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U.S. Department of the Interior
U.S. Geological Survey
Western Ecological Research Center

Sierra Nevada Global Change Research Program

Sierra Nevada Forest Dynamics: Pattern, Pace, and Mechanisms of Change

Annual Report for Fiscal Year 2001

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INTRODUCTION

The Sierra Nevada Global Change Research Program began in 1991 as a peer-reviewed, competitively-funded component of the National Park Service's (now USGS-BRD's) Global Change Research Program. While Sequoia, Kings Canyon, and Yosemite national parks form the core study areas of the program, the full study region encompasses adjacent public lands.

The goal of the Sierra Nevada Global Change Research Program is to understand and predict the effects of global changes on montane forests. By far the greatest limitation to understanding and predicting the effects of future global changes is the lack of a precise mechanistic understanding of how contemporary forest structure and function are controlled by the physical environment, disturbances, and biotic processes. Our research program therefore places landscape patterns within the context of the physical template (abiotic factors such as climate and soils), disturbances (such as fire), and biotic processes (demography, dispersal, growth, and competition). Our program focusses on developing a mechanistic understanding of this simple model as it applies to Sierra Nevada forests in particular, but also for the montane forests of western North America in general.

Our 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 us to evaluate climatic mechanisms controlling forest composition, structure, and dynamics. The *modeling theme* integrates findings from the paleoecological and contemporary studies, and is the indispensable vehicle for scaling up our mechanistic findings to regional landscapes, and predicting which parts of montane landscapes may be most sensitive to future environmental changes.

The Sierra Nevada Global Change Research Program currently focusses on addressing nine central sets of questions:

- What is the relative importance of topography and soil on site water balance in the Sierra Nevada, and how well does this compare with model predictions?
- What is the role and importance of reproduction in determining forest pattern and forest sensitivity to climatic change? By what mechanisms does climate control reproduction, and therefore forest sensitivity to climatic change?
- How do seed dispersal, seedling dynamics, and fine-scale variations in topography and soils interact with climatic change to affect forest sensitivity and change at local scales?
- How does climatic change affect the spatial extent, landscape pattern, and severity of fires?
- What are the relative importances of tree recruitment, death, and growth rates, and their interannual variabilities, in determining forest response to climatic variation in space and time?
- What portions of Sierra Nevada landscapes are most sensitive to climatic changes (temperature, precipitation, and seasonality), what are the implications of this for a greenhouse world, and what are the implications for land managers?
- Does climate synchronize fire regimes at subcontinental scales? If so, what large-scale climatic phenomena drive the synchrony?

- Can agents of pattern formation and mechanisms of forest change be generalized at subcontinental scales?
- How do the relative importances of agents of pattern formation vary among different climates? Is our understanding of mechanisms of forest change sufficient for a single model to explain forest dynamics at several different sites across the continent?

Overview of Progress and Results

During 2001 we published, or had accepted for publication, 17 scientific manuscripts (including one Ph.D. dissertation) related to the Sierra Nevada Global Change Research Program, with another seven manuscripts currently in review, and several in progress. Examples of some of our significant findings are as follows. We have called into question some of the basic assumptions common to most forest dynamics models meant to predict the effects of climatic change, and have pointed out how those models might be improved. We have also found that the pattern of high-elevation conifer growth rates in the Sierra Nevada during the last half of the 20th century differs from any time in the past 1000 years, indicating a distinct biological signature of global change. Additionally, we have had some early successes in efforts to develop a fire hazard forecasting system for regions of the western U.S., based on climate-fire relations determined from tree-ring studies.

Significant progress was made in leveraging further support for the Sierra Nevada Global Change Research Program. Dean Urban (Duke University) and colleagues secured National Science Foundation funding to continue their cross-site comparison project of montane forest dynamics, including the Sierra Nevada. Urban and colleagues also secured a second grant, funded by the Joint Fire Science Program, to explore patterns of fine-scale spatial heterogeneity in microenvironment in the Sierra. Tom Swetnam (University of Arizona) and colleagues obtained funding for a paleofire and climate workshop, expected to result in new proposals for regional-scale collaborations and cross-comparisons of fire and climate histories in the western U.S. Andrew Bunn (a graduate student with Lisa Graumlich, Montana State University) received a prestigious Canon National Parks Science Scholarship, allowing him to expand his Ph.D. research efforts in the Sierra Nevada and Yellowstone National Park, thereby further supporting USGS-BRD's Western Mountain Initiative. Keeley secured funding through the Joint Fire Sciences program which will allow us to better determine the effects of fire on forest dynamics, particularly seedling dynamics.

