Topography, Microclimate, and Vegetation Patterns of the Landels-Hill Big Creek Reserve: Reflections, Cogitations, and Some Lessons

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My research began more than 20 years ago here at the Big Creek Reserve when I was an undergraduate student at the University of California at Santa Cruz (UCSC). I was one of two botanists in a group of seven undergraduates Ken Norris herded down to do a complete baseline inventory of the flora, fauna, and geology of the area (Bickford and Rich 1979; Carothers et al. 1980). The other botanist was Charisse Bickford, who is now Charisse Sydoriak and is in charge of research and management at Bandelier National Monument in New Mexico. The opportunity to do meaningful research—and to publish our results—launched my career as a biologist. So I owe my work in large part to Ken Norris, and this talk is a tribute to him.

Baseline Studies of Vegetation at Big Creek Reserve

During our research at Big Creek, I learned a number of important lessons about doing science, lessons that have guided my research ever since. I have organized my talk according to these lessons. Let's begin by considering two lessons:

Lesson 1: Vegetation can occur in relatively discrete communities.

Lesson 2: Establish a good baseline, and always dream big.

The first lesson, that vegetation can occur in relatively distinct communities, is an important one, because in many areas of the world—such as eastern North America and throughout much of the wet tropics, where I've also done research—vegetation does not occur in relatively distinct communities. If I had started my studies in some other part of the world, I would probably have developed a very different picture of the world. But here at Big Creek, one can observe distinct communities. The reasons for this are of great interest and I will explore them further in this talk.

The latter part of the second lesson, always dreaming big, was something that Ken Norris emphasized. The first part, establishing a good baseline, was the basis of our mission at Big Creek, and it was something I think we accomplished rather well. As the members of our group charged with establishing a botanical baseline, Charisse Bickford and I found 342 plant species in 224 genera and 72 families. Nine of the species, which include the Santa Lucia Fir (*Abies bracteata*), are narrow endemics, with distributions only in the Santa Lucia Mountains. A relatively large number of the species are near their northern or southern limit of distribution—we found 26 species at their northern limit and 33 at their southern limit. This is due in part to the large diversity of different microhabitats found in close proximity at Big Creek. We also found several disjunct species—such as ponderosa pine (*Pinus ponderosa*)—species that are isolated from their main populations further inland. Finally, we found a few rare species, in particular Hoover's manzanita (*Arctostaphylos hooveri*).

Another part of our baseline inventory work involved classifying and mapping the vegetation. In the end, we developed a vegetation scheme of 11 plant communities, with various subtypes, and used aerial photos—interpreted with the assistance of Pamela Matthews—to help us locate these communities on a map (Figure 1).

