FIRE USE, LANDSCAPE TRANSITION, AND THE SOCIOECOLOGICAL STRATEGIES OF HOUSEHOLDS IN THE FRENCH WESTERN PYRENEES

by

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(Under the Direction of Theodore L Gragson)

ABSTRACT

Dissertation research investigated the historical ecology of pastoral fire use and landscape change among Basque farmers in the French Western Pyrenees. The research focused on social institutions, legacies of land use and management, and spatial contexts of socioecological interaction. Specifically, I investigated fire use practices, historical land use and ownership, and the historical demography of households on the French side of the French-Spanish border in the rural mountain village of Larrau. I combined ethnographic methods and historical data with geospatial analytical tools to examine the socioecological dynamics of change and persistence in the landscape. Results show the degree to which the influence of social institutions on fire ecology has affected change and persistence in the landscape over the long term. While individual households greatly control the extent and character of pastoral fire use at the parcel level, inter-household institutions have conversely little influence on the practice itself. Landscape patterns persist partly as a result of the parcel level fire regimes that emerge from the socioeconomic strategies of individual households. On the other hand, historical differences in land use intensity between households and inter-household property institutions are strongly associated with spatial variation in fire management and land use over the long term. In addition, the socioeconomic strategies of individual households are strongly associated with the pace and character of landscape changes that have occurred over the last two centuries. This study highlights the importance of social institutions and socioeconomic strategies for understanding spatial and temporal variability in landscape transitions. In particular, this study suggests that the human use of fire as a land management tool is neither culturally nor demographically determined, but highly dependent on the institutional context of land use and tenure. Further, the influences of regional and global scale socioeconomic factors on land use and management are mediated by the local institutional context. These findings have important implications for both the historical ecology of fire use and for the practical implementation fire management.

INDEX WORDS: Basque Country, Ecological anthropology, Historical ecology, Fire ecology, Land use change, Landscape transition, Mountain subsistence, Pastoral fire use, Pyrenees Mountains, Socioecological interaction

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CHAPTER 1

INTRODUCTION

Theoretically informed history and historically informed theory must be joined together to account for populations specifiable in time and space, both as outcomes of significant processes and as their carriers (Wolf 1982:21).

Research Description

This dissertation research investigated the historical ecology of pastoral fire use and landscape change among Basque farmers in the French Western Pyrenees. Research focused on social institutions, legacies of land use and management, and spatial contexts of socioecological interaction. Specifically, I investigated fire use practices, historical land use and ownership, and the historical demography of households on the French side of the French-Spanish border in the rural mountain village (*commune*) of Larrau. I combined ethnographic methods and historical data with geospatial analytical tools to examine the socioecological dynamics of change and persistence in the commune landscape.

Humans directly and indirectly alter landscapes through daily livelihood activities. We are allogenic ecosystems engineers, intentionally modifying our environments to suit our needs (Jones, et al. 1994). The evolution and spread of agriculture during the Neolithic (ca. 12,000 -6,000 BP) provided humans with new reasons and means for significantly transforming landscapes (Redman 1999), even if the long term results of our modifications were coevolutionary rather than intentional (Rindos, et al. 1980). Significant portions of the world's terrestrial biomes are now dominated by agricultural land uses (Ellis and Ramankutty 2008) and landscape transformations are tightly linked with global environmental change (Vitousek, et al. 1997).

In some cases, millennial land use and management resulted in relatively sustainable agrarian systems through the coevolution of landscape and society (Blondel 2006; Butzer 1996). Transitions away from agrarian land use in such systems may represent a turn to less stable landscapes. For example, changes in land use and management in the Pyrenees Mountains and other mountainous areas over the last century or more present novel conditions that threaten the long term sustainability of regional socioecological systems (MacDonald, et al. 2000; Olsson, et al. 2000). Pyrenean landscapes have lost biological diversity, experienced transformations in soils and hydrological functions, and become increasingly vulnerable to catastrophic disturbances such as wildfire (Cerdà and Lasanta 2005; Moreira and Russo 2007; Viviroli, et al. 2003; Begueria, et al. 2003).

In order to maintain ecological integrity, conservation efforts face the specter of continuing or reconstructing historical agrarian disturbance regimes in absence of the social systems that formerly drove them (Bürgi, et al. 2013; Egan and Howell 2001; Gimmi, et al. 2008). There is a need to better understand the ecological role of traditional management practices such as fire use in shaping and maintaining landscapes (Agnoletti 2007; Anderson 1996; Berkes, et al. 2000; Bugalho, et al. 2011; Hobbs 2009; Peter and

Shebitz 2006). Further, understanding the historical processes that contributed to landscape change is paramount in designing policies that encourage sustainable socioecological systems (De Aranzabal, et al. 2008; Lambin, et al. 2001; Ostrom 2007). The aim of this dissertation is to advance our knowledge of historical patterns and processes of land use and fire management in mountain landscapes.

Field Site

I chose the commune of Larrau to conduct this research due the availability of "high resolution" historical documentation spanning more than two centuries, as well as the relative continuity of key aspects of traditional land use and complementary social institutions through which land use is managed. The commune comprises the headwaters of the Saison River in the Soule Valley, and ranges in elevation from 300 to 2000 meters above sea level (msl). The terrain is rugged and steep; its pockets of bucolic, pastoral landscape are enclosed by massive limestone outcrops, towering cliffs, and deeply incised gorges. The Beech (*Fagus sylvaticus*) dominated tree line extends to about 1400 msl where large expenses of pasture cover mountain sides and ridgetops. Due to the Atlantic influence, the climate is relatively mild and humid. Warm, sunny summers are complemented by cool, rainy winters punctuated with short periods of Mediterranean-like weather driven by southern winds.

The natal residents of the commune self-identify as Souletin Basque (*Xiberotar*). A tradition of endogamous marriage practices has ensured that Larrau has few full-time residents born outside the village and that non-Souletin residents are even fewer. The local dialect of Basque is spoken both in the home and in public alongside French, which residents learn in elementary school. Despite the abandonment of a significant number of farming households, as of 2011, 25 active farms remained in the commune. The traditional household structure follows the stem-family form (Arrizabalaga 1997; Le Play 1871), but nuclear families and neolocal residence are now commonplace. Farming families benefit from both a legacy of impartible inheritance of household landholdings and a heritage of communal land use and management (Bortoli and Palu 2009; Cunchinabe, et al. 2011). These relatively strong threads of language and cultural tradition contribute to the maintenance of the landscape and the *Xiberotar* ethnolinguistic identity.

Farmers raise livestock and cut hay and bracken fern for winter forage and bedding. Formerly, farmers grew plots of wheat, maize, potatoes, and beans. This traditional mixed-mountain agriculture system transitioned to an exclusive focus on livestock over the last 40 years. Farmers throughout the Soule valley continue to practice seasonal transhumance, transporting cows, sheep, and horses each summer to the high-mountain, communal pastures of Larrau. Communal lands in Soule are common pool resources (Welch-Devine 2010) managed by both inter-household and inter-commune institutions that represent the legacies of traditional Souletin social organization. Although most land management practices have been transformed by the technological and socioeconomic changes of the last century, farmers still use fire to manage pastures.

In addition to the living legacies of land use and management, the communal archives conserve spatially explicit land use and ownership records from 1830 forward. Land use and ownership records are complemented by birth abstracts, voter registration records, and miscellaneous household-level agricultural records that date from the French Revolution (ca. 1790s). In addition to these records, the private archives of individual households preserve a number of documents from the 1500s onward. The existence of these high resolution historical records allows for spatially and temporally explicit analyses of change.

