Planning for Global Climate Change Research

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An Example from Sequoia and Kings Canyon National Parks

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Prologue

The National Park Service is cooperating with other bureaus in the Department of the Interior in developing a cooperative global climate change research program. The program is part of the U.S. Global Change Research Program that is coordinated through the Committee on Earth Sciences (CES).

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Increased attention being given to the predicted ecological effects of trace-gas-induced climate change presents the National Park Service with the challenge and opportunity of better understanding park ecosystems and the factors influencing their distribution and health. As protected representatives of native ecosystems, our national park areas are becoming increasingly valuable laboratories for collecting data and studying the effects of human activities on natural communities. It behooves park managers and scientists to evaluate the role they might play in improving our understanding of the potential effects of a changing global climate. Such factors as resource sensitivity, availability of basic data, and the scope of existing science programs must be considered in evaluating the possible contributions of individual park units to the national global change research effort. In this paper we evaluate the potential of Sequoia and Kings Canyon National Parks to contribute to such a program. We urge other areas to begin a similar self-examination of their potential contributions.

A compelling case can be made for focusing global climate change research at Sequoia and Kings Canyon National Parks (SEKI). Located in the southern Sierra Nevada of California, SEKI offers the exceptional combination of an elevation gradient of 4,000 m; an extraordinary range of climate and topographic conditions; a wide variety of biotic communities sorted along environmental gradients; and a rich, active history of scientific study. A unique record of environmental history, together with ongoing programs of natural resource inventory, disturbance management and monitoring, community and ecosystem research, and a developing Geographic Information System (GIS), combine to put SEKI in an excellent position to contribute to understanding potential impacts of global change.

The Site

Established in 1890, Sequoia and Kings Canyon National Parks now encompass 349,811 ha. The parks are contiguous, form an International Biosphere Reserve, and are bounded on three sides by National Forest Wilderness. The protected nature of Park and surrounding lands assures maximum control over potential disturbances.

Elevations extend from 400 m to 4,418 m, including a broad range of climate and topographic conditions. The elevational temperature gradient (from warm Mediterranean to cold alpine) is overlaid by a broad west-east precipitation gradient; at comparable elevations, a several-fold decrease in precipitation occurs west to east from the moist Kaweah watershed, through the drier Kern watershed, to the desert Owens watershed (Stephenson 1988). Vegetation, ranging from grassland and chaparral to alpine, with associated fauna, is ordered more-or-less altitudinally according to species tolerances. Distinct physiognomic ecotones include grassland-shrub, shrub-forest, and forest-alpine tundra. These ecotones provide an excellent opportunity to detect sensitivity to climate change. The Parks' location near the western margin of the continent makes the area especiallfy sensitive to predicted shifts in Pacific storm tracks. The presence of a permanent Park research staff assures continued on-site capability for scientific direction and coordination. The Southern Sierra Research Center, located at park headquarters, provides limited laboratory, office and dormitory facilities for outside investigators. The park resources management staff provides significant support for air and water quality studies as well as wildlife, vegetation and fire management and monitoring programs. This infrastructure has proven its effectiveness in supporting recent interdisciplinary research programs in the areas of acid deposition, ozone effects, and fire history and effects. SEKI has in recent years come to be recognized as a major center for long-term ecological research.

Relevance to Global Change Issues

Within the relatively small area of SEKI, the range of climate, topography, and biota, together with a unique record of environmental history, provides an excellent opportunity to validate predictive models and to use spatial and temporal analogs to explore the influence of climate change on diverse ecosystems. In effect, the ecological conditions of a large part of the middle and high latitudes are condensed into this small region. Latitudinal changes in population and community dynamics may be seen as elevation changes within a very short distance in the Sierra Nevada; thus SEKI offers an excellent opportunity to observe species, community and ecotone movement in response to changing climatic parameters. The local and regional paleoecological record of past climate, vegetation, and disturbance regime provides a window on climate and community changes over much longer time spans than could ever be directly observed.

The past year has seen a progressive surge of interest in understanding potential effects of global climate change in California. Recent documents and meetings that have focused on the vulnerability of California to climatic change—including hydrologic changes, shifts in species and habitats, effects on plant growth and productivity, changes in fire frequency and intensity, and the incidence of atmospheric pollution and forest pathogens—include 1) the recent draft EPA report to Congress on the Potential Effects of Global Climate Change on the United States; 2) the May 20, 1989 hearing before the Senate Committee on Energy and Natural Resources on Global Warming and its Implications for California; 3) a June, 1989, report by the California Energy Commission on the Impacts of Global Warming on California; 4) a July, 1989, University of California Workshop on Global Climate Change and its Effects on California; 5) a January, 1989, publication by the Sierra Club calling for California leadership in addressing the greenhouse effect; and 6) major initiatives by NASA (program to study hydrology, hydrochemical modeling, and remote sensing in seasonally snow-covered alpine basins); and the National Park Service (FY91 budget priority to establish a multimillion dollar global change infrastructure). SEKI, with its protected status, comprehensive data infrastructure, and environmental diversity—including special sensitivity to drought, air pollution, and disturbance by fire, is an especially attractive site for studies on global change. The loosely knit group of scientists who have cooperated in past and present SEKI research are enthusiastic about possibilities of global change studies in this area.

