Landscape Ecology in Theory and Practice: Application to National Forest Management

Course Description

Overview

The purpose of this course is to provide advanced education (at the graduate level) in the science of landscape ecology, including understanding the structure, function, dynamics and management of ecosystems at the landscape scale. This course is intended for professionals specializing in a wide variety of resource management areas such as wildlife, fisheries, ecology, silviculture, recreation and scenery management, geology and soil, fire and fuels management.

Landscape ecology might be defined best by its focus on the interplay between spatial pattern and process; specifically, how to characterize spatial pattern, where it comes from, why it matters, how it changes through time, and how we manage it. Thus, in this course, we will focus on the following:

• **Defining the landscape.** Defining the spatial scale (grain and extent) and thematic content and resolution of the landscape in the context of specific objectives is the first and most important step in examining landscape ecological relationships.

• **Determining the causes of landscape patterns.** How patterns develop on landscapes, including the three major agents of pattern formation: the physical template of environmental constraints, biotic processes and disturbances.

• **Characterizing landscape patterns.** The ability to detect and quantify landscape pattern is generally considered prerequisite to the study of pattern-process relationships. We will focus on methods for quantifying the composition and spatial configuration of landscape pattern in categorical landscape mosaics.

• **Quantifying landscape dynamics.** How landscape patterns and processes change through time, including techniques for detecting, analyzing, or simulating landscape change; and modeling populations or communities in landscape mosaics (including spatially implemented metapopulation models).

• **Understanding the ecological implications of landscape pattern.** This is the central set of questions in landscape ecology. We will focus on processes at four levels of organization: genes, populations and metapopulations, communities, and ecosystem processes.

• **Managing landscapes.** How humans approach the management of complex landscapes to achieve management objectives, including two themes central to ecology today: Conservation biology and ecosystem management.

Beyond these overall content objectives, this course is intended to:

• Provide students an opportunity to work and learn in an interdisciplinary environment; specifically, to provide students the opportunity to develop natural resource problem-solving skills in an interdisciplinary team environment.

• Provide students an opportunity to engage in active, student-directed learning that emulates professional life.

• Provide students an opportunity to refine their written and oral communication skills.
Guiding Philosophy and Instructional Methods

The course objectives listed above dictate the teaching and learning methods used in this course. Specifically, this course is strongly focused on **project-based learning**. Consequently, learning new material from assigned readings and regurgitating it on exams is de-emphasized. Rather, the emphasis is on sharing knowledge and expertise (both pre-existing and newly acquired) with students from different disciplines (in a small group environment) to address contemporary issues in landscape ecology. The time and energy devoted to this course is largely in the form of interdisciplinary group analysis of data sets (largely via the use of computer models) and discussion of those results in reference to the concepts learned from lecture and assigned readings, not preparing for exams. In addition, in contrast to most conventional courses, the laboratory exercises constitute the major emphasis of the course. Indeed, lectures are primarily designed to support the lab exercises, not vice versa.

In addition, this course is strongly focused on **place-based learning**. Place-based learning entails building a theoretical and practical understanding of landscape ecology (in this case) around a single place - a case study landscape. The principles and concepts are presented in their general form (and perhaps illustrated with examples from a broad range of landscapes), but ultimately are related back to the case study landscape. The case study landscape acts as a common thread among course components and provides a unifying focus to the course. By applying the various principles and methods of landscape ecology to the study and management of a single case study landscape, students gain a greater appreciation for how landscape ecology can be used in practice. This follows from the fact that most students work on a single national forest and will likely apply the landscape ecology concepts and methods learned in this course to their task of managing a single landscape. Moreover, there are tremendous economies of scale associated with place-based learning. By gradually building a multi-faceted understanding of a single landscape, much less time has to be devoted to familiarizing students with new landscapes and new data sets for each exercise.