Chapter Objectives

Chapter 2 presents a review of the literature concerning human fire use and landscape change. I start by reviewing the historical development of thought concerning the relationships between fire use and landscapes. I then outline the historical ecology approach to this issue and describe how this approach frames research in the empirical context of the French Western Pyrenees. Specifically, I suggest that an anthropological approach to historical ecology broadens the human dimensions of socioecological systems research and helps reframe research questions concerning fire use, landscape change, and interaction between the two.

In Chapters 3 and 4 I draw on ethnographic research, historical evidence, and Bayesian Weights of Evidence (WoE) spatial analyses of historical fire use locations and land use maps. Bayesian WoE is a geospatial analysis technique common to geological prospecting (Bonham-Carter, et al. 1989) and has more recently been adapted to forecast wildfire and landslide occurrence (Poli and Sterlacchini 2007; Romero-Calcerrada, et al. 2008). For Chapters 3 and 4, I use the Bayesian WoE technique to backcast the spatial patterning of fire use, given fire use probabilities from the spatial associations between topography and known fire use locations from 1969 through 2011. Both chapters also make use of the 1830 and 2003 land use maps to establish relationships between fire use and land use change and persistence for the intervening period.

The objective of Chapter 3 is to shed some light on how Pyrenean farmers achieve pastoral fire management goals without damaging other resources. I show how cultural and ecological legacies reflect a self-organized fire management regime that emerges from fire use driven by the production goals of individual households. I frame the issue of fire control as a collective action problem where individual acts of fire use potentially conflict with the interests of society as a whole. However, both ethnographic evidence and spatiotemporal analyses show pastoral fire use as a persistent and relatively stable land management technique. Ignitions are strategically timed and placed such that fire behavior predictably follows the imprint of previous land and fire use. I describe this practice as employing a form of "landscape memory" that concerns the integration of social and ecological memory in the practice of fire. I argue that landscape memory, rather than institutional regulation, provides the principal control of fire behavior.

Chapter 4 investigates the relationships between landscape change, fire use, and the institutions that help determine land use and management. Others have hypothesized that land cover changes in the Pyrenees Mountains are partially explained by a cessation or decline of fire use following the abandonment of farming households (Métailié 2006). However, the specific relationships between landscape change, fire use, and the social institutions governing land use have never been modeled. This chapter establishes probability associations between land use change, fire use, and the historical intensity of household land use strategy. I constructed a spatial theme based on the change between land use categories given two temporal reference points (1830 and 2003). I used the 1830 cadastral tax records to derive a proxy for institutionally-determined intensity of land use strategies. I ranked the intensity of land use strategies according to land "ownership" by communal, collective, and private household institutions. I divided households into four additional categories by calculating the relative value of a household's landholdings on a per hectare basis. I then used backcasted fire use locations to examine the relationships between fire use associated land use change and the 1830 institutional land use strategies.

Chapter 5 presents an event history analysis of parcel-level land use extensification and household abandonment. Conventional narratives of landscape change in the Pyrenees suggest that important changes occurred only after the Second World War. The objectives of this chapter are to examine how individual households influenced the timing, pace, and scale of landscape change from 1830 through 1958. The analysis quantifies relationships between various socioeconomic factors and landscape change with a Cox proportional hazards regression. Analysis assesses the relative contributions of the shifting demographic compositions and land use strategies of households to extensification and abandonment events.

Chapter 6 provides a summary of the findings from the analyses presented in Chapters 3 – 5. I briefly discuss the application of the approach and methods explored in this dissertation to other research problems in historical ecology. Lastly, I synthesize and discuss the conclusions of each of the papers within the context of their implications for landscape management and conservation in the Pyrenees and in similar socioecological systems.

References

Agnoletti, M.
2007 The degradation of traditional landscape in a mountain area of Tuscany during the 19th and 20th centuries: Implications for biodiversity and sustainable management. *Forest Ecology and Management* 249(1-2):5-17.

Anderson, M. Kat
1996 Tending the Wilderness. *Restoration and Management Notes* 14(2):154-166.

Arrizabalaga, Marie-Pierre
1997 The Stem Family in the French Basque Country: Sare in the Nineteenth Century. *Journal of Family History* 22(1):50-69.

Begueria, Santiago, Juan I. Lopez-Moren, Adrian Lorente, Manuel Seeger and Jose M. Garcia-Ruiz
2003 Assessing the Effect of Climate Oscillations and Land-use Changes on Streamflow in the Central Spanish Pyrenees. *AMBIO: A Journal of the Human Environment* 32(4):283-286.

Berkes, Fikret, Johan Colding and Carl Folke
2000 Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications* 10(5):1251-1262.

Blondel, Jacques
2006 The ‘Design’ of Mediterranean Landscapes: A Millennial Story of Humans and Ecological Systems during the Historic Period. *Human Ecology* 34(5):713-729.

Bonham-Carter, G.F., F.P. Agterberg and D.F. Wright
1989 Weights of evidence modelling: a new approach to mapping mineral potential. In *Statistical Applications in the Earth Sciences*, edited by F. P. Agterber and G. F. Bonham-Carter. Geological Survey of Canada, Ottawa, Canada.

Bortoli, Dolores de and Pascal Palu
2009 Le système maison comme déterminant de la pérennité organisationnelle. *Revue française de gestion* 192:141-150.

Bugalho, Miguel N., Maria C. Caldeira, João S. Pereira, James Aronson and Juli G. Pausas
2011 Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. *Frontiers in Ecology and the Environment* 9(5):278-286.

Bürgi, Matthias, Urs Gimmi and Martin Stuber
2013 Assessing traditional knowledge on forest uses to understand forest ecosystem dynamics. *Forest Ecology and Management* 289(0):115-122.

Butzer, Karl W.
1996 Ecology in the Long View: Settlement Histories, Agrosystemic Strategies, and Ecological Performance. *Journal of Field Archaeology* 23(2):141-150.

Cerdà, Artemi and Teodoro Lasanta
2005 Long-term erosional responses after fire in the Central Spanish Pyrenees: 1. Water and sediment yield. *Catena* 60(1):59-80.

Cunchinabe, Dominique, Pascal Palu, Dolores De Bortoli and Marie-Paule Lavergne
2011 *Histoire de l'écosystème cultivé et de la biodiversité à Larrau: Analyse de l'impact agropastoral dans la gestion du milieu.*

De Aranzabal, Itziar, María Fe Schmitz, Pedro Aguilera and Francisco D. Pineda
2008 Modeling of landscape changes derived from the dynamics of socio-ecological systems: A case of study in a semiarid Mediterranean landscape. *Ecological Indicators* 8(5):672-685.

Egan, Dave and Evelyn A. Howell
2001 *The historical ecology handbook : a restorationist's guide to reference ecosystems*. Island Press, Washington, D.C.

Ellis, Erle C. and Navin Ramankutty
2008 Putting People in the Map: Anthropogenic Biomes of the World. *Frontiers in Ecology and the Environment* 6(8):439-447.

Gimmi, U., M. Burgi and M. Stuber
2008 Reconstructing anthropogenic disturbance regimes in forest ecosystems: A case study from the Swiss Rhone Valley. *Ecosystems* 11(1):113-124.

Hobbs, Richard
2009 Woodland restoration in Scotland: Ecology, history, culture, economics, politics and change. *Journal of Environmental Management* 90(9):2857-2865.

Jones, Clive G, John H Lawton and Moshe Shachak
1994 Organisms as ecosystem engineers. *Oikos*:373-386.

