March 2007

# PHD THESIS CHAPTER ONE

# INTRODUCTION

## 1.1 INTRODUCTION

The term 'Land-Use/Cover Change' (LUCC) acknowledges the interaction of human (e.g. cognitive, social, economic) and biophysical (e.g. ecological, hydrological, atmospheric) processes and systems driving land change. It is a term that implicitly considers human-influenced landscapes as integrated socio-ecological systems. The terms 'Land-Use' and 'Land-Use Change' (LUC) consider human use of land and changes in the purpose for which that land is used. For example, land uses include 'agricultural' and 'recreational'. 'Land-Cover' and 'Land-Cover Change' (LCC) refer to the physical, biotic cover of the land, regardless of the human use (or lack thereof), and any changes occurring to it. For instance, land cover might be defined as *Pinus* forest or *Quercus* shrub-land. Because human activities and land-use often directly determine land cover, change in the former often results in change in the latter. However, changes in land-cover due to biophysical processes may equally have consequences that in turn influence human land-use. This reciprocal change frequently demands that LUCC research crosses traditional academic subject boundaries, utilising theoretical and practical tools from multiple fields and requiring collaboration between 'experts' from different backgrounds, in a manner that has come to be known as 'interdisciplinary' (e.g. Naveh 2000). A primary concern of this thesis is how LUCC models can and should be developed, when an interdisciplinary approach is required to address a problem.

## 1.2 MEDITERRANEAN LANDSCAPES

Prime examples of socio-ecological systems are found in the Mediterranean Basin where human activity has extended over millennia. The Mediterranean Basin is one of the most biologically diverse regions on the planet, with around 10% of all plant species on Earth in an area covering just 1.5% of the Earth's land surface (Blondel and Aronson

1999). High levels of habitat diversity and human activity, when combined with the heterogeneous nature of the Mediterranean climate and soil conditions produce a biological spatial ‘patchiness’ not found in more temperate, arid or tropical regions of the world (Blondel and Aronson 1999). Biophysical and human processes promote, and are shaped by, this biological patchiness, producing spatially heterogeneous, mosaic-like landscapes of land covers. The highly seasonally variable characteristics of the Mediterranean climate make landscapes in these environments amongst the most fire prone in the world (Smith 1992). Wildfire disturbance, and subsequent patterns of vegetation regeneration that in turn influence future wildfire activity, typify the feedbacks between pattern and process emphasised by landscape ecologists (Turner 1989). When humans are present in a landscape they become part of this pattern/process feedback – human patterns of land-use influence where wildfires occur and how they spread. In turn, wildfire influences patterns of vegetation and its regeneration, and thus human land-use. Naveh (1994 p.164) identifies this very close interaction between humans, vegetation and fire, noting that fire has had vitally important roles in the evolution of both floral and cultural landscapes over previous millennia, serving “as a major driving force in the co-evolution of Mediterranean humans and their landscapes”. The close relationship between humans and fire is highlighted by the fact that, while across the majority of the globe wildfires are predominantly ignited by natural causes (mainly lightning), in the Mediterranean Basin humans are the principle cause (Vazquez and Moreno 1993).

Regardless of their interaction with wildfire, traditional human land-use alone has been an important disturbance (either directly or indirectly) of Mediterranean vegetation. For example, tree crops are cut for management purposes and land is widely used to graze livestock. A common human land-use in Spain is the open, savanna-like landscapes of managed oak woodlands known as *dehesa*. Grazing livestock on grasslands between trees in these woodlands prevents growth of saplings and has been shown to reduce the number and quality of acorns available to initiate future establishment, due to predation (Leiva and Fernandez-Ales 2003, Cierjacks and Hensen 2004). The maintenance of fields exclusively for cereal cropland prevents any succession-type processes to occur, reducing species diversity and above-ground biomass that otherwise might occur. However, recent technological and socio-economic changes in the Mediterranean Basin have led to increasing land-use change, and notably the abandonment of agricultural and managed land. Such abandonment may lead to increases in vegetation biomass – the fuel of wildfires. That is, changes in social processes are influencing spatial biophysical landscape patterns. These patterns will in turn affect biophysical processes (such as wildfire and vegetation dynamics) in the reciprocal manner described above. These reciprocal links between landscape patterns and processes (across the traditional boundaries of social and ecological study), non-linear feedbacks and historical landscape contingency mean potential changes are unclear, with a wide range of possible future outcomes. This thesis sets out to examine the potential consequences of these feedbacks over the coming decades for a Spanish landscape.