Lastly, this course is strongly oriented towards **national forest planning and management**, and is specifically designed to meet the needs of Forest Service professionals. Hence the project- and place-based approach emphasizes learning landscape ecology principles that are most relevant to the management of national forests in general, and those that are particularly relevant to the management of the case study landscape. In addition, the course content is weighted towards the current needs of national forest managers. For example, given the heavy emphasis in the current forest planning regulations on using historic range of variation in landscape structure and characteristics of disturbance regimes as a guide to setting desired future conditions, we have placed a disproportionate emphasis on the landscape dynamics component of the course.

Accordingly, the course is logically divided between conventional lectures and hands-on lab exercises. In general, the morning session each day is devoted to lecture and discussion, and is intended to provide the necessary theoretical and conceptual background needed to complete the afternoon lab exercises. Completing the course pre-work, largely consisting of assigned readings, is essential to this aspect of the course. Importantly, lectures are designed to review and highlight the most relevant material from the assigned readings and provide illustrated examples and references to ecosystems from throughout North America to assure relevance to all students, as well as provide an
opportunity for class discussion of the important concepts.

The afternoon session each day is devoted to hands-on exercises. The purpose of these exercises is to provide students with hands-on experience analyzing real data using state-of-the-art landscape analysis software, all centered around the case study landscape. Students work in small groups of two to four to complete each exercise and are responsible for presenting written and oral reports of their findings (see below). These exercises are not intended to provide students exposure to a comprehensive suite of landscape ecological applications and analytical tools. Rather, these exercises are intended to expose students to a variety of real-world applications that highlight some of the key underpinnings of landscape ecology, and to give students an appreciation for some of the sophisticated analytical tools used in the field. Importantly, it is not possible or practical for students to become proficient in the use of any of the software tools used during these short exercises. Instead, students gain enough familiarity with the various analytical approaches used by landscape ecologists to be able to interact with trained landscape ecologists in a team environment. In addition, although the exercises are built around applications involving the case study landscape, the principles learn from these exercises and the methods and tools used are generalizable to any region and ecological system.

Overall, there is an emphasis in all lectures and lab exercises on management implications and applications to heighten relevance of the subject matter to field professionals and assure students can apply concepts on their home units. In this regard, every lecture topic includes key theories/concepts/principles as well as a discussion of their management implications. Further, the lab exercises are strongly oriented towards practical management applications. Lastly, the written lab reports require students to apply the key findings and lessons learned to their home units.

The Case Study Landscape

The case study landscape, in accordance with the “place-based” approach of this course, is drawn from a local landscape. The Coconino and Kaibab National Forests and Grand Canyon National Park are conveniently located in northern Arizona in close proximity to Flagstaff. This public landscape supports a wide range of environmental gradients producing a forest diverse in vegetation and disturbance processes. Understanding this spatial heterogeneity, its causes and consequences, and its change over time (past and future) presents a major challenge to the management of natural resources on these public lands. Landscape ecology provides a framework, including a set of principles and a variety of decision-support tools, that can contribute greatly towards meeting this challenge. This course will provide students an overview of how these principles and tools can be applied to improve understanding and management of these public lands and will serve as an example of how landscape ecology can be applied to the study and management of any real landscape.

Course Content and Organization

As noted above, this course is project-based and is built around the lab exercises associated with the case study landscape. The course schedule (below) reflects a logical sequence of lab exercises and supporting lectures in which students build an increasingly in-depth and multi-faceted understanding
of how to apply landscape ecology to the study and management of the case study landscape. We acknowledge that the lab/lecture sequence below does not cover the full complement of landscape ecology topics, nor does it provide exposure to the full suite of available landscape ecology tools. However, it is not possible to provide complete coverage in the two week time frame available. For example, there are dozens of relevant computer models (i.e., decision-support tools) that are applicable to the study and management of the case study landscape. We selected a suite of exercises and set of tools that illustrate various landscape ecological principles deemed most appropriate to the study and management of the case study landscape. Importantly, the particular exercises and chosen set of tools would likely vary to some degree for each case study landscape.

A tentative course schedule is given below based on previous course offerings. However, future course offerings are subject to change in both course content and the list of instructors.