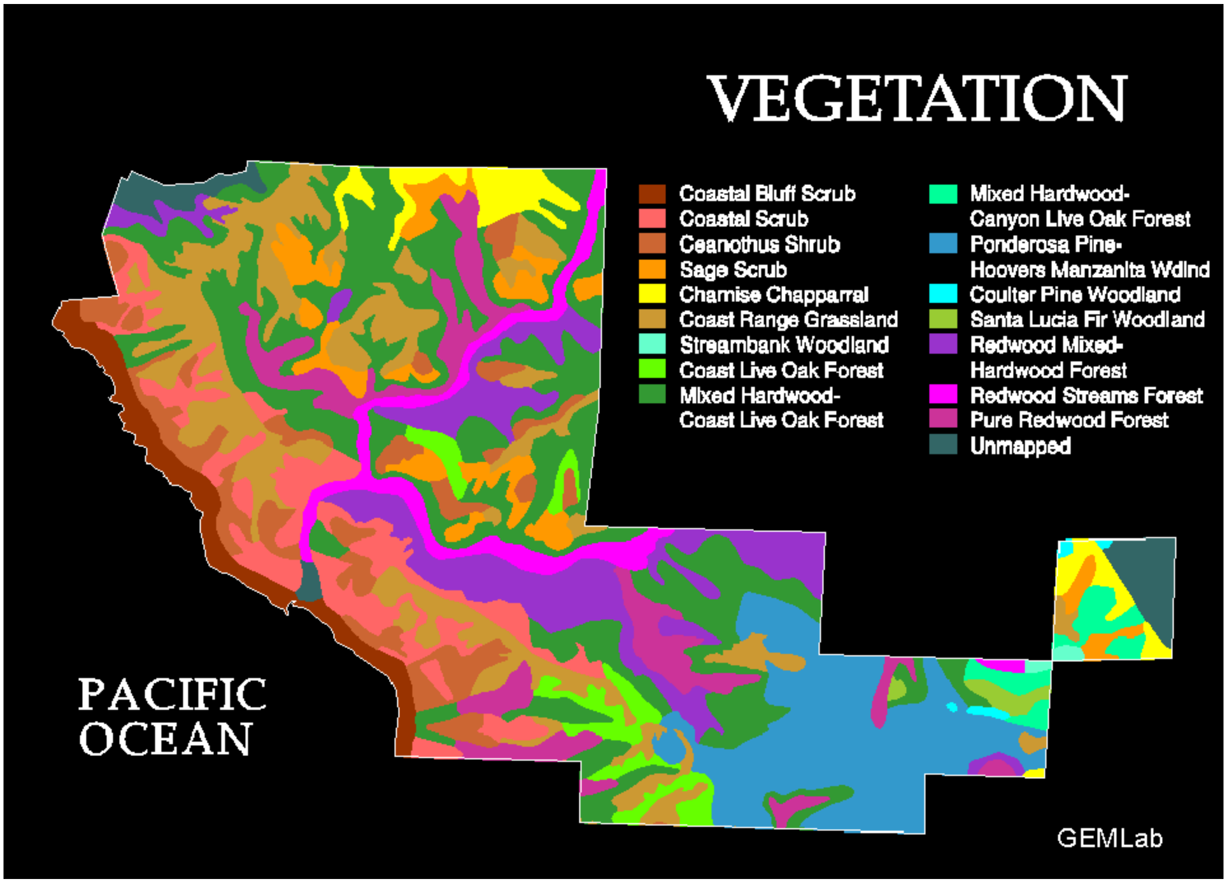

Figure 1. Vegetation of Big Creek Reserve.

While we were constructing the vegetation map we were struck by how the pattern of vegetation seemed to reflect the underlying topography of the landscape, something you can see relatively clearly in the map. We have, for instance, on south-facing slopes by the coast, a coastal sage scrub community. More inland, in the canyons and on the lower parts of north-facing slopes, we have redwoods. At higher elevations we have a chaparral community. This relationship between vegetation and topography formed the basis for the next set of lessons:

> **Lesson 3:** Topography determines microclimate, which in turn determines species' distributions and performance.
>
> **Lesson 4:** It's not as easy as it looks.

Lesson 3—that topography determines microclimate, which in turn determines species' distributions—is really the theme of this talk. What strikes one about Big Creek, of course, is the very dramatic topography. The elevation ranges from sea level to more than 1200 meters (4000 feet) in a short distance. There are deep canyons with steep north- and south-facing slopes, and there are also distinct east- and west-facing slopes. This dramatic topography results in strong environmental gradients that go from very dry to very wet, often over a short distance and often abruptly.

Ecological theory states that each species of plant responds independently to the underlying environmental gradients. Redwoods (*Sequoia sempervirens*) grow only where it is very wet, in the bottom of drainages that are often bathed in fog; whereas, Hoover's manzanita can tolerate the much hotter and drier conditions of the ridgetops. But if species are responding independently, why do we see distinct communities of plants? This is part of what I mean by lesson 4—that it's not as easy as it looks.

Part of the explanation is that we define communities by looking at dominant species. The distribution of the coastal scrub community, for example, is essentially defined by the distribution of its dominant, California sagebrush (*Artemisia californica*). Beyond this type of bias, however, there is something going on with the steep, abrupt environmental gradients. The fact is that environmental conditions change abruptly. There are real boundaries imposed by the topography itself, and these give plant communities distinct edges.

Modeling Biophysical Processes to Understand Vegetation Patterns

Trying to understand what was going on with the vegetation patterns at Big Creek lead me to the next stage of my work, which involves developing models that relate spatial information to biophysical and biological processes. This has been the focus of much of my research since the initial baseline survey at Big Creek, and it can be summarized with another set of lessons:

> **Lesson 5:** Spatial models enable generalization of biophysical processes in two and three dimensions, and in turn provide the underpinnings of population, community, and ecosystem models.
>
> **Lesson 6:** Embrace an understanding of the whole, but remember simplicity.