Available Databases and Ongoing Studies

Historical Data

SEKI contains an exceptional record of paleoenvironmental history. Data currently available or being collected include past climatic patterns (from tree-rings), past distributions of plant species (from pollen and macrofossils preserved in meadow and lake sediments and packrat middens), and fire history (from tree-rings and charcoal sediments). Such data provide a basis for developing and testing models of how current conditions might change with changing climate.

The only multi-millenia, multi-species network of tree-ring chronologies in the world occurs in and around SEKI. The Laboratory of Tree Ring Research at the University of Arizona is currently extending and improving the existing 3,200 year giant sequoia (*Sequoiadendron giganteum*) chronology, as well as extracting a climate record (Hughes at al. 1989). In the nearby White Mountains, bristlecone pine (*Pinus longaeva*) chronologies have been used to reconstruct more than 8,500 years of past climate change. More recently, tree-ring records of high elevation conifers in the southern Sierra have been used to detect changes in treeline and for dating glacial advances (Scuderi 1987), as well as in exploring more subtle growth responses to seasonal temperature and precipitation (Graumlich 1989). The latter work is closely coordinated with studies of fire history and vegetation dynamics to better understand the relationship between climate, disturbance, and vegetation (Parsons et al. 1989).

Recent palynological studies of long-term vegetation change in SEKI show that species composition has changed substantially through the Holocene (Anderson 1987). A distinct shift towards more mesic species during that time parallels a gradual cooling in the world climate. When considered together with detailed climatic reconstruction and additional data that might be collected from higher and lower elevations, this information provides some indication of how local vegetation might respond to both warmer and changing temperatures. Limited data on pollen and macrofossils collected from packrat middens provide an exciting indication of the potential for reconstructing vegetation change into the Pleistocene (Cole 1983). The historical records of vegetation and climate available for the SEKI area make this an ideal place in which to study the interactions of species and climate, including testing models of the response of vegetation to climate change.

Studies currently underway in SEKI are using tree-rings and fire scars from giant sequoias to develop 2,000 to 3,000 year chronologies of drought and fire occurrence in at least five different sequoia groves (Swetnam unpubl. data). Emerging evidence suggests that fire—an important force in community dynamics—changes with climate. These high resolution, millennial records provide a unique opportunity to identify responses of forest ecosystems to changes that occur at time scales of years, decades, and centuries. Other studies of the ecological effects of fire as a major disturbance agent (e.g., effects on fuels, understory vegetation, pathogens, etc.) are also underway.

Climate

Because the Sierra Nevada supplies much of the water used in California, three major agencies (California Department of Water Resources, U.S. Army Corps of Engineers, and NOAA) have established a fairly good network of weather stations in the mountains. The network in and near SEKI fairly well covers all elevations from 100 m to 3300 m, but with a hole between about 1000 and 1800 m (Stephenson 1988). Sixteen stations in Sequoia National Park and vicinity measure daily temperature, 17 measure daily precipitation, and four measure annual precipitation. Records from most of these stations began in the 1930s or more recently, but records from the adjacent San Joaquin Valley date to the late 1800s. Several stations within the Park also measure wind speed, wind direction, net radiation, and relative humidity.

Snow hydrology is measured at a network of 23 permanent snow courses (some of which have continuous records beginning in the 1920s), where snowpack water contents are measured monthly during the winter. Starting in the 1960s, 9 snow pressure pillows capable of measuring daily snowpack water contents have been installed. Comparison of adjacent pressure pillow and precipitation gauge records allows local hydrology to be calculated in detail. Snowfall and accumulation data are being acquired and put into a local database as a basis for building a precipitation isobar model for the Parks.