Specific Accomplishments and Results

Results derived from analysis of our long-term forest demography data challenge some of the basic assumptions of current models of forest dynamics. A particularly important assumption of current models is that the only way environmental changes can affect tree death rates is by altering tree growth rates. However, our data suggest that environmental changes may have some of their greatest effects not by altering growth rates, but by altering the fundamental nature of the relationship between growth rates and death rates. Our results will be submitted to the journal *Ecology*.

Collaborators Bunn, Graumlich, and Urban found that the pattern of high-elevation conifer growth rates in the Sierra Nevada during the last half of the 20th century differs from any time in the past 1000 years, indicating a distinct biological signature of global change. They came to this conclusion after analyzing a multi-species Sierra Nevada tree-ring database using non-parametric ordination and cluster analysis. They decomposed tree-ring variability at annual to decadal time scales into two dimensions, both of which are significantly correlated to temperature and precipitation variation.

Collaborator Tom Swetnam, working with Dr. Anthony Westerling at Scripps Oceanographic Institute, had some early successes in efforts to develop a fire hazard forecasting system for regions of the western U.S. In preliminary tests using Swetnam's Sierra Nevada and Southwestern fire-scar networks, regression models calibrated on 20th century Palmer Drought Severity Index and area burned data (from fire scars) effectively "retrodicted" pre-20th century fire occurrence.

Analysis of data from our two burned forest demography plots indicates that in addition to the usual predictors of tree mortality (such as crown scorch), pre-burn growth rate is a significant predictor of tree mortality following fire. This finding provides a conceptual link between models of tree mortality with and without fire. Our results have been submitted to *Ecological Applications*.

In studies tied to their Sierra Nevada work, collaborators Bunn, Graumlich, and colleagues at Montana State University found further evidence of the importance of the physical environment in affecting tree growth variability. Examining the spatial distribution of strip-barked trees in the Greater Yellowstone region, they found that strip-barked tree locations were not random, but correlated to abiotic proxies for soil moisture. Furthermore, the difference in growth rates between strip-bark trees and entire-bark companion trees increased with increasing soil moisture.

Collaborators Dean Urban and colleagues codified an integrated approach to sampling and analysis of vegetation-environment relationships in montane landscapes, putting this approach forward as a general method for extending community ecology to landscapes in a spatially explicit manner. The approach consists of spatially articulated sampling, spatial statistics and distance-based multivariate analyses, to build a preliminary explanatory model. This model is then dissected to reveal its errors and weakest points, which are then mapped into geographic space to provide a set of candidate sites for follow-up studies -- sites which will provide the most valuable data in the most efficient manner. This iterative approach to sampling and analysis can be generalized to any system.

Urban and colleagues devised and prototyped two new field approaches to discover the mechanisms of tree demographic response to environmental constraints, and which constraints are most important in defining species distributions. They developed "gradient focus plots" as a tool to isolate the relative importance of seedling establishment, relative growth, and survival in response to spatial variability in temperature and soil moisture along rapidly changing gradients. These plots are mapped transects along which microenvironmental variables are measured directly and all woody stems are tallied by species, size, age, and growth rate. They have implemented these in the Sierra Nevada, Yellowstone area, and the Oregon Cacades.

Keeley secured funding through the Joint Fire Sciences program to explore the ecological consequences of burning Sierra Nevada forests in different seasons. Besides complementing Swetnam's work using tree-rings to determine the season of past fires, this work has allowed us to establish three more long-term forest demography plots to better determine the effects of fire on forest dynamics, particularly seedling dynamics. The plots were burned this autumn.

Urban and colleagues secured additional funds to further leverage the support of USGS-BRD's global change research program. One grant, from NSF--Ecosystems, is a continuation of the cross-site comparison project that involved the Sierra Nevada for the past several years. This new grant ($300,000; 3 yrs) will support work in the Sierra along with sites in the Oregon

Cascades, the southern Appalachians, and the White Mountains in New Hampshire. The second grant, funded by the Joint Fire Science Program (JFSP), explores patterns of fine-scale spatial heterogeneity in microenvironment, fire effects, and herbaceous layer seedling response (including tree seedlings).