Lambin, Eric F., B. L. Turner, Helmut J. Geist, Samuel B. Agbola, Arild Angelsen, John W. Bruce, Oliver T. Coomes, Rodolfo Dirzo, Günther Fischer, Carl Folke, P. S. George, Katherine Homewood, Jacques Imbernon, Rik Leemans, Xiubin Li, Emilio F. Moran, Michael Mortimore, P. S. Ramakrishnan, John F. Richards, Helle Skånes, Will Steffen, Glenn D. Stone, Uno Svedin, Tom A. Veldkamp, Coleen Vogel and Jianchu Xu
2001 The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11(4):261-269.

Le Play, Frédéric
1871 *L'organisation de la famille selon le vrai modèle signalé par l'histoire de toutes les races et de tous les temps. Avec trois appendices*. Téqui, Bibliothécaire de l'oeuvre Saint-Michel,, Paris.

MacDonald, D., J. R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. Gutierrez Lazpita and A. Gibon
2000 Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* 59(1):47-69.

Métailié, Jean-Paul
2006 Mountain Landscape, Pastoral Management and Traditional Practices in the Northern Pyrenees (France). In *The Conservation of Cultural Landscapes*, edited by M. Agnoletti. CAB International.

Moreira, F. and D. Russo
2007 Modelling the impact of agricultural abandonment and wildfires on vertebrate diversity in Mediterranean Europe. *Landscape Ecology* 22(10):1461-1476.

Olsson, E. G. A., G. Austrheim and S. N. Grenne
2000 Landscape Change Patterns in Mountains, Land Use and Environmental Diversity, Mid-Norway 1960-1993. *Landscape Ecology* 15(2):155-170.

Ostrom, Elinor
2007 Sustainable Social-Ecological Systems: An Impossibility? *Available at SSRN 997834*.

Peter, David and Daniela Shebitz
2006 Historic Anthropogenically Maintained Bear Grass Savannas of the Southeastern Olympic Peninsula. *Restoration Ecology* 14(4):605-615.

Poli, S. and S. Sterlacchini
2007 Landslide Representation Strategies in Susceptibility Studies using Weights-of-Evidence Modeling Technique. *Natural Resources Research* 16(2):121-134.

Redman, Charles L
1999 *Human impact on ancient environments*. University of Arizona Press, Tucson, Arizona.

Rindos, David, Homer Aschmann, Peter Bellwood, Lynn Ceci, Mark N. Cohen, Joseph Hutchinson, Robert S. Santley, Jim G. Shaffer and Thurstan Shaw
1980 Symbiosis, Instability, and the Origins and Spread of Agriculture: A New Model [and Comments and Reply]. *Current Anthropology* 21(6):751-772.

Romero-Calcerrada, Raul, C. Novillo, J. Millington and I. Gomez-Jimenez
2008 GIS analysis of spatial patterns of human-caused wildfire ignition risk in the SW of Madrid (Central Spain). *Landscape Ecology* 23(3):341-354.

Vitousek, Peter M., Harold A. Mooney, Jane Lubchenco and Jerry M. Melillo
1997 Human Domination of Earth's Ecosystems. *Science* 277(5325):494-499.

Viviroli, Daniel, Rolf Weingartner and Bruno Messerli
2003 Assessing the Hydrological Significance of the World's Mountains. *Mountain Research and Development* 23(1):32-40.

Welch-Devine, Meredith
2010 Local Places, Global Influences: Pastoralism in Xiberoa and EU Regulation. In *Social and Ecological History of the Pyrenees: State, Market, and Landscape*, edited by I. Vaccaro and O. Beltran. Left Coast Press, Walnut Creek, California.

CHAPTER 2

HISTORICAL ECOLOGY, LANDSCAPE CHANGE, AND PASTORAL FIRE-USE, A LITERATURE REVIEW WITH A FOCUS ON THE FRENCH WESTERN PYRENEES MOUNTAINS

In this way fire wrought for man, first making his house, then as a master of his childhood, and last of all acting the part of maid of all work. (Mason 1894:157)

Introduction

The role and significance of fire use in the transformation of landscapes is a contentious topic in a wide variety of socioecological contexts ranging from that of early hominids to late Holocene agriculturalists (Caldararo 2002; Carcaillet, et al. 2007; Clark 2005; Daniau, et al. 2010; Denevan 1992; Mason 2000; Moore 2000; Simmons and Innes 1987; Vale 2002). In the Pyrenees Mountains of Western Europe, scholars generally agree that since the Neolithic (ca. 6000 BP), agropastoral burning practices were likely extensive and significant at the landscape level, even if not synchronous or uniform at the regional level. (Galop and Jalut 1994; Galop, et al. 2002; Métailié 1981; Rius, et al. 2009; Rius, et al. 2012). Yet, with respect to human-fire-landscape interactions, the specific relationships between social and ecological process and pattern remain poorly defined in this area. Recent literature reviews focused on landscape fire suggest that knowledge gaps concerning the role of humans are widespread (Bowman, et al. 2011; Conedera, et al. 2009; Coughlan and Petty 2012).

In this chapter, I review literature pertaining to the historical ecology of pastoral fire use and landscape change, the subject of this dissertation. I begin this review with a broad lens, examining the scholarship on human-fire-landscape interaction across a variety of disciplines and a wide range of research contexts. The objective is to reframe salient and emergent research questions from the perspective of an anthropologically oriented historical ecology. Throughout this process, I highlight the central role of anthropological contributions to human-fire-landscape studies.

The review is organized into four main sections (A-D). Section A and B review the historical progression of literature and theory surrounding the topic of fire use and landscape change. I focus on two interrelated questions that dominated fire use discussion from the 19th century through the late 1990s: (1) How did humans first transform the "primeval forest" into agropastoral landscapes and, (2) How and why do people use fire? In section C, I discuss the historical ecology approach to human-fire-landscape dynamics. In section D, I relate theoretical concepts and definitions of an historical ecology perspective to the empirical situation of fire use and landscape change in the French Western Pyrenees. In this section I discuss how anthropological theory helps frame the historical ecological analyses presented in Chapters 3, 4, and 5 of this dissertation.

A: Fire and Landscape in the Era of Environmental Determinism

In the 19th century, most theories about the relationships between humans and their environment held that humans on lower ends of variously conceived stages of "civilization" lacked the organizational and technological capabilities to actively transform the conditions of their existence (Guyot 1849; Malthus 1798; Morgan 1985 [1877]). Outside of “civilization,” peoples and their cultures were more or less determined by the environments in which they lived (Mason 1894). Scholars fused the newly devised theory of evolution (Darwin 1859) with concepts of unilineal progress (Spencer 1860), falling back on environmental determinism to explain differentiation between peoples (Trigger 1989). Environmental determinism was so strongly entrenched in theories concerning the evolution of prehistoric settlement and land use that Neolithic (in Europe) and Pre-Columbian (in America) farmers were seen as incapable of significantly altering forest land cover (Day 1953; Zon 1920).

By the end of the 19th century, anthropologists were well positioned to address these misconceptions. Franz Boas, a founding father of American anthropology, understood early on that the power of the anthropological approach was to illustrate, “the relative value of all forms of culture … as a check to an exaggerated valuation of the standpoint of our own period, which we are only too liable to consider the ultimate goal of human evolution” (Boas 1904:524). Anthropologists of this era studied a wide variety of so-called “primitive” and “backward” peoples who employed fire in order to manage landscapes (cf.Williams 2005). Documentation of fire use had the potential to empirically refute theoretical assumptions of the environment as static, immutable, and deterministic because it showed that even with “simple” technologies, humans could alter their surroundings in ways that were often better suited to their needs.