To illustrate these lessons, I want to look briefly at some actual models developed by me and my colleagues. My general approach in formulating models involves relating spatial patterns to biophysical processes, and then relating these biophysical processes to biological processes (Figure 2). Such models generalize the processes that determine such environmental factors as temperature and the amount of water at a particular location and help one understand what is influencing the distribution of species, populations, and communities. In building these models, I try to adhere closely to lesson 6, in that the models represent my attempt to understand the whole, but I keep them relatively simple to capture the essence of what is going on.

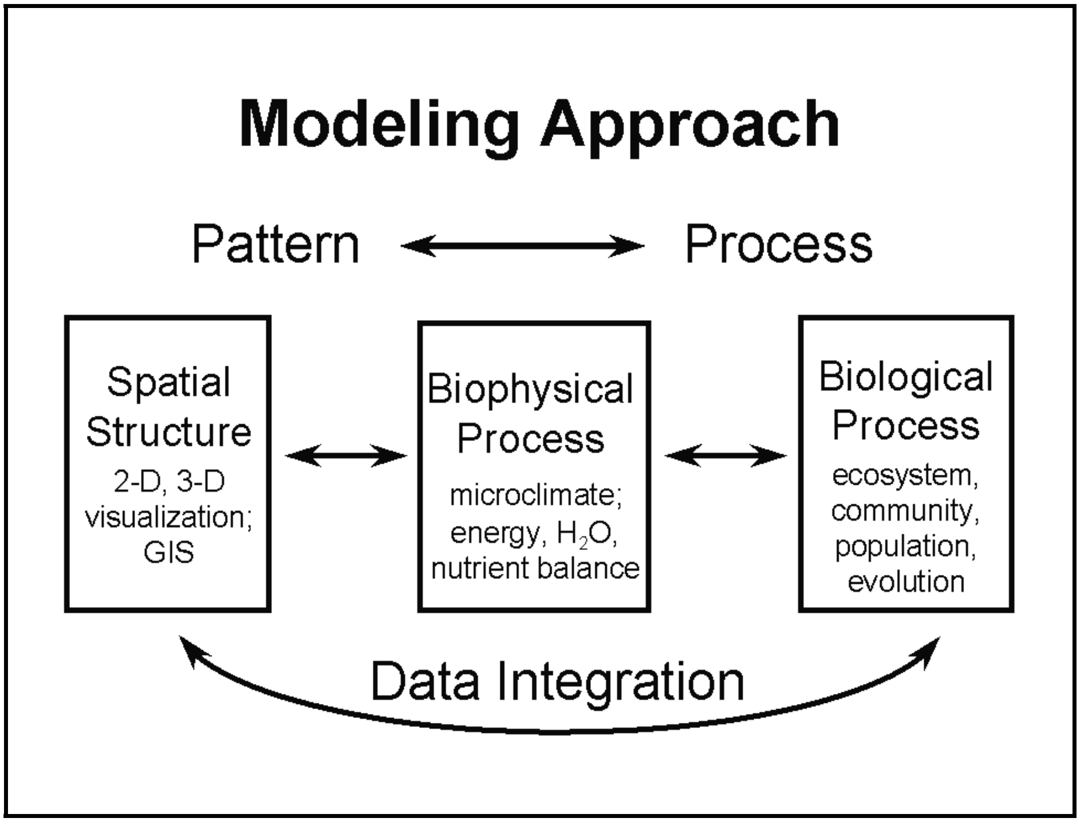

Figure 2. The modeling approach.

One biophysical factor of considerable importance is incoming solar radiation. I've worked on this factor a great deal, in particular in the tropical rain forest, looking at how plants in the understory experience different amounts of solar radiation (Rich 1990; Rich et al. 1993; Clark et al. 1996).

The radiation arriving at a site depends on the amount of direct radiation from the sun, the amount of diffuse radiation from the sky, and the amount of reflected radiation from the surrounding landscape. Ignoring the third component, which is typically small, the amount of direct and diffuse radiation is going to be strongly determined by the slope and aspect—the surface orientation—of the site and the angle of the incoming sunlight. It is simply a matter of geometry and the path of the sun through the sky. Using models that have been around for awhile, we can calculate, for any given location, the incoming solar radiation, or insolation, during a given day. It requires millions of calculations, but it is relatively straightforward with modern computers.

We can't stop there, however, because the insolation at any particular location is also influenced by every other location that is visible within the landscape—the so-called "viewshed" (Rich et al. 1994). A ridge to the west of a site, for example, may cast a shadow on the site late in the day during the winter months, and we have to take this into consideration.