Swetnam and colleagues planned and obtained funding for a paleofire and climate workshop to be held in Tucson, Arizona, March 23 to March 28, 2002. About 70 climatologists and experts on tree-rings and pollen and charcoal sediment will meet at this workshop to discuss paleofire climatology, exchange data, and discuss new research initiatives. The workshop is expected to result in new proposals for regional-scale collaborations and cross-comparisons of fire and climate histories in the western U.S., and with South American scientists.

Andrew Bunn (a graduate student with Lisa Graumlich) received a prestigious Canon National Parks Science Scholarship partly on the strength of his accomplishments and results as a collaborator in the Sierra Nevada Global Change Research Program. This allows him to expand his Ph.D. research efforts in the Sierra Nevada and Yellowstone National Park, thereby further supporting the Western Mountain Initiative.

As usual, USGS personnel in the Sierra Nevada Global Change Research Program frequently assisted the National Park Service in such tasks as setting research priorities and fire management objectives. Additionally, Stephenson was appointed by the Secretary of Agriculture to serve on the Science Advisory Board for the newly-created Giant Sequoia National Monument.

Stephenson and others were contacted frequently by the press, often for information ultimately derived from the Sierra Nevada Global Change Research Program. These contacts included interviews by National Public Radio, Britain's NOW channel, the Los Angeles Times, the San Francisco Chronicle, the Natural Resources News Service, the Fresno Bee, the Porterville Recorder, the Bakersfield Californian, and the Forestry Source (Society of American Foresters).

PROGRESS TOWARD INTEGRATION WITH OTHER PROJECTS WITHIN RESEARCH THEME

Swetnam's fire history research group at the University of Arizona's Laboratory of Tree-Ring Research has been building collaborations with fire historians in several other montane regions of the western U.S. These collaborations include Drs. Amy Hessl and David Peterson of USGS, USFS, and University of Washington; Dr. Emily Heyerdahl of USFS Fire Sciences Lab; Dr. Lisa Graumlich of Montana State University; Peter Brown, Rocky Mountain Tree-Ring Lab; Dr. Thomas Veblen, University of Colorado, and others. The scientific objectives of these collaborations include: (1) compare fire and climate histories at multiple spatial scales over the past 300-500 years to identify important climatic drivers of past fire regimes, (2) identify potential relationships between the El Nino-Southern Oscillation and Pacific Decadal Oscillation and forest fire activity in the past that may be useful for fire hazard forecasting in the future, and (3) to identify any consistently correlated (positively or negatively) fire history patterns among different regions of the western U.S. Swetnam has also been collaborating with Dr. Anthony Westerling at Scripps Oceanographic Institute in an effort to develop a fire hazard forecasting system for regions of the western U.S.

Swetnam and colleagues will hold a paleofire and climate workshop in Tucson, Arizona, March 23 to March 28, 2002. About 70 climatologists and experts on tree-rings and pollen and charcoal sediment will meet at this workshop to discuss paleofire climatology, exchange data, and discuss new research initiatives. The workshop is expected to result in new proposals for regional-scale collaborations and cross-comparisons of fire and climate histories in the western U.S., and with South American scientists.

Urban's modeling efforts have focussed on products applicable to any montane site. He has already done cross-site comparisons among the Sierra Nevada, Oregon Cascades, and southern Appalachians. His new fire project funded by the Joint Fire Sciences Program includes a substantial emphasis on generalizing the approach and disseminating it to other western systems.

Graumlich is active in pursuing integration within the framework of the Western Mountain Initiative. In 2001 she and Dan Fagre (USGS Western Mountain Initiative, Glacier National Park) initiated a project to use tree-ring records to reconstruct interannual to decadal scale climate variability in Glacier National Park. The 400+ year records will be used to provide a climatic context for the interpretation of the 20th century retreat of alpine glaciers as well as in interpreting treeline dynamics. In a similar vein, Graumlich is continuing her NSF-funded and USDA-funded projects to investigate the nature of climate variability at decade to century time scales in the Greater Yellowstone Ecosystem and to detect its impact on pre-historic fire regimes.

Stephenson continued his analyses of forest demographic data similar to those collected by the Sierra Nevada Global Change Research Program, but from Mount Rainier, Washington. The Rainier data will provide a valuable contrast to the Sierra Nevada data, allowing us to look for broad generalities about relationships between climate and forest dynamics.