## 1.3 LANDSCAPE MODELLING

Naveh (2001) coined the term ‘multifunctional landscape’ to describe a system manifested by the interaction between cognitive, cultural, economic, and biophysical processes and phenomena. These systems of interactions will be termed here as a ‘socio-ecological’ systems, of which ‘landscapes’ are a physical manifestation. The nature of the processes occurring in socio-ecological systems means that they function at scales on the order of the human observer. Thus the ‘landscape scale’ is taken here to be on the order of $1 \times 10^2 – 1 \times 10^9$ $m^2$ (100 $m^2$ – 1,000 $km^2$) and $1 \times 10^4 – 1 \times 10^9$ sec (1 day – 100 years). The ‘multifunctional’ nature of Spanish landscapes outlined above suggests an interdisciplinary approach must be taken to study the dynamics of these systems. Geography has traditionally been the academic discipline to address the processes and scales associated with socio-ecological systems and landscapes. More recently, landscape ecology has emerged as an interdisciplinary field of study as ecologists came to terms with the idea that there are few ecosystems remaining that are uninfluenced by humans and their activities (see Naveh and Liberman 1994). Geography considers questions of space, place and scale. Landscape ecology addresses ecological problems and questions of ecological structure and function, often incorporating human influence, but also stresses the importance of space, scale, and feedbacks between spatial pattern and ecological process. These disciplines provide the theoretical and academic background to this thesis. However, one of the primary aims of this thesis (see section 1.4 below) is to improve understanding of the impacts of agricultural and other LUCC on ecological patterns and processes, specifically wildfire regimes. Thus, whilst human activities (and changes in them) are important drivers of LUCC in these landscapes the focus of study here is on the ecological consequences of these changes.

At any point in time the state of heterogeneous and multifunctional landscapes, such as the study area examined here, is a result of spatio-temporal interactions and contingencies. These landscapes are complex in the sense that "the cause of a difficulty may lie far back in time from the symptoms, or in a completely different and remote part of the system" (Forrester 1969 p8). Space matters as much as time, patterns matter as much as process, social dynamics matter as much as ecological dynamics. How, then, should these landscapes be investigated and understood? Generally some sort of simplification, a model, of the actual system is required to investigate the system. Spatially-explicit modelling is a useful tool to examine the processes and phenomena occurring at the landscape scale as they provide a means to logistical, political and financial constraints of empirical experimentation. Particularly, when a problem is not analytically tractable (i.e. closed form equations cannot be written down and are non-integrable) simulation models may be used to represent a system by making certain approximations and idealisations (Winsberg 1999). Spatially-explicit simulation models of LUCC have been used since the 1970s and have dramatically increased in use recently with the growth in computing power available. This thesis capitalises on previous LUCC simulation and contemporary technology to develop an integrated cellular-automata/agent-based model of vegetation dynamics, wildfire regimes and agricultural decision-making.

As implied above, by definition a model is simplified representation, or theory, of how real world systems function. However, when the system being modelled contains many heterogeneous interacting components, the model itself can become complex (*sensu* Forrester 1969 above). In this case, analysing, interpreting and explaining both model dynamics and output becomes challenging. Furthermore, the epistemological issues raised by attempting to put boundaries on these systems so that they can be represented *in silico*, means deduction and falsification become less useful methods by which to assess the knowledge gained. As models of socio-ecological systems represent actual people in the real world, opportunities are present to engage with the subjects of the model to develop, assess and improve it. However, engaging non-modellers with models raises issues of expertise and the 'public understanding of science'. This thesis investigates not only the processes and routes of change in a Mediterranean landscape, but also the processes and routes of investigation themselves given the potential for model engagement with those being modelled.

## 1.4 THESIS AIMS

This thesis has the following aims:

i) examine the impacts of human land use/cover change upon wildfire regimes in a Mediterranean landscape
ii) explore and evaluate novel methods to 'validate' simulation models (and processes of modelling) of environmental change considering human activity

These aims will be achieve via the following objectives. To achieve aim i) a spatially-explicit computer simulation model will be developed to examine:

1. impacts of change in land use/cover configuration (specifically fragmentation) on future wildfire regime (spread component)
2. impacts of change in vegetation (land cover) composition on future wildfire regime (spread and ignition risk components)
3. impacts of change in human population (size and 'type' of inhabitant) on future wildfire regime (ignition risk component)

To achieve aim ii) the thesis will:

1. consider the epistemological and sociological issues confronting attempts to model socio-ecological systems
2. examine the possibility of using local stakeholder input to 'validate' the construction of the model
3. reflect on the experience of developing a socio-economic simulation model to examine the interaction of LUCC and wildfire