Day 1 (Monday): **Introduction to landscape ecology**

8:00-8:30 Introduction and overview of course

8:30-9:30 Introduction to landscape ecology [chapter 1]

*Instructor:* K. McGarigal

*Assigned Reading:* Turner et al. 2001 (Chapter 1)

*Objective:* Describe the focus of the science of landscape ecology, including its historical context and its contrast to other ecology disciplines. Highlight importance of landscape ecology in addressing current resource management topics.

*Topics covered:*
  - What is landscape ecology
  - History of landscape ecology
  - Why it is important to resource managers

9:30-10:30 Federal land management context for landscape ecology [chapter 2]

*Instructor:* S. Cushman

*Assigned Reading:* None

*Objective:* Describe the role of landscape ecology in the Forest Service and other federal land management agencies. Highlight how landscape ecology principles can make land managers/specialists more effective in meeting agency goals.

*Topics covered:*
  - Why should we care about landscape ecology as federal land managers/specialists?
  - Whose job is it? Is it my job?
  - In what way do I need to understand and utilize landscape ecology principles to be an
effective forest manager?

10:45-12:00 What is a landscape? [chapter 3]

**Instructor:** K. McGarigal

**Assigned Reading:** McGarigal (Lecture notes)

**Objective:** Provide a basic understanding of the concept of a “landscape” to serve as a foundation for understanding landscape ecology topics. Review basic approaches for defining a landscape. Highlight importance of landscape definition in resource management planning and analyses.

**Topics covered:**
- Landscape defined
- The landscape concept – composition, structure and function
- The digital challenge – importance of scale
- Landscape context

1:00-5:00 Field trip – the Case Study landscape

**Instructors:** K. McGarigal and S. Cushman

**Overview:** On this field trip, students will visit sites along an elevational gradient extending from the semi-arid desert grasslands up through pinyon-juniper woodlands, ponderosa pine forest, mixed-conifer forest and subalpine spruce-fir forest to learn about the ecology and management of these major ecological systems. The purpose of this field trip is to familiarize students with the case study landscape so that subsequent labs have more meaning. Local experts will participate in the field trip and lead the discussion at each site.

**Day 2 (Tuesday): Defining a landscape (models of landscape structure)**

8:00-9:00 Lab exercise #1 - Part 1 presentations & discussion (groups 1 & 2 lead)

9:00-12:00 Models of landscape structure [chapter 4]

**Instructor:** K. McGarigal

**Assigned Reading:** McGarigal (Lecture notes)

**Overview:** Provide a basic description of several alternative models of landscape structure, including models based on point, categorical and continuous patterns. Highlight the importance of selecting a meaningful model for the question under consideration given the constraints of data availability and software tools available for analyzing pattern-process relationships.

**Topics covered:**
- Models of landscape structure
• Point pattern model
• Patch mosaic model - island biogeographic and landscape mosaic models
• Landscape gradient model
• Graph matrix model

1:00-5:00  Lab exercise #1 – Defining the landscape: Part 1

Instructors: K. McGarigal and S. Cushman

Overview: In this exercise, students will experience the challenges associated with defining the case study landscape in an ecologically meaningful manner given real-world practical considerations (e.g., data limitations) and management objectives. Students will use GIS to create and evaluate alternative landscape definitions and discuss the challenges and implications of their decisions. In Part 1, students will focus on gaining familiarity with the case study landscape and the corresponding spatial data base and examine the sensitivity of landscape pattern analysis to landscape definition.

Day 3 (Wednesday): Characterizing landscape patterns

8:00-9:00 Lab exercise #1 - Part 2 presentations & discussion (groups 3 & 4 lead)

9:00-11:00 Characterizing landscape patterns – conceptual foundation [chapter 5]

Instructor: K. McGarigal

Assigned Reading: Turner et al. 2001 (Chapter 5); Gustafson (1998)

Objective: Provide a basic understanding of how to characterize and quantify landscape pattern. Highlight importance of landscape definition in landscape pattern analysis and the difference between measured and functional heterogeneity.