Indeed, some scholars did recognize the potential of fire use to transform forested landscapes, but the practices were considered ignorant, destructive, and irrational in the context of modern forest management (Leopold 1920; Marsh 1865; Mason 1894;

Maxwell 1910; Pinchot 1911). However, most anthropologists ignored fire use at their field sites or failed to find significance in it (Lewis 1978). For example, Kroeber (1956) suggested that in North America, Boasian era ethnographers believed they arrived too late to capture a detailed cultural memory of "primitive economics" such as land tenure and use (including fire management) because Native Americans had already been forced from their "ancestral soil."

The paucity of ethnographic accounts of fire use undoubtedly relates to the methodological proclivities as well as to the theoretical interests of the period. Under the influence of Boas, many anthropologists turned away from the study of human interactions with the environment. The main Boasian rejection of materialistic explanations for "ethnological phenomena" was based on the possibility that "unlike causes produce like effects," (Boas 1887:485). As a consequence, the study of human-environment interaction could lead one to erroneous conclusions. Culture-area studies revived interest in material conditions (Forde 1934; Kroeber 1939; Steward 1937, 1938; Wissler 1926) but only mentioned fire use in passing (Lewis 1972). Deterministic approaches were perpetuated through notions like "civilizational level," a measure for the ability of a people to modify their environment (Meggers 1954). Whether by theoretically or pragmatically determined research priorities, fire use practices remained understudied. Yet, if fire use was just an epiphenomenal, irrational, and destructive practice, how did humans transform the "primeval" forests into productive agropastoral landscapes?

British archaeologist Grahame Clark was one of the first scholars to move beyond armchair speculations concerning the historical and ecological significance of fire use.

Clark (1947, 1989) used sedimentary pollen and charcoal to refute deterministic hypotheses that early agricultural peoples did not possess the knowledge or ability to clear forests for settlement. Clark drew on historical European slash and burn agriculture to understand the practices responsible for changes in the sedimentary archives. His insights were derived from a novel approach to research that made use of an interdisciplinary team to investigate Neolithic settlement at the landscape scale (1989 [1953]). In his seminal work, *Archaeology and Society*, Clark (1957:176) articulated a perspective that conceived of humans as dominant ecological actors and human-environment relations as "reciprocal." These key insights were important prerequisites for theorizing human-fire-landscape interaction.

B: Ecological Anthropology and Fire Management

Outside of the anthropological tradition, the growing importance of scientific forest management in the early part of the 20th century had a vested interest in understanding traditional fire use practices. Although most Native American burning practices were squelched with the reservation system, traditional fire use by Euro-American farmers continued in many rural areas (Pyne 1982). In the late 1930s, the USDA Forest Service contracted a psychologist, J.P. Shea, and a sociology student, H.D. Kaufman, to investigate fire use by farmers both within and bordering National Forests (Kaufman 1939a; Shea 1939). In order to understand what Shea considered "primitive" behaviors, he consulted British-trained social anthropologist Bronislaw Malinowski and employed Malinowski's research framework (Shea 1939, 1940). Shea's preconceived notions of fire use as "primitive" and "irrational" prevented him from making any insights into the socioecological rationale of fire use. On the other hand, Kaufman provided rich empirical evidence on the depth of local knowledge pertaining to fire use and its ecological effects, but offered no analysis of its theoretical implications (Kaufman 1939a, b).

By the 1950s, scholars in geography and anthropology began to more vigorously challenge the validity of the various polemics clouding understandings of fire use and human-fire-landscape interaction (Day 1953; Sauer 1950; Stewart 2002; Stewart 1951). These scholars established a new research program for fire use. They asserted that (1) through fire use, even the earliest humans were agents of landscape change, and (2) fire use practices were a rational and "constructive" form of land management.

At the same time, a nascent ecological anthropology began to tackle agricultural fire use, examining "slash-and-burn," "shifting," or "swidden" cultivation in particular (Conklin 1954, 1961; Dumond 1961; Geertz 1963). This work highlighted fire use as a key component for transforming and "domesticating" landscapes. It showed the cyclical importance of fire to land use practices that formed the backbone of economic production in a wide variety of societies across the Earth. Conklin's (1954) case study in the Philippines described how swidden fires were controlled by both timing and placement of ignitions as well as by labor invested in constructing fire breaks and piling fuels. These fire control practices contained fires while ensuring fire severity levels high enough to transform intended fuels into nutrient rich ash.

Beginning in the 1960s, interest in the application of fire use to land management started to crystallize in some circles as observers noted the often negative and transformative effects of fire suppression policies on forest landscapes (Hartesveldt and Harvey 1967; Kayll 1967; Kilgore 1973; Komarek 1962; Minnich 1983; Stoddard 1962;

Trabaud 1981). Forest managers wanted to know how and why people used fire: what seasons and weather people burned in, how often they burned, and how extensive the fires were. This piqued the interests of a few anthropologists and geographers to focus on broadcast fire use, including pastoral fire, which had remained relatively understudied (Ferguson 1979; Jones 1969; Lewis 1978; Lewis and Bean 1973; Métailié 1981). Other research efforts focused on establishing the historical validity of past fire use (Cronon 1983; Pyne 1982; Russell 1983; Vankat 1977).

Revisionists grappled with explaining why fire use, among other human activities of historical ecological significance, had been ignored and misunderstood for so long (Dove 1983; Lewis 1989; Pyne 1982). Fire use became a crucial component in the argument that humans were a dominant force shaping landscapes even in systems previously believed to be “pristine” (Denevan 1992; Kay 2000; Krech 1999; Lewis and Ferguson 1988; Williams 2002).

Across disciplines, fire use progressively gained recognition as an important land management tool for obtaining a livelihood from the landscape. In support of this transition in thinking, a growing number of studies of contemporary peoples found that fire use represents an essential aspect of livelihoods in land-based societies across the globe (Anderson 1999; Anderson 1996; Bird, et al. 2005; Bloesch 1999; Coggins 2002; Eriksen 2007; Hough 1993; Kepe 2003; Kepe and Scoones 1999; Kull 2002; Laris 2002; Russell-Smith, et al. 2007; Russell-Smith, et al. 1997; Tacconi and Ruchiat 2006).

C: Historical Ecology

By the 1980s, anthropology (Crumley and Marquardt 1987; Headland 1997; Wolf 1982) and ecology (Christensen 1989; Forman and Godron 1986; Pickett and White

1985) began to embrace the importance of historical and spatial perspectives. As part of this shift in research priorities, the concepts of “disturbance” (Pickett, et al. 1989; Pickett and White 1985) and non-equilibrium dynamics moved into the forefront of ecological science (Botkin 1990; Wu and Loucks 1995). Scholars from a variety of disciplines increasingly recognized the historical signature of humans in landscapes (Balee 1992; McDonnell, et al. 1993; Savage and Swetnam 1990; Seklecki, et al. 1996). For example, studies of long term human-fire-landscape dynamics have correlated changes in fire regimes with broadly construed cultural periods or regional-scale changes in land use (Bowman, et al. 2011; Delcourt and Delcourt 1997; Foster, et al. 2002; Foster and Cohen 2007; Galop, et al. 2002; Granstrom and Niklasson 2008; Rius, et al. 2009). Other studies correlated changes in fire regimes with estimates of human population density and settlement/migration dynamics (Guyette, et al. 2003; Guyette, et al. 2002; Stambaugh and Guyette 2006).