## 1.5 THESIS STRUCTURE

The structure of this thesis may be broken into three sections (Table 1.1). The first section (chapters two and three) review the context of both the subject of study and the means of studying it. This necessary prelude to any modelling project examines the key features of the systems under study that will need to be incorporated into a model, and reflect on how previous modelling research has approached similar systems. Chapter two, introduces and outlines the key features of the history and contemporary condition of Mediterranean landscapes that are pertinent for this work. The study area, EU Special Protection Area number 56 (SPA 56) is introduced and described in detail. Chapter three considers the broad array of tools and techniques that have been developed to investigate and model LUCC in many regions around the globe. Empirical models are used to examine the data available for SPA 56 and to establish what observed change suggests may unfold in the future.

**Table 1.1 Thesis structure.** The thesis has three main parts – part one is a review of the subject of study and the means to study it, part two concerns the construction and results of the simulation model, and part three is an examination of the appropriate methods by which to assess models of socio-ecological systems.

| Research Questions | Chapter | Subject |
|---|---|---|
| | ONE | Introduction |
| What are the important issues here? | TWO | Study Area |
| How should this be LUCC modelled? | THREE | Review of Modelling Methods |
| How should this model be built? | FOUR | BioPhysical Model |
| | FIVE | Socio-Economic Model |
| What does this model tell us? | SIX | Integrated Model Results |
| How to 'validate' socio-ecological models? | SEVEN | Model Validation Discussion |
| Do others think this model is any good? | EIGHT | Stakeholder Evaluation |
| What have we learnt? | NINE | Summary and Conclusions |

The second section describes the construction, and initial results from, an integrated simulation model of LUCC and wildfire. Chapter four reviews previous models of Mediterranean vegetation dynamics and disturbance (i.e. wildfire) and uses this as the basis to describe and justify the structure of the Landscape Fire Succession Model (cellular automata approach). A similar approach to presentation is taken in Chapter five, which details the socio-economic (agent-based) model of agricultural decision-making. Both chapters conclude with initial results from testing and sensitivity analyses. Chapter six then presents the use of the integrated model to examine potential LUCC and the consequences for wildfire regimes as a result of different scenarios of economic and demographic change.

The third section of the thesis considers how interdisciplinary models of socio-ecological systems, such as the one developed in chapters four and five, should be assessed given the nature of systems they represent. Chapter seven discusses the epistemological and sociological issues that arise when 'open', middle-numbered systems, such as those considered by geographers and landscape ecologists, are modelled. Chapter eight takes the model outside the 'ivory tower' to engage with local stakeholders in the study area and uses the validation criteria suggested in chapter seven to evaluate the model. Chapter nine takes a narrative approach to summarise and reflect upon what was learnt during the research presented in the thesis.

## References

Blondel, J. and Aronson, J. (1999) *Biology and wildlife of the Mediterranean region* Oxford: Oxford University Press

Cierjacks, A. and Hensen, I. (2004) Variation of stand structure and regeneration of Mediterranean holm oak along a grazing intensity gradient *Plant Ecology* **173**:215-223

Forrester, J. W. (1969) *Urban Dynamics* Cambridge, Mass.: MIT Press

Leiva, M. J. and Fernandez-Ales, R. (2003) Post-dispersive losses of acorns from Mediterranean savannah- like forests and shrublands *Forest Ecology and Management* **176**:265-271

Naveh, Z. (1994) The role of fire and its management in the conservation of Mediterranean ecosystems and landscapes *In:* Moreno, J. M. and Oechel, W. C. *The role of fire in Mediterranean-type ecosystems*:163-185 New York: Springer-Verlag

Naveh, Z. (2000) What is holistic landscape ecology? A conceptual introduction *Landscape and Urban Planning* **50**:7-26

Naveh, Z. (2001) Ten major premises for a holistic conception of multifunctional landscapes *Landscape and Urban Planning* **57**:269-284

Naveh, Z. and Liberman, A. S. (1994) *Landscape ecology: theory and application* New York: Springer-Verlag

Smith, K. (1992) *Environmental hazards: Assessing risk and reducing disaster* London: Routledge

Turner, M. G. (1989) Landscape Ecology: The effect of pattern and process *Annual Review of Ecology and Systematics* **20**:171-197

Vazquez, A. and Moreno, J. M. (1993) Sensitivity of Fire Occurrence to Meteorological Variables in Mediterranean and Atlantic Areas of Spain *Landscape and Urban Planning* **24**:129-142

Winsberg, E. (1999) Sanctioning models: The epistemology of simulation *Science in Context* **12**:275-292