Topics covered:
• Perspectives on categorical landscapes
• The importance of scale
• Landscape context
• Scope of analysis
• Levels of heterogeneity
• Components of landscape structure
• Structural versus functional metrics
• Theoretical behavior of metrics
• Metric redundancy: In search of parsimony
• Metric reference framework

11:00-12:00 Landscape metrics for categorical map patterns [chapter 6]

Instructor: K. McGarigal
**Assigned Reading**: Turner et al. 2001 (Chapter 5); McGarigal (Lecture notes)

**Objective**: Provide an overview of common landscape metrics and insights into their use and interpretation. Here, select a few of the more important metrics that highlight different aspects of landscape structure. Highlight the importance of selecting the “right” metric for the “right” problem.

**Topics covered**:
- Area/density/edge metrics
- Shape metrics
- Core area metrics
- Contrast metrics
- Contagion/interspersion metrics
- Isolation/proximity metrics
- Connectivity metrics
- Diversity metrics

1:00-5:00  Lab exercise #2 – Quantifying landscape patterns

**Instructors**: K. McGarigal and S. Cushman

**Overview**: In this exercise, students will learn to use the program FRAGSTATS and interpret the output in the context of the case study landscape. FRAGSTATS is a program for quantifying landscape patterns for categorical maps. Students will gain a practical understanding of how to select and compute landscape metrics. Specifically, students will quantify habitat loss and fragmentation due to roads and vegetation management in the case study landscape and identify the challenges and limitations of quantifying landscape patterns.

Day 4 (Thursday): **Landscape models**

8:00-9:00  Lab exercise #2 presentations & discussion (groups 5 & 6 lead)

9:00-12:00 Landscape disturbance-succession models [chapter 7]

**Instructor**: E. Gustafson

**Assigned Reading**: Turner et al. 2001 (Chapter 3); Scheller and Mladenoff (2007)

**Objective**: Provide an overview of the varied types of dynamic landscape models and their applications for examining pattern-process relationships. Highlight the use of stochastic landscape disturbance-succession simulation models (e.g., LANDIS, LANDSUM, RMLANDS).

**Topics covered**:
- Introduction to landscape disturbance-succession models (LDSM’s)
- Types and components of LDSM’s
- Major LDSM’s in use today
• Testing and validation of LDSM’s
• Limitations of LDSM’s
• Choosing the “best” LDSM

1:00-5:00  Lab exercise #3 – Quantifying HRV and current landscape departure: Part 1

_Instructors:_ K. McGarigal and S. Cushman

_Overview:_ In this exercise, students will use RMLANDS to quantify HRV and current departure in landscape structure for the case study landscape. Students will gain a practical appreciation for the challenges associated with quantifying HRV and current departure and the importance of scale. Specifically, students will learn how to interpret current landscape departure within the scope and limitations of the analysis (e.g., scale of analysis). In Part 1, students will focus on assessing the model in terms of its adequacy, and examine the model equilibration in the HRV simulation and its meaning.

_Day 5 (Friday):_ Natural disturbance regimes and historic range of variability (HRV)

8:00-9:00 Lab exercise #3 Part 1 presentations & discussion (groups 7 & 8 lead)

9:00-11:00  Disturbance and disturbance regimes [chapter 8]

_Instructor:_ B. Keane

_Assigned Reading:_ Turner et al. 2001 (Chapter 7); Reice (1994); Romme et al. (1995)

:Objective. Provide an overview of natural disturbances as ecological drivers of landscape pattern and change. Understand the attributes of natural disturbance regimes, the ecological role of disturbance and the factors affecting disturbance regimes. Highlight the role of disturbance (with an emphasis on fire and insects/pathogens) in shaping landscapes and affecting biodiversity.

_Topics covered:_
• Characteristics of disturbance and disturbance regimes
• Landscape disturbance ecology
• Interactions and feedbacks among disturbances
• Management implications – vegetation management (disturbance emulation), intermediate disturbance hypothesis, minimum dynamic area concept, etc.

11:00-12:00 Historic range of variability (HRV) in landscape structure [chapter 9]

_Instructor:_ B. Keane

_Assigned Reading:_ Landres et al. (1999); Keane et al. (2009)
Objective. Provide an overview of HRV concepts and their application in landscape planning and management. Highlight the use of HRV in establishing context for the current landscape condition and its potential role in guiding specification of desired future landscape condition.