However, over the last few decades, theory in ecological anthropology has moved away from many of the concepts these approaches use to tackle the “human dimension” of fire in the landscape. As part of the break from the neo-evolutionist (e.g.Sahlins and Service 1960; Service 1962) and neo-functionalist (e.g.Rappaport 1968) view of culture, anthropology no longer relies on the concept of simplistic or isolated cultural-ecological systems (Headland 1997; Moran 1990; Orlove 1980; Vayda and McCay 1975). Further, ecological anthropology redefined its principle units of analysis (Brumfiel 1992; Netting 1993; Smith 1988; Wilk and Rathje 1982) and its understandings of human-environment interactions across space and time (Crumley 2007; Redman 2008). This means that from an anthropological perspective, one cannot meaningfully infer human-fire-landscape interactions based on a matching of time periods between sequences of carbon dated charcoal from a specific peat bog and a regional cultural chronology. Instead, arguments should be place-based (Gragson 2012) and multi-proxy evidence should be derived from comparable resolutions.

By the 1990s, several new research trajectories emerged in ecological anthropology including similarly oriented interdisciplinary efforts that may be collectively termed "historical ecology" (e.g. Balee 2006; Crumley 1994; Gragson 2005; Kirch 2007; Redman 1999). An inclusive characterization of anthropological historical ecology finds conspicuous commonalities in the focus on landscape, historical contingency, human agency, and the dynamic processes of human-environment interaction.

Anthropological historical ecology begins with a number of theoretical assumptions. Firstly, human-environment interactions are spatially inscribed in the landscape through human agency (Sauer 1956). Secondly, humans are not simply external agents of environmental destruction (Balee 1998; Barton, et al. 2004; Blondel 2006; Butzer 1996; Gragson 1998). Thirdly, the character of the relationship between humans and landscape is reciprocal (Butzer 1982; Clark 1957; Crumley 1994; Sahlins 1964) and co-evolutionary (Kuznar 1993, 2001; McGlade 1995). In other words, human-landscape interaction is understood as mutually "imprinting," such that social and ecological components constitute an integrated system (Liu, et al. 2007; Redman and Foster 2008). Historical ecology therefore considers landscape as "the material manifestation" of human-environment interaction (Crumley 1994). Further, landscape may be interpreted as an historical archive of human-environment interaction (Balee

1998; Marquardt and Crumley 1987). Conversely, understanding human history enhances our understanding of the landscape (Christensen 1989).

Approaching the topic of fire use and landscape change, anthropological historical ecology asks not only how and why people use fire in a given landscape, but also how and why fire use varies through time and across space. Anthropology shifts research and analyses from univariate representations of the human "dimensions" of a multivariate ecology, to an integrative consideration of social and environmental factors influencing the actions of humans in landscapes. In order to do this, an anthropological approach to historical ecology brings to bear the theoretical and methodological tools of anthropology on its subject, while leaving behind the vernacular tendencies of interpretive anthropology (Gragson 2012).

D: Fire Use and Landscape Change in the French Western Pyrenees

The Pyrenees are an east-west trending mountain range dividing the Iberian Peninsula from the rest of Europe and forming the border between France and Spain. The western portion of the range is characterized by a humid, oceanic climate, with mild temperatures and relatively high precipitation resulting from an Atlantic influence. Forests at lower elevations are dominated by oak, middle elevations support a mixture of beech and fir, while upper elevations tend to be dominated by alpine and subalpine grasslands and heaths with patches of mixed conifers (Gómez-Ibáñez 1975; Ninot, et al. 2007). Due to the temperate climate and the east-west orientation of the mountains, biogeographic differences exist between cooler, wetter north-facing slopes and drier, warmer south-facing slopes (Rica and Recoder 1990).

Agropastoralists in the Pyrenees use fire to create and maintain landscape conditions amenable to livestock production. In this respect, historical ecological research on this topic has much to gain from previous anthropological studies of mountainous socioecological systems (Burns 1961; Cole and Wolf 1974; McGuire and Netting 1982; Netting 1981, Orlove, 1985; Ott 1993; Otto 1983; Rhoades and Thompson 1975; Wolf 1972) and smallholder agricultural societies in general (Barlett 1976; Durrenberger 1980; Netting 1974, 1993). This research, too, has evolved from a theoretical interest in typology and cross-cultural characteristics of "peasant" economies (Dalton, et al. 1972; Foster 1965; Wolf 1955, 1957, 1966, 1969) to the dynamic processes involved in making a living (Berkner 1972; Cook 1970; Godoy, et al. 2004; Minge-Kalman 1977, 1978; Wiber 1985).

In many agropastoral societies, the household represents the institutional focus for understanding smallholder domestic production and reproduction (Netting 1993; Netting, et al. 1984). In the Western Pyrenees, the "household" is not simply the default institutional housing arrangement for a family. Pyrenean households represent a historically persistent, culturally significant institution that provides logic and structure to the socioecological system as a whole (Bortoli and Palu 2009; Bourdieu 1962; Cursente 1998; Ott 1993; Palu 1992). The social structure of the household follows the stem-family pattern (Arrizabalaga 1997; Le Play 1871; Parish and Schwartz 1972; Zink 1969). Ideally, the traditional stem-family household could consist of a post-reproductive conjugal couple, a reproductive age conjugal couple (with either son or daughter of the former couple), a small number of subordinate, celibate siblings from any generation, and the sub-adults and child offspring of the reproductive couple.

A primary constraint influencing the economic strategies of households concerns the scarcity of land (Netting 1993). People solve the problems imposed by land scarcity through the institutional strategies of settlement, marriage, and inheritance (Bentley and Netting 1993; Berkner 1972; Cole 1977b; Cole and Wolf 1974; Netting 1981; Netting 1972). For example, in the Pyrenees, traditional inheritance followed the custom of primogeniture and impartibility of the household estate (Arrizabalaga 2005; Douglas 1984; Gómez-Ibáñez 1975). The estates of farming households consisted of a diverse collection of privately owned land management units including crop fields, hay meadows, coppice woodlots, and small pastures. Household inheritance also conferred usufruct rights to communal property and labor through shares in the grazing cooperatives that use and manage pasture commons (Ott 1993). Furthermore, use of the commons was limited households dating to the creation of the village (Zink 1997). The vast majority of villages currently in existence throughout the French Pyrenees were established between the 11th and the 13th century AD (Cursente 1998). Consequently, institutionalized inheritance practices represent long term solutions to the management of scarce land.

The socioecological dynamic of fire use

Household institutions have clearly determined the structure and intensity of land use and management in the Pyrenees since the late Middle Ages. A historical ecology of fire use and landscape change in the Pyrenees must grapple with the household and its relationships with inter-household institutions that have bound communities together for the last millennia. For example, in contexts of relatively scarce land, anthropologists have long wondered how agrarian societies balance individual or household material wants with those of the larger community (McGuire and Netting 1982; Netting 1981; Ruttan and Mulder 1999; Wolf 1972). This is a particularly salient question for historical ecological research concerning the relationships between fire use and landscape change. Given that human control of fire is imperfect (Bowman, et al. 2009), if fire use results from the livelihood interests of individual households, then the proximate decisions to burn a particular parcel have the potential to negatively impact others or even the system as a whole. So how did/do farmers regulate and control fire use?