PLANS FOR COMING YEAR

All collaborators will continue field work, data analysis, and writing. Particular emphasis will be placed on a book (in progress) that synthesizes results to date. Swetnam plans to finish crossdating all remaining samples within his extensive Sierra Nevada fire scar collection. Additionally, inter- and intra-regional fire-climate investigations and fire regime comparisons will proceed as described above. Urban will be fielding two crews in the Sierra Nevada to further develop the gradient focus plots and environmental settings approaches, and to continue work on the new project funded through the Joint Fire Sciences Program. Bunn and Graumlich will further explore the relationship between climate, biotic interaction, the physical environment, and tree growth. They will combine dendrochronological techniques, their recently-obtained imagery from the satellite-based IKONOS sensor, and a very fine scale DEM to shed light on these relationships. Graumlich will continue to work with the Western Mountain Initiative to understand the impacts of climatic variability on mountain ecosystems from the Sierra to Yellowstone. Keeley will place particular emphasis on analysis of the seed and seedling data collected over the last three years within the forest demography plots. Stephenson and van Mantgem will continue analysis of the extensive tree demography data set, with particular emphasis at examining forest carbon dynamics along the Sierra Nevada climatic (elevational) transect.

PRODUCTS

Publications:

Bunn, A. G., L. J. Graumlich, and D. L. Urban. In review. Interpreting the climatic significance of trends in twentieth-century tree growth at high elevations. Submitted to *Global Change Biology*.

Bunn, A. G., R. L. Lawrence, G. J. Bellante, L. A. Waggoner, and L. J. Graumlich. In review. Spatial variation in distribution and growth patterns of old growth strip-bark pines. Submitted to *Ecoscience*.

Graumlich, L. J., M. F. J. Pisaric, L. A. Waggoner, J. Littell, and J. King. In review. Upper Yellowstone River flow and teleconnections with Pacific basin climate variability during the past three centuries. Submitted to *Climate Change*.

Gutsell, S. L., E. A. Johnson, K. Miyanishi, J. E. Keeley, M. Dickinson, and S. R. J. Bridge. 2001. Varied ecosystems need different fire protection. *Nature* 409:377.

Keane, R. E., R. E. Burgan, and J. W. van Wagtendonk. 2001. Mapping wildland fuels for fire management across multiple scales: integrating remote sensing, GIS, and biophysical modeling. *International Journal of Wildland Fire* 10(3&4):301-319.

Keeley, J. E. 2001. Fire management of California shrubland landscapes. *Environmental Management* 29:395-408.

Keeley, J. E. 2001. We still need Smokey Bear! *Fire Management Today* 61(1):21-22. http://www.werc.usgs.gov/seki/pdfs/smokey.pdf

Keeley, J. E. 2002. Fire and invasives in mediterranean-climate ecosystems of California. Pages 81-94 *in* T. P. Wilson and K. E. M. Galley (editors), Proceedings of the Invasive Species Workshop: The Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

Keeley, J. E. In press. Fire management of California shrublands. *In* California's 2001 Wildfire Conference and Public Events: Ten Years After the 1991 East Bay Hills Fire. California Association of Fire Ecology, Oakland, CA.

Keeley, J. E. In press. Plant diversity and invasives in blue oak savannas of the southern Sierra Nevada. *In* Fifth Symposium on California's oak woodlands: Oaks in California's changing landscape; October 22-25, 2001, San Diego, California. University of California, Davis.

Keeley, J. E. In review. Fire as a threat to biodiversity in California shrublands. Proceedings of the Conference, Biodiversity of California Ecosystems. USDA Forest Service.

Keeley, J. E. and W. J. Bond. 2001. On incorporating fire into our thinking about natural ecosystems: A response to Saha and Howe. *American Naturalist* 158:664-670. http://www.werc.usgs.gov/seki/pdfs/AmerNat2001.pdf

Keeley, J. E. and C. J. Fotheringham. 2001. The historical role of fire in California shrublands. *Conservation Biology* 15:1536-1548. http://www.werc.usgs.gov/seki/pdfs/ConBio1.pdf

Keeley, J. E. and C. J. Fotheringham. 2001. History and management of crown-fire ecosystems: A summary and response. *Conservation Biology* 15:1561-1567. http://www.werc.usgs.gov/seki/pdfs/ConBio2.pdf

Keeley, J. E. and C. J. Fotheringham. In press. Impact of past, present, and future fire regimes on North American Mediterranean shrublands. *In* T. T. Veblen, W. Baker, G.