What we developed in my research lab—largely through the efforts of a talented undergraduate engineering student named Bill Hetrick—is a way of translating topography into insolation (Hetrick et al. 1993a, 1993b; Rich et al. 1995). We call it the Solarflux model. We can apply the Solarflux model to any area where we have created a digital elevation model of the topography, which is basically a matrix or grid of X-Y-Z values, where X and Y coordinates are location and Z is elevation.

One of the fun things we've done is apply the Solarflux model to the topography of Big Creek Reserve, which for me means returning to my roots and visualizing what I think is strongly influencing the spatial patterning of the vegetation. As part of his Masters research, my former graduate student Shawn Saving constructed a digital elevation model for Big Creek and then used the Solarflux model to create a set of maps of the reserve (Figure 3) that quantitatively represent the amount of insolation at each location (Savings et al. 1993).

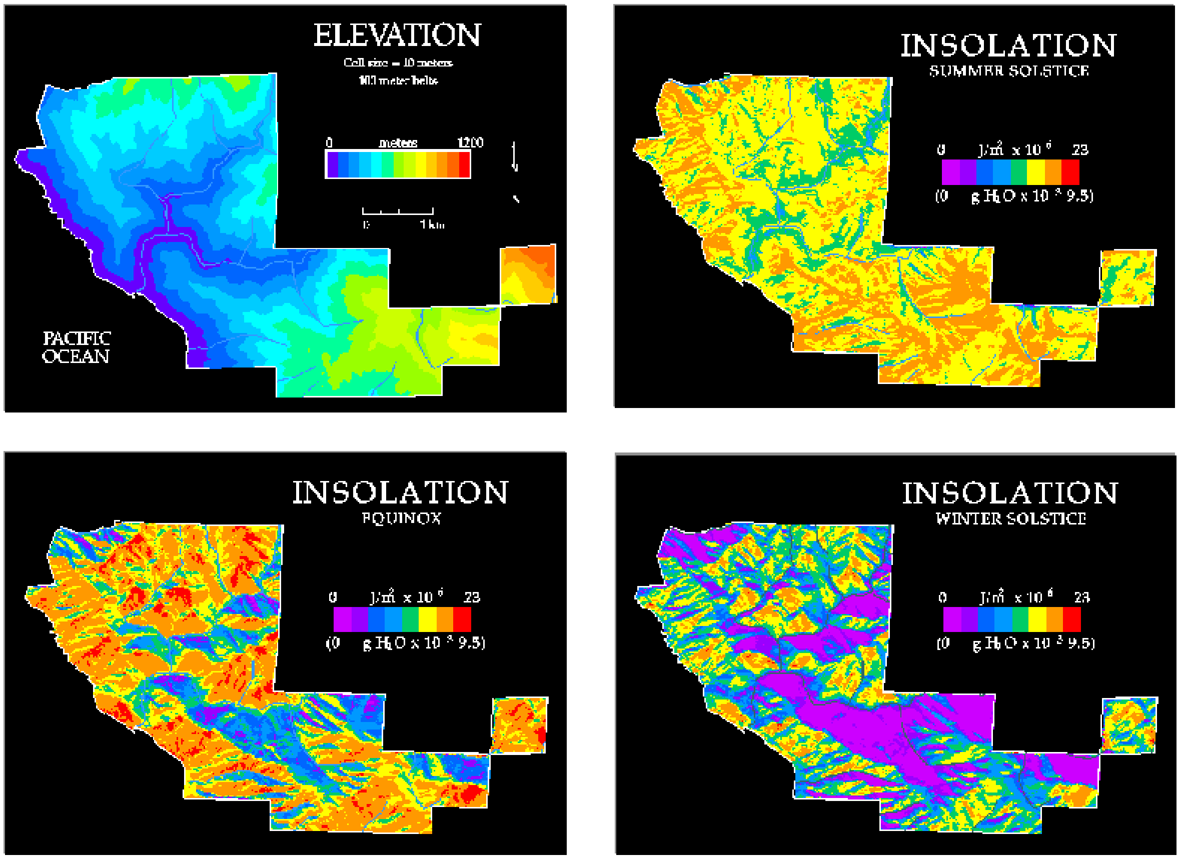

Figure 3. A digital elevation model (A) used as input to the Solarflux model, and the resulting insolation maps of Big Creek Reserve for different times of year (B–D).