This question is especially relevant in the Pyrenees given the reliance of smallholders on common property for a portion of their production. While Hardin's (1968) *Tragedy of the Commons* suggests maintaining commons requires privatization (or coercive measures) to curtail selfish usurpation, privatization is not an option in the case of mountainous pastures since it would allocate insufficient territory to each user (Netting 1981). Recent research on common property has focused on apparently paradoxical situations where cooperation is costly for an individual, but beneficial for the group (Feeny, et al. 1990; Fehr and Fischbacher 2002; Ostrom 2000; Ruttan 1998; Smith and Wishnie 2000). This is referred to as a "collective action" problem and is generally solved through the establishment of social institutions. Do social institutions actively control farmers' use of fire in the Pyrenees? Has the institutional environment of fire use changed through time? Chapter 3 of this dissertation attempts to answer these questions through a combination of ethnographic and spatial analyses.

Socioecological dynamics of fire use and landscape change

In spite of continued use and management of the agropastoral landscape during the last millennia, changes have occurred. Landscape transitions in the Pyrenees are especially notable over the last 60 years or so with shrub and forest encroachments common on areas more intensively used and maintained in former times (Métailié 2006; Pasche, et al. 2004; Roura-Pascual, et al. 2005). Studies have attributed these changes to broad scale socioeconomic factors such as demography, agricultural practices, and labor opportunities (MacDonald, et al. 2000).

The task of a historical ecology account of fire use and landscape change is to identify the factors influencing socioecological processes at the local institution level. In the Pyrenees, this involves the investigation of land and fire use change at the parcel level through the lens of the household. Household level studies of landscape transition are rare in the Pyrenees (Mottet, et al. 2006). Basic questions remain unresolved. How did households contribute to landscape change? How did different factors (e.g. demography, economic strategies, etc.) contribute to parcel level changes in land and fire use?

Historically in the Pyrenees, the traditional agrarian smallholders constitute a particular type of rural cultivator that Eric Wolf (1966) characterized as "peasants." Traditional agrarian smallholders present a special case because they formed the backbone of a "tributary mode of production" (Wolf 1982) but were also "partially integrated into incomplete markets" (Ellis 1993:4). Theories derived from both Marx and Chayanov have attempted to bridge the theoretical divide between the market and non-market economy represented by the "peasant" (Chayanov 1986; Cole 1977; Cole and Wolf 1974; Durrenberger 1980; McGuire and Netting 1982; Netting 1981; Roseberry 1988). The influence of Chayanov, for example, helped to introduce the importance of the household life cycle as a determinant of the intensity of production (Berkner 1972; Durrenberger 1980; Minge-Kalman 1978).

These theories stand in contrast to central place theory and neoclassical economic explanations of land use change that rely on the idea that smallholders optimize production to meet market demands (Gellrich and Zimmermann 2007; Ricardo 1891; Rudel 1998; von Thünen and Hall 1966). By the 20th century, nearly all agrarian smallholder societies were impacted to some extent by the world capitalist system even where tributary states persisted (Wolf 1982). Responding to critiques of his characterization of an isolated alpine village, Netting conceded that individuals in Torbel participated in market trade and as wage laborers (Netting 1990). Participation in market economies was, in part, forced by limited options available in the Alpine context (Cole 1969). However, individuals in societies on the peripheries of capitalist markets may choose to participate in order to offset subsistence uncertainty (Gragson 1994). So how did various market and non-market factors influence landscape change?

Institutions such as agricultural cooperatives were formed as a defense against outside encroachment on land resources, at the same time providing solutions to problems of scheduling and temporary labor shortages experienced by households. As Wolf (1972) explains, institutions respond dialectically to the penetration of local social fabric by states and markets. Since smallholder societies were not isolated from the broader social environment; their institutions do not simply represent adaptations to local ecological conditions. Did the management of land by cooperative institutions insulate against "externally" driven land and fire use changes?

In Chapters 4 and 5 I attempt to answer the questions presented in this subsection. Chapter 4 uses spatial probabilities to examine the relationships between institutional strategies of land use and management, fire, and landscape change between two points:

1830 and 2011. Chapter 5 narrows the spatial extent but expands to an annual temporal resolution for the years 1830 to 1958. I use event history analysis to examine demographic and socioeconomic factors contributing to parcel-level land use extensification and household abandonment. Land use is a driver of both intentional ignitions (Eriksen 2007; Russell-Smith, et al. 2007; Tacconi and Ruchiat 2006) and fire spread more generally (Ehrlich, et al. 1997). Explaining human-fire-landscape interaction in the Pyrenees requires an understanding of how demographic and socioeconomic factors shaped the management strategies and use trajectories of local institutions that, in turn, guided decisions of when, where, and how to employ or abandon fire practices. Through its focus on human agency, local institutions, and landscapes, the historical ecology approach offers the potential to answer some of the questions posed in this review. Through this process, an historical ecology perspective may help to identify the social and ecological legacies past land and fire use strategies have left us in terms of their implications for the future trajectory of the landscape, fire ecology, and agricultural livelihoods.

References

Anderson, M.
1999 The Fire, Pruning, and Coppice Management of Temperate Ecosystems for Basketry Material by California Indian Tribes. *Human Ecology* 27(1):79-113.

Anderson, M. Kat
1996 Tending the Wilderness. *Restoration and Management Notes* 14(2):154-166.

Arrizabalaga, Marie-Pierre
1997 The Stem Family in the French Basque Country: Sare in the Nineteenth Century. *Journal of Family History* 22(1):50-69.

Arrizabalaga, Marie-Pierre
2005 Succession strategies in the Pyrenees in the 19th century: The Basque case. *The History of the Family* 10(3):271-292.

Balee, William
1992 People of the Fallow: A Historical Ecology of Foraging in Lowland South America. In *Conservation of Neotropical Forests: Working with Traditional Resource Use*, edited by K. H. Redford and C. Padock. Columbia University Press, New York.

Balee, William
1998 Historical Ecology: Premises and Postulates. In *Advances in Historical Ecology*, edited by W. Balee. Columbia University Press, New York.

Balee, William
2006 The Research Program of Historical Ecology. *Annual Review of Anthropology* 35(1):75-98.

Barlett, Peggy F.
1976 Labor Efficiency and the Mechanism of Agricultural Evolution. *Journal of Anthropological Research* 32(2):124-140.

Barlett, Peggy F.
1980 Adaptive Strategies in Peasant Agricultural Production. *Annual Review of Anthropology* 9(1):545-573.

Barton, C. Michael, Joan Bernabeu, J. Emili Aura, Oreto Garcia, Steven Schmich and Luis Molina
2004 Long-Term Socioecology and Contingent Landscapes. *Journal of Archaeological Method and Theory* 11(3):253-295.

Berkner, Lutz K.
1972 The Stem Family and the Developmental Cycle of the Peasant Household: An Eighteenth-Century Austrian Example. *The American Historical Review* 77(2):398-418.

Bird, Douglas W., Rebecca Bliege Bird and Christopher H. Parker
2005 Aboriginal Burning Regimes and Hunting Strategies in Australia's Western Desert. *Human Ecology: An Interdisciplinary Journal* 33(4):443-464.

Bloesch, Urs
1999 Fire as a Tool in the Management of a Savanna/Dry Forest Reserve in Madagascar. *Applied Vegetation Science* 2(1):117-124.

Blondel, Jacques
2006 The ‘Design’ of Mediterranean Landscapes: A Millennial Story of Humans and Ecological Systems during the Historic Period. *Human Ecology* 34(5):713-729.

Boas, Franz
1887 The Occurrence of Similar Inventions in Areas Widely Apart. *Science* 9(224):485-486.

Boas, Franz
1904 The History of Anthropology. *Science* 20(512):513-524.