Montenegro, and T. W. Swetnam, editors. *Fire and Climatic Change in the Americas*. Springer-Verlag.
Manley, J., M. Keifer, N. Stephenson, and W. Kaage. 2001. Restoring fire to wilderness: Sequoia and Kings Canyon National Parks. *Fire Management Today* 61(2):24-28.
Montenegro, G., R. Ginocchio, A. Segura, and J. E. Keeley. In press. Fire regimes and vegetation responses in two mediterranean-climate regions. In G. A. Bradshaw and P. A. Marquet (editors), *How landscapes change: Human disturbance and ecosystem disruptions in the Americas*. Springer-Verlag.
Pierce, K. B., T. R. Lookingbill, and D. L. Urban. In review. A method for predicting relative potential radiation over complex terrain. Submitted to *Landscape Ecology*.
Stephenson, N. L., P. J. van Mantgem, P. E. Moore, J. F. Franklin, and D. J. Parsons. In review. Tree growth rates and causes of death in Sierra Nevada forests: implications for the effects of environmental changes. Submitted to *Ecology*.
Swetnam, T. W., and C. H. Baisan. In press. Tree-ring reconstructions of fire and climate history in the Sierra Nevada and Southwestern United States. *In* T. T. Veblen, W. Baker, G. Montenegro, and T. W. Swetnam, editors. *Fire and Climatic Change in the Americas*. Springer-Verlag.
Urban, D. L. In press. Strategic monitoring of landscapes for natural resource management. *In* J. L. Liu and W. W. Taylor (editors), *Integrating Landscape Ecology into Natural Resource Management*. Cambridge University Press.
Urban, D., S. Goslee, K. Pierce, and T. Lookingbill. In press. Extending community ecology to landscapes. *Ecoscience*.
van Mantgem, P. J. 2001. Fire-induced Tree Mortality in the Mixed Conifer Forests of the Sierra Nevada, California. Ph.D. dissertation. University of California, Davis. 107 pages.
van Mantgem, P. J., N. L. Stephenson, L. S. Mutch, V. G. Pile, A. M. Esperanza, and D. J. Parsons. In review. Searching for a general model of tree death in burned and unburned stands. Submitted to *Ecological Applications*.
van Mantgem, P., M. W. Schwartz, and M. Keifer. 2001. Monitoring fire effects for managed burns and wildfires: coming to terms with pseudoreplication. *Natural Areas Journal* 21:266-273.

Selected presentations:

Bunn, A. G., L. G. Graumlich, and D. L. Urban. 2001. Interpreting the climatic significance of trends in twentieth-century tree growth at high elevations. Annual meeting of the American Geophysical Union. San Francisco, CA. December 2001.
Bunn, A. G., L. G. Graumlich, and D. L. Urban. 2001. Interpreting the climatic significance of trends in twentieth-century tree growth at high elevations. Annual meeting of the Ecological Society of America. Madison, WI. August 2001.
Bunn, A. G., D. L. Urban, and L. G. Graumlich. 2001. Variability in the physical and biotic templates of alpine treeline. Annual meeting of the International Association of Landscape Ecologists. Tempe, AZ. April 2001.
Stephenson, N. L. 2001. Predicting vegetation change: how good are our assumptions? *Abstracts*, The Big Unknowns of Global Change, University of Georgia State-of-the-Art Conference and Workshop, p. 15.

Stephenson, N. L. 2001. Giant sequoias: the past, present, and future of California's big trees. USGS Public Lecture Series, Menlo Park, California.

van Wagtendonk, J. W., and R. R. Root. 2001. The use of multi-temporal Landsat Normalized Difference Vegetation Index (NDVI) data for mapping fuels in Yosemite National Park, USA. 3rd International Workshop on Remote Sensing, GIS, and Fire Management. Paris, France, May 17-18, 2001.

van Wagtendonk, K. A., J. W. van Wagtendonk, and J. B. Meyer. 2001. The use of geographic information for fire management planning in Yosemite National Park. 2001 Spatial Odyssey: a Servicewide Conference on Geographic Information Systems (GIS) and Related Technologies, National Park Service. Primm, NV, December 3-7, 2001.

Latitude and Longitude of study sites:

The two primary study sites are at approximately 118 45' W, 36 35' N (Sequoia National Park, California) and 119 50' W, 37 50' N (Yosemite National Park, California).

WEB PAGE REVIEW

No changes are required to our web page.

UPDATED SIS DESCRIPTION

We have submitted updates to our SIS description, but as of 15 February 2002, they have not yet appeared on the web site.