Topics covered:
• Introduction to HRV
• Methods for determining HRV and current departure
• Interpretations of HRV and current departure
• Importance of scale in HRV assessments
• Resource planning and management applications of HRV and current departure (e.g., LANDFIRE)

1:00-5:00 Lab exercise #3 – Quantifying HRV and current landscape departure: Part 2

Instructors: K. McGarigal and S. Cushman

Overview: In this exercise, students will continue to examine HRV and current departure in landscape structure for the case study landscape. In Part 2, students will focus on quantifying HRV and current departure and interpreting the findings.

Day 6 (Monday): Fire, fuels and climate agents

8:00-9:00 Lab exercise #3 Part 2 presentations & discussion (groups 1 & 2 lead)

9:00-12:00 Fire, fuels and climate [chapter 10]

Instructor: J. Littell


Objective. Provide an overview of the interaction between fuels, climate, and fire and the role of management practices in the alteration of fire regimes. Highlight the role of fire and fuels management in shaping landscapes (patterns and change) and the ecological implications of these changes.

Topics covered:
• Fire and fuels management (how do we know what we think we know?)
• Review of factors influencing fire regimes
• Scientific basis for modifying forest structure to modify fire behavior
• Scaling up to landscape level fire management
• The future of fire and fuels management in the context of resource management

1:00-3:00 Landscape ecology of fuels management [chapter 11]

Instructor: M. Finney
**Assigned Reading:** Finney and Cohen (2003)

**Objective:** Provide an overview of the landscape ecology of fuels management, emphasizing the interaction between fuels treatments and fire behavior. Highlight that the benefits of fuel management can be realized only when treatments are applied at the appropriate scale to the appropriate source of the problem(s) and that accomplishing the broad goals for fuel management requires understanding how proposed treatments directly contribute to solving specific problems.

**Topics covered:**
- Expectations for fuel management
- Local and landscape scales of fuel management
- Goals and objectives of fuel management

3:00-5:00 Lab exercise #4 – Management scenarios: Part 1

**Instructors:** K. McGarigal and S. Cushman

**Overview:** In this exercise, students will use RMLANDS to quantify the dynamics in landscape structure for the case study landscape under several alternative management scenarios, for example representing different levels (e.g., spatial extent and configuration) of fuel treatments and their effectiveness (e.g., altered probabilities of initiation, spread and severity) under alternative climates. Students will gain a practical understanding of scenario analysis as an aid to forest planning and gain an appreciation for the challenges and limitations associated with interpretation of results. Specifically, students will learn how to conduct scenario analysis to compare the potential impacts of management actions aimed at controlling fire and insect/pathogen disturbance regimes. In Part 1, students will focus on creating alternative management scenarios that reflect meaningful management objectives and simulating those scenarios.

Day 7 (Tuesday): **Biological disturbance agents**

8:00-9:00 Lab exercise #4 Part 1 presentations & discussion (groups 3 & 4 lead)

9:00-12:00 Biological disturbance agents [chapter 12]

**Instructor:** D. Six

**Assigned Reading:** Romme et al (1986), Parfitt (2007), and Castello et al. (1995)

**Objective:** Provide an overview of management practices directed towards insects and pathogens and the alteration of biological disturbance regimes. Highlight the role of treatments in shaping landscapes (patterns and change) and the ecological implications of these changes.

**Topics covered:**
- Forest health issues – insects and pathogens as agents of landscape pattern and change
• Forest health management practices affecting landscape pattern and process (e.g., salvage)
• Interactions and feedbacks affecting landscape pattern and process (e.g., climate)
• Ecological consequences of forest health management (e.g., species conservation)

1:00-5:00 Lab exercise #4 – Management scenarios: Part 2

*Instructors:* K. McGarigal and S. Cushman

*Overview:* In this exercise, students will continue to examine alternative management scenarios. In Part 2, students will focus on examining the impacts of their alternative scenarios on landscape structure and discussing the implications.