Bortoli, Dolores de and Pascal Palu
2009 Le système maison comme déterminant de la pérennité organisationnelle. *Revue française de gestion* 192:141-150.

Botkin, Daniel B.
1990 *Discordant Harmonies: A New Ecology for the Twenty-First Century*. Oxford University Press, New York.

Bourdieu, Pierre
1962 Célibat et condition paysanne. *Études rurales* 5-6.

Bowman, David M. J. S., Jennifer Balch, Paulo Artaxo, William J. Bond, Mark A. Cochrane, Carla M. D’Antonio, Ruth DeFries, Fay H. Johnston, Jon E. Keeley, Meg A. Krawchuk, Christian A. Kull, Michelle Mack, Max A. Moritz, Stephen Pyne, Christopher I. Roos, Andrew C. Scott, Navjot S. Sodhi and Thomas W. Swetnam
2011 The human dimension of fire regimes on Earth. *Journal of Biogeography* 38(12):2223-2236.

Bowman, David M. J. S., Jennifer K. Balch, Paulo Artaxo, William J. Bond, Jean M. Carlson, Mark A. Cochrane, Carla M. D'Antonio, Ruth S. DeFries, John C. Doyle, Sandy P. Harrison, Fay H. Johnston, Jon E. Keeley, Meg A. Krawchuk, Christian A. Kull, J. Brad Marston, Max A. Moritz, I. Colin Prentice, Christopher I. Roos, Andrew C. Scott, Thomas W. Swetnam, Guido R. van der Werf and Stephen J. Pyne
2009 Fire in the Earth System. *Science* 324(5926):481-484.

Brumfiel, Elizabeth M.
1992 Distinguished Lecture in Archeology: Breaking and Entering the Ecosystem - Gender, Class, and Faction Steal the Show. *American Anthropologist* 94(3):551-567.

Burns, Robert K., Jr.
1961 The Ecological Basis of French Alpine Peasant Communities in the Dauphine. *Anthropological Quarterly* 34(1):19-35.

Butzer, Karl W.
1982 *Archaeology as human ecology : method and theory for a contextual approach*. Cambridge University Press, Cambridge ; New York.

Butzer, Karl W.
1996 Ecology in the Long View: Settlement Histories, Agrosystemic Strategies, and Ecological Performance. *Journal of Field Archaeology* 23(2):141-150.

Caldararo, N.
2002 Human ecological intervention and the role of forest fires in human ecology. *The Science of The Total Environment* 292(3):141-165.

Carcaillet, C., I. Bergman, S. Delorme, G. Hornberg and O. Zackrisson
2007 Long-term fire frequency not linked to prehistoric occupations in northern Swedish boreal forest. *Ecology* 88(2):465-477.

Chayanov, A. V.
1986 The Theory of Peasant Economy. In *A.V. Chayanov on The Theory of Peasant Economy*, edited by D. Thorner, B. Kerblay and R. E. F. Smith. The University of Wisconsin Press, Madison.

Christensen, Norman L.
1989 Landscape History and Ecological Change. *Journal of Forest History* 33(3):116-125.

Clark, Grahame
1947 Forest Clearance and Prehistoric Farming. *The Economic History Review* a17(1):45-51.

Clark, Grahame
1957 *Archaeology and society; reconstructing the prehistoric past*. Harvard university Press, Cambridge,.

Clark, Grahame
1989 Farmers and Forests In Neolithic Europe. In *Economic prehistory: papers on archaeology*, edited by G. Clark, pp. 29-46. Cambridge University Press, Cambridge [Cambridgeshire] ; New York.

Clark, Grahame
1989 [1953] The Economic Approach to Prehistory. In *Economic prehistory: papers on archaeology,* edited by G. Clark, pp. xviii, 638 p. Cambridge University Press, Cambridge [Cambridgeshire] ; New York.

Clark, James S.
2005 Why Environmental Scientists are Becoming Bayesians. *Ecology Letters* 8:2-14.

Coggins, Christopher Reed
2002 Ferns and Fire: Village Subsistence, Landscape Change, and Nature Conservation in China's Southeast Uplands. *Journal of Cultural Geography* 19(2):129.

Cole, John W.
1977 Anthropology Comes Part-Way Home: Community Studies in Europe. *Annual Review of Anthropology* 6:349-378.

Cole, John W. and Eric R. Wolf
1974 *The hidden frontier; ecology and ethnicity in an Alpine valley*. Studies in social discontinuity. Academic Press, New York.

Conedera, M., W. Tinner, C. Neff, M. Meurer, A. F. Dickens and P. Krebs
2009 Reconstructing past fire regimes: methods, applications, and relevance to fire management and conservation. *Quaternary Science Reviews* 28(5-6):555-576.

Conklin, Harold C.
1954 An Enthoecological Approach to Shifting Agriculture. *Transactions of the New York Academy of Sciences* 17:133-142.

Conklin, Harold C.
1961 The Study of Shifting Cultivation. *Current Anthropology* 2(1):27-61.

Cook, Scott
1970 Price and Output Variability in a Peasant-Artisan Stoneworking Industry in Oaxaca, Mexico: An Analytical Essay in Economic Anthropology. *American Anthropologist* 72(4):776-801.

Coughlan, Michael R. and Aaron M. Petty
2012 Linking humans and fire: a proposal for a transdisciplinary fire ecology. *International Journal of Wildland Fire* 21(5):477-487.

Cronon, William
1983 *Changes in the Land, Indians, Colonists, and the Ecology of New England*. Hill and Wang, New York.

Crumley, C. L.
2007 Historical ecology: integrated thinking at multiple temporal and spatial scales. In *The World System and the Earth System: Global Socioenvironmental Change and Sustainability since the Neolithic*, edited by A. Hornborg and C. L. Crumley, pp. 15-28. Left Coast Press, Walnut Creek, CA, USA.

Crumley, Carole L.
1994 Historical Ecology: A Multidimensional Ecological Orientation. In *Historical Ecology: Cultural Knowledge and Changing Landscapes*, edited by C. L. Crumley. School of American Research Press, Santa Fe.

Crumley, Carole L. and William H. Marquardt
1987 *Regional dynamics : Burgundian landscapes in historical perspective*. Academic Press, San Diego.

Cursente, Benoît
1998 *Des maisons et des hommes : la Gascogne médiévale (XIe-XVe siècle)*. Tempus. Presses universitaires du Mirail, Toulouse.

Dalton, George, H. Russell Bernhard, Beverly Chiňas, S. H. Franklin, David Kaplan and Eric R. Wolf
1972 Peasantries in Anthropology and History and Comments and Replies. *Current Anthropology* 13(3/4):385-415.

Daniau, Anne-Laure, Francesco d'Errico and Maria Fernanda Sánchez Goñi
2010 Testing the Hypothesis of Fire Use for Ecosystem Management by Neanderthal and Upper Palaeolithic Modern Human Populations. *PLoS ONE* 5(2):e9157.

Darwin, Charles
1859 *On the origin of the species by means of natural selection, or, The preservation of favoured races in the struggle for life*. J. Murray, London,.

Day, Gordon M.
1953 The Indian as an Ecological Factor in the Northeastern Forest. *Ecology* 34(2):329-346.

Delcourt, Hazel R. and Paul A. Delcourt
1997 Pre-Columbian Native American Use of Fire on Southern Appalachian Landscapes. *Conservation Biology* 11(4):1010-1014.

Denevan, William M.
1992 The Pristine Myth: The Landscape of the Americas in 1492. *Annals of the Association of American Geographers* 82(3):369-385.