Whereas limited studies have failed to identify the southern Sierra Nevada as a region in which the El Niño-Southern Oscillation (ENSO) strongly influences annual climate variability, strong ENSO events sometimes are characterized by extremely wet winters. Studies to the north of SEKI in the Sierra Nevada documented a distinct growth depression of needle length for two species of high elevation pine during the wet 1982-83 ENSO event as compared to the following more normal year (Armstrong et al. 1988). Similarly, a distinct decline in growth of conifers and shrubs, attributed to cold temperatures and a late snowpack, was detected at the subalpine Emerald Lake watershed in Sequoia National Park (Rundel, unpubl. data). In contrast, growth at lower elevations may well have been stimulated by the increased moisture of that record year. Other work indicates the potential effect of ENSO events on fire frequency and severity; Swetnam and Betancourt (1989) have documented a decrease in area burned during strong ENSO events in the ponderosa pine (*Pinus ponderosa*) forests of the southwest. ENSO control of fire occurrence in the Sierra Nevada needs to be investigated.

Resource Inventory

In Recent years nearly 500 0.1 ha permanently-marked plots have been established on a systematic 1 km grid within SEKI, primarily to provide information on the distribution of vascular plants and vertebrates. Information collected for plants includes tree diameters, shrub and herb cover, and an exhaustive list of the species present. Environmental variables are documented and fuel loading and soil type characterized. Vertebrates are recorded as present through observation and trapping. Plans are to continue expanding this plot network over the next 5–10 years. This inventory network provides a moderate-resolution picture of the present ecological range of plant and animal species within the Parks, and in concert with the Parks' geographic information system (GIS), a means of conducting powerful correlation analyses.

The Park's vascular flora, determined from herbarium specimens and contemporary field surveys, has been cataloged on a computer database that includes information about biological characteristics and legal status. Historic and contemporary wildlife observations have been placed in a database as well, and are used to generate distribution maps on the GIS. Additional inventories of Park resources that are readily available include documentation of rare plants, mapped locations and sizes of all giant sequoia trees, and an extensive collection of historical photographs.

Vegetation Dynamics and Succession

A number of studies carried out in SEKI provide a basis for evaluating potential change in vegetation dynamics and succession. A total of thirteen 1.0 to 2.4 ha permanent reference stands (in which all trees are individually tagged and mapped) have been established in different forest types within the coniferous forest zone. These stands are evaluated annually for mortality and every 5 years for growth, vigor, and establishment. Litter accumulation and decomposition and coarse woody debris decomposition (Stohlgren 1988, Harmon and Cromack 1987) have been evaluated in several of these stands. In addition, about 70 variable size (generally 0.1 ha) permanent plots have been established in different ecosystems as part of a comprehensive long term fire effects monitoring program. Many more will be established in the next few years. These are evaluated at regular intervals for seedling establishment, tree death, growth, and ground fuel accumulation.

A model designed to simulate the effects of changing fire regime on the mixed conifer forest has been developed (Kercher and Axelrod 1984), but has not been effectively utilized due to a lack of adequate input data. More recently, two other groups have proposed development of a disturbance-driven forest succession model for the mixed conifer forests of the southern Sierra Nevada. Modeling efforts by Leverenz and Lev (1987) have focused on the predicted effects of increased temperatures resulting from an effective doubling of CO_2 on the distribution of ponderosa pine. Their conclusions should be testable in SEKI. Westman (1987) has collected detailed data on productivity in white and red fir (*Abies concolor* and *A. magnifica*), while Franklin et al. and Rundel (unpublished) have developed dimensional analysis equations for selected tree species. Other studies have used Thematic Mapper Simulator data to predict forest basal area and canopy closure (Peterson et al. 1986).

Hydrology and Aquatic Resources

SEKI is characterized by hundreds of small, remote, headwater basins in the alpine and subalpine regions. The hydrology, biology and biogeochemistry of these watersheds are sensitive to the influences of temperature, drought, flooding, and pollution. Climate change may be expected to influence water quality, water supply, evaporative demand, and biota. Relevant baseline data include a digital map of lakes and streams, historic information from the 1970s on depth and fish presence in most lakes, long-term record of flow for the Kaweah River near its point of departure from the Park, and detailed precipitation, outflow, and chemistry data, including hydrologic flux and ecosystem response, for a subalpine watershed (Emerald Lake) and a montane stream system (Log Meadow). Present studies of amphibians (several species of which appear to be mysteriously disappearing from much of the Sierra), subalpine and alpine lake processes, modeling of subalpine hydrogeochemistry, and monitoring of snow deposition provide data relevant to questions of global change. Concerns over possible effects on regional water supply (Roos 1989) will begin to be addressed in coming years by a proposed NASA/EOS funded project with UC–Santa Barbara on hydrology, hydrochemical modeling, and remote sensing in seasonally snow-covered alpine drainage basins.