**Day 8 (Wednesday):** Ecological consequences of landscape pattern – populations

8:00-9:00 Lab exercise #4 Part 2 presentations & discussion (groups 5 & 6 lead)

9:00-12:00 Ecological consequences of landscape pattern – populations [chapter 13]

*Instructor:* B. Goodwin

*Assigned Reading:* Turner et al. 2001 (Chapter 8); With and King (2001)

*Objective:* Provide an overview of the consequences of landscape pattern to populations and species; principles of conservation biology. Highlight the influence of landscape pattern on population and metapopulation processes and population viability.

*Topics covered:*
  • Populations and metapopulations
  • Habitat loss and fragmentation
  • Continuity and connectivity
  • Spatially explicit population models (SEPM’s)
  • Population viability analysis (PVA)
  • Population/species conservation – focal species approach (e.g., indicators), ecological process approach, landscape pattern approach, coarse- and fine-filter approach

1:00-5:00 Lab exercise #5 – Metapopulation assessment: Part 1

*Instructors:* K. McGarigal and S. Cushman

*Overview:* In this exercise, students will use a spatially explicit metapopulation viability model to evaluate the impacts of alternative forest management scenarios on a metapopulation of marbled salamanders in western Massachusetts. Students will gain a practical understanding of metapopulation concepts and population viability analysis as an aid to forest planning and gain an appreciation for the challenges and limitations associated with the interpretation of results. Specifically, students will develop a forest management scenario involving commercial timber harvesting and evaluate the potential impacts on the marbled salamander metapopulation with
the aim of trying to devise a management scenario that minimizes adverse impacts on the salamander while simultaneously achieving timber harvest objectives. In Part 1, students will create an initial management scenario, implement it in the simulation, and examine the results. Based on the results they will create and implement one or more alternative scenarios to improve on their performance.

**Day 9 (Thursday): Ecological consequences of landscape pattern – genetic diversity**

8:00-9:00 Open discussion

9:00-12:00 Ecological consequences of landscape pattern – genetic diversity [chapter 14]

*Instructor:* M. Schwartz

*Assigned Reading:* Manel et al. 2003

*Objective:* Provide an overview of the emerging discipline of landscape genetics – the integration of population genetics and landscape ecology. Highlight the influence of landscape pattern on gene flow and the conservation of genetic diversity in the context of evolutionary processes.

*Topics covered:*
- Population genetics and genetic diversity
- How is genetic diversity lost
- Influence of landscape pattern on patterns of genetic diversity
- Role of landscape genetics in conservation and management

1:00-5:00 Lab exercise #5 – Metapopulation assessment: Part 2

*Instructors:* K. McGarigal and S. Cushman

*Overview:* In this exercise, students will continue to examine the metapopulation viability impacts of the forest management scenarios. In Part 2, students will compare and contrast the results of their management scenarios and discuss the implications.

**Day 10 (Friday): Ecological consequences of landscape pattern – synthesis**

8:00-9:00 Lab exercise #5 presentations & discussion (groups 7 & 8 lead)

9:00-12:00 Ecological consequences of landscape pattern – synthesis [chapter 15]

*Instructor:* S. Cushman

*Assigned Reading:* Turner et al. 2001 (Chapter 8); Urban et al. (2002)
Objective. Provide an overview of the consequences of landscape pattern to communities; principles of community ecology. Highlight the influence of landscape pattern on community structure.

Topics covered:
- Communities - what are they and are they real?
- Niche concept and individual species-level focus
- Past, present and future communities
- Communities across the landscape
- Disturbance and community succession
- Fire, climate and community change
- Integrated community modeling
- Management and conservation

1:00-3:00 Course synthesis and discussion [chapter 16]

Instructors: K. McGarigal

Assigned Reading: Turner et al. 2001 (Chapters 10 & 11)

Objective. Provide a synthesis of the course. Highlight the key take-home messages of how landscape ecology applies to the management of national forests.

Topics covered:
- Key axioms of landscape ecology
- How to apply landscape ecology to national forest management

3:00 Course evaluation