Landscape Analysis and Management

ENV724: Course Synopsis

Course Objective

Landscape ecology embraces a diverse range of topics concerned with the causes and consequences of spatial heterogeneity and pattern in natural systems as well as those dominated by human activities. This course is a task-oriented perspective on the discipline, focusing on the fundamental tasks in landscape ecology and management. These tasks include:

- sampling designs for landscape-scale applications;
- landscape inventory and monitoring;
- species distribution modeling (habitat classification),
- interpreting landscape-scale data (which invites multivariate and spatial statistics);
- site prioritization and multi-criteria decision frameworks for landscape management;
- detecting, interpreting, and forecasting landscape change; and
- integrated ecological assessment in a multivariate framework.

These tasks are couched in the logic of structured decision-making and adaptive management, a perspective that informs the workflow of the course. The aim is that students will learn *which* tools to use in any given application, and *how* to use those tools effectively.

Organizing Logic

I have always wanted to couch this course in the format of the adaptive management cycle: *plan*, *act*, *monitor*, *react*. But much of landscape management doesn't really work that way, in part because landscape management itself spans a huge variety of applications with different aims. That said, I believe there is a core set of tasks that show up repeatedly in a range of applications; they just don't necessarily flow directly from one to another. I think of this not as a linear flow but more of a braided stream of tasks.

For example, some agencies have a mandate to track the resources they manage, and so inventory and monitoring are central tasks. By contrast, other agencies focused on protecting lands with high conservation value might focus more on identifying the best targets for conservation. And in more research-oriented agencies, devising and interpreting management experiments might play a larger role. All of these share some similar tasks but in with different emphases. In this class, my approach is to consider some fundamental tasks and to instill a craftsman's appreciation of how to use the tools, and how the different tools can be combined into integrated workflows for a range of applications with different objectives.

There is, of course, a ridiculous variety of tools in this toolbox and new ones appear almost daily. I cannot hope to cover all of this variety in a single-semester class. My approach is to choose a few representative tools and develop a protocol for these cases. My hope is that students can then expand, as needed, their applications to other or emerging tools … and that the same workflow logic and best practices will carry over. For example, there are now dozens of species distribution models available, including many variations on common models such as generalized linear models. In my class, I delve into just three representative and complementary models, in the hope that this coverage will suffice if/when a student needs to choose among the larger and growing menu of choices. The same logic applies to other tasks.

Course Format

The class consists of lecture/discussion sessions alternating with computer labs. Lectures provide background and technical explanation of the fundamental tasks. Labs are hands-on exercises, mostly in the R statistical computing environment, designed to provide a craftsman's appreciation for conducting, interpreting, and presenting these analyses. Labs sometimes use geospatial data but do not involve analyses in a geographic information system (GIS). (In large part, this is because we have other courses in GIS.) For a few topics, we hold in-class discussion sessions to give us a chance to delve into practical, management-relevant details on the task at hand.

Course Materials

All materials for this course are on-line via Duke's intranet. The course is modular, and each module includes the necessary background readings, lecture materials, and details on any assignments (including annotated scripts for all analyses in R). All course resources are linked via a gateway (webpage) for each module. I am currently writing a textbook based essentially on this course, and the lecture notes for this class comprise a draft version of that book.

There are a *lot* of books on topics covered in this class; none of them covers all of the material in this course. I will point to some of these along the way, but my intent is that students need not invest in other resource books unless they want to own them anyway.

Course Topics & Syllabus

An outline of topics to be covered is provided separately. What follows is more of an overview of the logic of how the tasks are woven together.

Tools of the Trade

In this course, we will cover a lot of analytic tools, introduced briefly here. A few key tools are emphasized in labs, while some others are covered as demonstrations only (i.e., introduced so that, if students later find that they need them, they'll know where to look).

Sampling Designs for Landscapes. This is not a tool but rather, a logic applied to data collection schemes. An efficient and effective logical design is critical to inventory and monitoring, and especially crucial for applications that aim to make inferences from landscape-scale studies. The reality is that most observations collected from landscapes are not very informative, so there is a huge premium on maximizing the information content represented in samples that are collected from study area that are too large to be sampled efficiently.