Ecosystem Studies/Biogeochemical Cycling

Since 1982 SEKI has been the site of broad, interdisciplinary research on the effects of acidic deposition on Park ecosystems. Based on a watershed approach, this program has developed as a cooperative venture with the California Air Resources Board, providing the infrastructure necessary to support interdisciplinary ecosystem studies. Utilizing the extreme elevation gradient found in the Parks, research focuses on watersheds in the foothill chaparral, middle elevation mixed conifer forest, and subalpine–alpine zones. Studies have included meteorology, precipitation chemistry, snow deposition and hydrology, dry deposition, stream hydrology and chemistry, aquatic and terrestrial productivity, soil characterization and solution chemistry, input/output budgets, and modeling ecosystem processes (California Air Resources Board 1988). A special 1990 issue of Water Resources Research will highlight many of the investigations at the high elevation Emerald Lake site.

Atmospheric Pollution

One of the consequences of increasing global temperature is expected to be elevated concentrations of oxidant air pollutants such as ozone. Air quality data from the southern Sierra Nevada indicate that SEKI already receives high concentrations of ozone, particulates, and other atmospheric pollutants. The effects of air pollution on visibility and vegetation in the Parks are well documented.

The SEKI region has been the focus of considerable research on the effects of oxidant air pollutants on vegetation. This includes investigations of the extent of visual injury (Duriscoe and Stolte 1989), effects of ambient ozone levels on tree growth (Peterson and Arbaugh 1988) and physiology (Patterson and Rundel 1989), and fumigation studies to determine the effects of ambient and elevated ozone levels on growth and photosynthesis of seedlings and rooted cuttings (Grulke et al. 1989). Current studies include reevaluation of permanent plots to detect injury trends, fumigation of branches of mature giant sequoia to evaluate effects of varying ozone levels on gas exchange, and an Electric Power Research Institute (EPRI) funded study of the interaction of ozone, acid mist, and drought on ponderosa pine. The latter, which includes 30 fumigation chambers, is located on state land immediately adjacent to SEKI. Understanding of such effects will be critical in evaluating the multiple stresses apt to accompany global change.

Geographic Information System

SEKI is in the midst of building a comprehensive geographic information system (GIS) based on a Sun 4–260C workstation running GRASS software under UNIX. The GIS is designed to combine historic resource information, contemporary field data (such as the biotic resources inventory described above), and data available from other sources for purposes of geographic analysis and display. The GIS will provide a basis for understanding environmental control of both organismic and ecosystem aspects of Sierran ecosystems. It can provide insights into species distributions as well as the modeling of productivity, trace gas emissions, etc. The following themes are presently available or in progress:

- 30m [horizontal] resolution digital elevation data derived from high-altitude photography. This is the GIS map base, equivalent to the USGS 7.5'map series.

- 30m resolution TM remote sensing from Landsat. This is georeferenced to the map base and will be classified using field ground truth to produce a land cover/vegetation map. Historic vegetation maps produced in the 1930s and 1960s will also be digitized.
- Order 4 resolution soil map for most of the drainage of the Kaweah River, with some ultra-detailed sections.
- Surficial geology based on 15' map series.
- Surface hydrology. Based on Digital Line Graphs (DLG–3) derived from 7.5' map series, this shows all lakes and streams visible at that scale.
- Fire history. All fires since 1930 are mapped.
- Additional environmental parameters will be mapped as they are needed for scientific research, management, and planning.

Management Applications

Whereas the emphasis of this paper has been on predicting and detecting change, we will ultimately be faced with the challenge of managing such change. An advantage of focusing a global change research program in a place like SEKI is the ability to directly apply results and recommendations to a management program. National Parks will be forced to confront the consequences of changing climates both in their management programs and in interpreting trends and causes to the general public. For example, the potential migration of new species into parks, loss of entire ecosystems as communities dissociate or are forced up in elevation, changing disturbance regimes, or even the potential loss of our eponymous species, will force difficult management decisions. Goals and policies aimed at protecting natural ecosystems and allowing them to continue to function with only minimal human interference may have to be reevaluated in favor of policies aimed at preserving biodiversity, for example. Increasingly sophisticated management of critical resources will be required to perpetuate them in hostile environments. The existance of site-specific information for an area that will be confronted with such difficult questions could serve as a model for the ultimate, but critical, step of applying program findings to the real world.

Summary

We are convinced that the southern Sierra Nevada offers a superb opportunity for long-term studies related to the potential effects of global climate change. The protected status of a large, diverse natural area that has demonstrated its usefulness and receptiveness to significant interdisciplinary research offers many advantages that cannot be duplicated in many other areas. The emphasis we have placed on commmunity and population studies, and especially on historical data, offers a superb opportunity to both better understand park resources and make major strides in predicting the potential impacts of a significant environmental perturbation.

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