As one can see on the maps, north-facing slopes in winter have incoming radiation values of approximately zero, while south-facing slopes can receive lots of radiation. In summer the differences even out somewhat, although large differences still persist. Assuming that precipitation is the same regardless of slope, the radiation differences are so extreme that the water balance varies greatly by location. Water availability is a major determinant of vegetation distribution in California, and thus the map predicts which areas should be vegetated by dry-adapted species and which areas should be vegetated by moisture-loving plants such as members of the redwood community.

In addition to producing maps and predicting vegetation distribution, this kind of modeling also acts as a kind of filter, predicting what microclimates will exist under a given climatic regime. Thus, given the current climate, we can predict the microclimate at each location in the reserve, even calculating the area and position of each microclimate patch. If the climate were to change, the size of each patch would be expected to expand or contract, with some patches appearing or disappearing. For example, if a given microclimate patch is suitable for a lizard that requires a dry microclimate, and if the regional climate were to become more drying, then we may see expansion of the suitable habitat patches.

Data and Good Science

Now I want to shift the focus to some broader issues having to do with scientific data. In my lab at the University of Kansas we use large databases, and face the challenge of finding and using the right information and making sure it is of good quality. We have fancy tools and a vast amount of information, information that is crucial to understanding biodiversity and landscape-level biological processes. But with all of the information and tools and modeling we run the risk of disconnecting ourselves from nature. We can't assume that we have all the answers, because the answers lie out there in the real world.

What I'm getting at are two more important lessons:

> **Lesson 7:** Good science requires the right information, with attention to quality and accessibility.
>
> **Lesson 8:** "Nature is the ultimate authority"—observe, consider, and use discretion.

Lesson 8 comes directly from Ken Norris. He often cautioned his students to remember that "nature is the ultimate authority," and it is clear to me that it's important to always remember this in whatever we do. Lesson 7, I think, is becoming the key to progress in environmental science and conservation. We are reaching the point where we can collect, deal with, and analyze incredible volumes of information and data about the natural world, but all this information is useless if it isn't good information and if it isn't accessible. We are witnessing the rise of a new discipline called informatics, which is concerned with information management. Bioinformatics and ecoinformatics will play an increasing role in natural reserve management.

A major challenge is to *integrate* all the data we are collecting. In studies of biodiversity, for example, we need to integrate data from many sources—collections, archives, field studies, remote sensing, modeling, and so on. And then all this information must be geo-referenced—tied to spatial locations through geographic information systems (GIS). One way we are furthering this goal at our lab is by participating in a data clearinghouse, whereby we provide an on-line catalog of metadata (see http://www.gemlab.ukans.edu). Metadata consists of standardized documentation about what data is available for a particular series of sites, in our case focused on Costa Rica and the Kansas Ecological Reserves.

A Vision for the Future of Natural Reserves

The promise of integrating data, and making it available in standardized ways, is that it offers the possibility of what I call grand synthesis, the subject of my last set of lessons:

> **Lesson 9:** Grand synthesis involves deep understanding, careful planning, and working together.
>
> **Lesson 10:** Remember your roots, welcome change, and find inspiration in nature.

My vision for natural reserves, such as Big Creek, is to work toward such grand syntheses by reaffirming the leadership role that reserves can play. More and better-coordinated monitoring, more extensive use of remote sensing, use of roving expert teams, and automation of certain kinds of data gathering are all needed (Figure 4).

A Vision for Natural Reserves

Redefining the Role of the Natural Reserves

- Leadership in research—individual, multidisciplinary teams
- Leadership in education—understanding natural systems
- Leadership for land stewardship—outreach, coordination

Coordinated Monitoring & Sampling

- Baseline Information—species inventories, maps, weather…
- Remote Sensing—satellite, aircraft, ground-based…
- Expert Teams—discipline & technique based
- Automation—acquisition, processing, archiving

Data Integration & Communication

- Common, User, & Management Databases—streamlined processes for design, entry, metadata creation, archiving, & updating

- Metadata & Data Clearinghouse—online search & access
- Real-Time Integration & Visualization

Figure 4. New directions for natural reserve management.

I imagine that one day we will be able to walk into the UCSC chancellor's office and use the internet to look up what is happening that day at any of the University of California reserves. What is happening to a species that is being monitored or what is the latest interesting biological result? To realize this we need a common infrastructure involving users, databases, and real-time integration and visualization.

Let me conclude by stating again the words of Ken Norris: "Nature is the ultimate authority." May we have the wisdom to observe carefully and do our best to understand the lessons written in the land.

Acknowledgements

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