Support (EMDS) program (1999). EMDS integrates a user-developed fuzzy logic knowledge base with a grid-based geographic information system to evaluate the degree of truth for assertions about a road's environmental impact. Using spatial data for natural and human processes in the Tahoe National Forest, the authors evaluated the assertion that “the road has a high potential for damaging the environment.” There was a high level of agreement between the products of this evaluation and ground observations of a Tahoe National Forest transportation engineer, as well as occurrences of road failures. Network analysis showed that, of 8,233 kilometers of road analyzed in the Forest, 3,483 kilometers (42 percent) must be kept in a modified road network to ensure access to 1,573 points of interest in the Forest. The modified network was found to have significantly fewer “cherry stem” roads intruding into patches, an improved area-weighted mean shape index, and larger mean patch sizes, as compared to the original network. This system could be used by public agencies to analyze infrastructure for environmental or other risk.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Influence of Vegetation and Land Use on Central Sierra Nevada Ranchers¹

Adriana Sulak² and Lynn Huntsinger²

Central Sierra Nevada ranchers own thousands of foothill woodland acres, grazed as parts of livestock operations that often use National Forest montane lands in summer. In 2000 and 2001, ranchers with and without Forest Service grazing permits were interviewed about their rangeland use. Fifty-two percent of permittees and 14 percent of non-permittees reported that vegetation change was having a highly important impact on their summer ranges. Ranchers stated that a decline in burning and timber harvest has led to lower understory production, thickening brush, and encroachment into meadows. Prescribed burning and brush removal on summer range were more frequently carried out by non-permittees, whereas on National forest lands, riparian fencing was more frequent. Eighty-seven percent of permittees and 54 percent of non-permittees reported that land development was a “more important” or “highly important” influence on the management of their ranches. Dogs were a major problem, but limits to cattle driving, ownership fragmentation, trespassing, complaints, cars crashing into fences, and poisonings were all mentioned as consequences of demographic change. Participants estimated that an average of 7.6 ranches had been sold in their communities over the past 10 years, fewer than two kept in ranching and the rest developed or soon to be.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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The California Legacy Project¹

Heather Barnett²

The California Legacy Project aims to help State agencies and conservation partners make better decisions about how to conserve natural resources and working landscapes. The Legacy Project is creating science-based analytical tools to assist State and Federal agencies, local and regional governments, and public and private groups assess resource values and risks and conservation opportunities for large landscape areas in the state’s major bioregions. Such evaluations guide decision makers to more effective and strategic allocations of funds. Initial landscape-level analyses then can be expanded by individual entities to support more specific planning and project identification. The decision-support tools created by the Legacy Project are flexible. They allow a wide range of users to apply their own values in assessing conservation options in addition to helping frame a statewide conservation strategy. The California Legacy Project poster display includes information on the Project’s goals and key steps in the Project’s work plan. It also includes a demonstration of the California Conservation Digital Atlas, a web-based mapping system developed by the Legacy Project. Users of the Conservation Atlas will be able to combine existing information to derive new information, create custom maps, and download data to their own computers.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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A Landscape of Change in Sierra Nevada Watersheds¹

Thomas Gaman² and Ron Arnett²

The Sierra Nevada of California is undergoing rapid change owing to past mining, logging, grazing, fire suppression, and road-building practices. Coupled with ongoing urbanization, climate change, fire, and resource use, the choices for Sierra Nevada conservation are fewer and more complex. The Sierra Nevada Ecosystem Project (SNEP) provided a rich foundation of scientific information, but provided no direction. Post-SNEP planners are looking at ways to assess and manage change. Today, many citizens, politicians, agencies, and environmental groups are advocating the establishment of a Sierra Nevada Conservancy.

During spring 2002, as part of a broad effort to quantify natural resource issues, East-West Forestry Associates, Inc. used a geographical information system (GIS) to assess impacts of the drivers of change upon Sierra Nevada natural resources. Based on SNEP, California Department of Forestry and Fire Protection, and Fire and Resource Assessment Program (FRAP) data, the 2000 Census, California Department of Finance demographic projections, and a wide variety of other public information, 20 thematic coverages of the Sierra Nevada region were assembled. From these, three primary map sets were created: (1) population pressure, (2) resources at risk, and (3) change in the working landscape. This poster presents these maps, which highlight and quantify current conditions and projected changes throughout the 25 major Sierra Nevada watersheds.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Forest and Range 2002 Assessment: The Changing California, Assessing Resource Sustainability within the Sierra Nevada and across California¹

Chris Zimny²

Policies and strategies that guide use and management of the Sierra Nevada are extensive because there are so many topics of concern. This situation is no different than at the statewide, national, or international level. The California Department of Forestry and Fire Protection's Fire and Resource Assessment Program (FRAP) is mandated to periodically assess the status and trends of California's 80 million acres of forest and rangeland resources to provide information for developing and implementing resource policies for the State.

The Web-based assessment has adopted international criteria and indicators for resource sustainability from the Montreal Process as the framework for assessing forest and rangeland resources in California and subregions such as the Sierra Nevada. This framework identifies seven board criteria that are essential to resource sustainability: biological diversity; maintenance of productive capacity; forest health and vitality; soil and water conservation; forest contribution to global carbon cycles; socioeconomic benefits; and legal, institutional, and economic framework for forest conservation and sustainable forest management. Highlighted findings from the assessment focus on the interrelationships of change agents, such as fire, global markets for products, global environmental impacts, and the potential impact of California's growing population on ecosystem and rural socioeconomic conditions.

¹ This abstract summarizes a poster that was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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Protection and management of resources on 191 million acres of National Forest lands;

Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest land and associated range and watershed lands;

Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas; and

Research on all aspects of forestry, rangeland management, and forest resources utilization.

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