

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.

² Duke University, Nicholas School of the Environment and Earth Sciences, Durham, NC 27708.

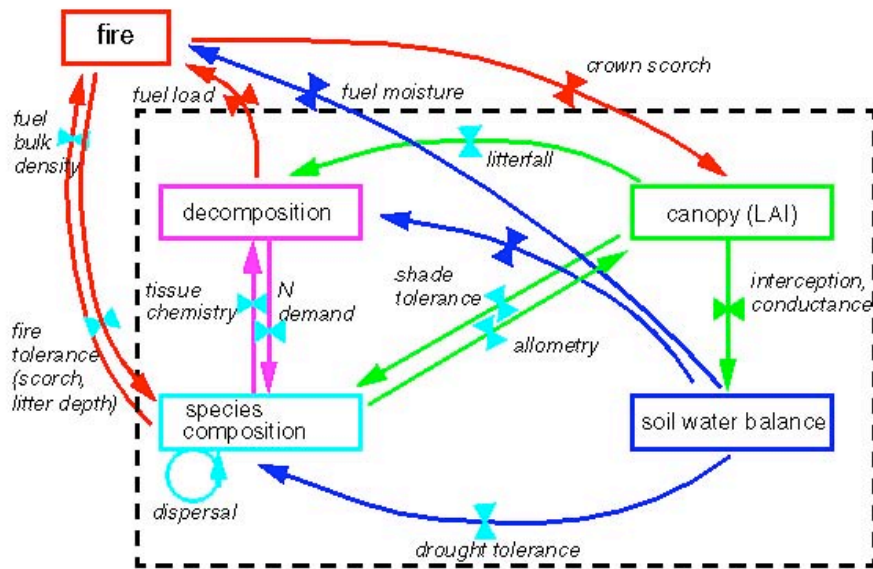


Figure 1— Schematic (Forrester) diagram of the forest simulator ZELIG version FACET as implemented for the Sierra Nevada. Boxes represent component modules, and arrows denote biophysical couplings between modules. Switches (bow-ties) are rate moderators, and those in cyan are couplings in which details 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.

References

- Miller, C.; Urban, D.L. 1999a. **Fire, climate, and forest pattern in the Sierra Nevada, California.** *Ecologic Modeling* 114: 113-135.
- Miller, C.; Urban, D.L. 1999b. **Forest pattern, fire, and climatic change in the Sierra Nevada.** *Ecosystems* 2: 76-87.
- Miller, C.; Urban, D.L. 1999c. **Interactions between forest heterogeneity and surface fire regimes in the southern Sierra Nevada.** *Canadian Journal of Forest Research* 29: 202-212.
- Miller, C.; Urban, D.L. 2000a. **Connectivity of forest fuels and surface fire regimes.** *Landscape Ecology* 15: 145-154.
- Miller, C.; Urban, D.L. 2000b. **Modeling the effects of fire management alternatives in Sierra Nevada mixed-conifer forests.** *Ecological Applications* 10: 85-94.
- Urban, D.L. 2000. **Using model analysis to design monitoring programs for landscape management and impact assessment.** *Ecological Applications* 10: 1820-1832.
- Urban, D.L.; Acevedo, M.F.; Garman, S.L. 1999. **Scaling fine-scale processes to large-scale patterns using models derived from models: Meta-models.** In: Mladenoff, D.; Baker, W., editors. *Spatial modeling of forest landscape change: Approaches and applications.* Cambridge, UK: Cambridge University Press; 70-98.
- Urban, D.L.; Goslee, S.; Pierce, K.B.; Lookingbill, T.R. 2002. **Extending community ecology to landscapes.** *Ecoscience* 9: 200-212.
- Urban, D.L.; Miller, C.; Stephenson, N.L.; Halpin, P.N. 2000. **Forest pattern in Sierran landscapes: The physical template.** *Landscape Ecology* 15: 603-620.