Species Distribution Models. These tools, also known as habitat classification, habitat suitability, or niche models, are a foundational tool in ecology and natural resource management. There are scads of these tools available. I focus on a few complementary approaches: generalized linear models (GLMs, e.g., logistic regression) and related generalized additive models (GAMs), tree-based models (classification and regression trees and random forests), and maximum entropy modeling (maxent). In each case we will aim to understand how to fit the model, how to interpret the results, and how to present the analysis.

Tools for Multivariate Ecological Data. Ecological data are multivariate and noisy. Ecologists rely on two sets of tools to deal with multivariate data. These include *ordinations*, which reveal and summarize continuous trends in complex data, and *classification* techniques, which reveal naturally discrete groups in data. Ordinations include principal components and factor analysis, nonmetric multidimensional scaling (NMS), and a few other tools. Classifications include cluster analysis and a few partitioning methods (k-means pooling, partitioning around medoids). An allied tool, indicator species analysis, identifies species that can be used to identify communities created via classification. Other tools are used to address spatial structure in ecological data (we will look at these mostly as demonstrations). Collectively, these are the tools for exploratory data analysis, visualization, community assembly, image classification, and many other tasks in natural resource management.

We also will spend some time with an emerging tool that uses path models to pose direct and indirect causal influences (an indirect path is one by which *A* causes *B* and *B* causes *C*). Structural equation models (SEMs) provide a means to estimate direct and indirect effects. SEM also allows us to pose models in terms of conceptual constructs (latent variables), which themselves are identified by empirical indicator variables. Ecologists routinely think in these terms (e.g., water quality, ecosystem health, sustainability) and SEM provides a rigorous way to deal with these concepts.

Site Prioritization. A central task in conservation is to identify conservation targets: sites or properties with the highest conservation value. Rankings or prioritization can be simple if the criteria that define value are themselves simple (e.g., habitat suitability for a focal species). But in most cases, there are multiple and sometimes conflicting or competing values at play, which invites a structured decision-making approach. We explore this first by considering the logic of site prioritization, focusing on the *greedy heuristic algorithm*. We practice this logic using software providing greedy heuristic decision support, and touch on related tools available in R.

Landscape Change. Given a monitoring program or repeated data sets such as time series of classified land cover, it is natural to want to capture the trends in the data over time. This begins with change detection, and invites models that can project the observed changes into the future. We consider a few alternative ways to do this, and delve into a simple modeling approach (a Markov model) for projecting land cover change in the Triangle.

Ecological Assessment. A crucial task in management is to assess observed changes to decide if they are consistent with expectations. This is the *react* stage of adaptive management cycle, which interprets data from the monitoring stage. An important example is the assessment of restoration treatments to determine if they are working as planned. We will use ordinations (especially NMS) to visualize these assessments, and back this up as appropriate with statistical tests (e.g., corresponding to the Before/After, Control/Intervention or BACI design explicit in restoration projects).

Student Evaluation

This is a writing-intensive course. My logic in this is simple: technical prowess is of little use if the technician cannot explain the logic and meaning of the analyses to a stakeholder without the same level of technical expertise.

In this class, labs are reported in the format of journal articles or technical memos, but focusing exclusively on the Methods and Results sections. In the Methods section, students practice itemizing an analysis so that it meets the litmus test of reproducibility: every important detail explained. In the Results section, the focus is on presenting the findings in an engaging narrative, supported by clearly interpretable figures and tables. In every case, the aim is to be *precise* and *concise*.

An important lesson in scientific writing is that we typically do a *lot* more analyses than can be reported in a journal article or technical memo. As a result, we typically write the report (Methods, Results) as a minimalist document and then provide ancillary information as supporting materials (for journals, as digital appendices). In this class, students submit their written exercises in two parts: the main Report, and Supporting Materials. Learning which pieces belong in each part is an important learning objective.

Finally, most of the labs in this class are done in small groups of 3-4 students. This serves two purposes. First, it ensures that students can learn from each other. Some of this material is new and technically challenging, so having the opportunity to listen to other students explain key concepts to each other, in a safe setting, is really helpful. Second, students learn to jointly author technical documents—a skill they will need in their professional careers, and a skill that one masters only with practice.