Douglas, William A.
1984 Sheep Ranchers and Sugar Growers: Property Transmission in the Basque Immigrant Family of the American West and Australia. In *Households*, edited by R. M. Netting, R. R. Wilk and E. J. Arnould. University of California Press, Berkeley.

Dove, Michael R.
1983 Theories of swidden agriculture, and the political economy of ignorance. *Agroforestry Systems* 1(2):85-99.

Dumond, D. E.
1961 Swidden Agriculture and the Rise of Maya Civilization. *Southwestern Journal of Anthropology* 17(4):301-316.

Durrenberger, E. Paul
1980 Chayanov's Economic Analysis in Anthropology. *Journal of Anthropological Research* 36(2):133-148.

Ehrlich, Daniele, Eric F. Lambin and Jean-Paul Malingreau
1997 Biomass burning and broad-scale land-cover changes in Western Africa. *Remote Sensing of Environment* 61(2):201-209.

Eriksen, C.
2007 Why do they burn the 'bush'? Fire, rural livelihoods, and conservation in Zambia. *Geographical Journal* 173:242-256.

Feeny, David, Fikret Berkes, Bonnie McCay and James Acheson
1990 The Tragedy of the Commons: Twenty-two years later. *Human Ecology* 18(1):1-19.

Fehr, Ernst and Urs Fischbacher
2002 Why Social Preferences Matter - The Impact of Non-Selfish Motives on Competition, Cooperation and Incentives. *The Economic Journal* 112(478):C1-C33.

Ferguson, Theresa A.
1979 *Productivity and predictability of resource yield aboriginal controlled burning in the boreal forest*. Canadian theses on microfiche = Thèses canadiennes sur microfiche,; 43398; Variation: Canadian theses ;; 43398. National Library of Canada, Ottawa.

Forde, C. Daryll
1934 *Habitat, Economy, and Society, a Geographical Introduction to Ethnology*. E. P. dutton and Co. Inc., New York.

Forman, Richard T. T. and Michel Godron
1986 *Landscape ecology*. Wiley, New York.

Foster, D. R., S. Clayden, D. A. Orwig and B. Hall
2002 Oak, chestnut and fire: climatic and cultural controls of long-term forest dynamics in New England, USA. *Journal of Biogeography* 29(10-11):1359-1379.

Foster, George M.
1965 Peasant Society and the Image of Limited Good. *American Anthropologist* 67(2):293-315.

Foster, Thomas H. II and Arthur D. Cohen
2007 Palynological Evidence of the Effects of the Deerskin Trade in Forest Fires During the Eighteenth Century In Southeastern North America. *American Antiquity* 72(1):35-51.

Galop, D. and G. Jalut
1994 Differential human impact and vegetation history in two adjacent Pyrenean valleys in the Ariège basin, southern France, from 3000 B.P. to the present. *Vegetation History and Archaeobotany* 3(4):225-244.

Galop, Didier, Boris Vanniere and Michel Fontugne
2002 Human Activities and Fire History Since 4500 BC on the Northern Slope of the Pyrenees: a Record from Cuguron (Central Pyrenees, France). Paper presented at the Charcoal analysis: methodological approaches, palaeological results and wood uses. Proceedings of the Second International Meeting of Anthracology, Paris.

Geertz, Clifford
1963 *Agricultural involution : the process of ecological change in Indonesia*. Published for the Association of Asian Studies by University of California Press, Berkeley.

Gellrich, Mario and Niklaus E. Zimmermann
2007 Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning* 79(1):65-76.

Godoy, Ricardo A., Michael Gurven, Elizabeth Byron, Victoria Reyes-García, James Keough, Vincent Vadez, David Wilkie, William R. Leonard, Lilian Apaza, TomÃ¡s Huanca and Eddy Pérez
2004 Do Markets Worsen Economic Inequalities? Kuznets in the Bush. *Human Ecology: An Interdisciplinary Journal* 32(3):339-364.

Gómez-Ibáñez, Daniel Alexander
1975 *The Western Pyrenees : differential evolution of the French and Spanish borderland*. Oxford research studies in geography. Clarendon Press, Oxford [Eng.].

Gragson, Ted L.
1998 Potential Versus Actual Vegetation. In *Advances in Historical Ecology*, edited by W. Balee. Columbia University Press, New York.

Gragson, Ted L.
2005 Time in Service to Historical Ecology. *Ecological and Environmental Anthropology* 1(1):2-9.

Gragson, Ted L.
2012 Anthropology as a Disciplinary Bridge Between the Biological and Social Sciences in LTSER Research. In *Long Term socio-ecological research: Studies in society-nature interactions across spatial and temporal scales*, edited by S. J. Singh, H. Harberl, M. Chertow, M. Mirtl and M. Schmid. Springer, Berlin.

Granstrom, A. and M. Niklasson
2008 Potentials and limitations for human control over historic fire regimes in the boreal forest. *Philosophical Transactions of the Royal Society B-Biological Sciences* 363(1501):2353-2358.

Guyette, R. P., D. C. Dey and M. C. Stambaugh
2003 Fire and human history of a barren-forest mosaic in southern Indiana. *American Midland Naturalist* 149(1):21-34.

Guyette, R. P., R.M. Muzika and D.C. Dey
2002 Dynamics of an Anthropogenic Fire Regime. *Ecosystems* 5(5):472-486.

Guyot, Arnold
1849 *The earth and man: lectures on comparative physical geography, in its relation to the history of mankind*. Gould, Kendall, and Lincoln, Boston, Mass.

Hardin, Garrett
1968 The Tragedy of the Commons. *Science* 162(3859):1243-1248.

Hartesveldt, R. J. and H. T. Harvey
1967 The Fire Ecology of Sequoia Regeneration. *Proceedings of the Tall Timbers Fire Ecology Conference* 7.

Headland, Thomas N.
1997 Revisionism in Ecological Anthropology. *Current Anthropology* 38(4):605-630.

Hough, John L.
1993 Why burn the bush? Social approaches to bush-fire management in West African national parks. *Biological Conservation* 65(1):23-28.

Jones, Rhys
1969 Fire-stick farming. *Australian Natural History* 16(7):224-228.

Kaufman, Harold F.

1939a A Psycho-Social Study of the Cause and Prevention of Forest Fires in the Clark National Forest; June-October 1938. In *Man-Caused Forest Fires: The Psychologist Makes a Diagnosis*, edited by J. P. Shea. USDA Forest Service, Washington.

Kaufman, Harold F.

1939b Social factors in the reforestation of the Missouri Ozarks. MA Thesis, University of Missouri, Columbia.

Kay, Charles E.

2000 Native Burning in Western North America: Implications for Hardwood Forest Management. *Proceedings of the Workshop on Fire, People, and the Central Hardwoods Landscape*.

Kayll, A. J.

1967 Moor Burning in Scotland. *Proceedings of the 6th Annual Tall Timbers Fire Ecology Conference*. Tallahasee.

Kepe, Thembela

2003 Grasslands Ablaze: vegetation burning by rural people in Pondoland, South Africa. In *Working Papers*. 51 vols. Fort Hare Institute of Social and Economic Research.

Kepe, Thembela and Ian Scoones

1999 Creating Grasslands: Social Institutions and Environmental Change in Mkambati Area, South Africa. *Human Ecology* 27(1):29-53.

Kilgore, Bruce M.

1973 The Ecological Role of Fire in Sierran Conifer Forests. *Quaternary Research* 3(3):496-513.

Kirch, P. V.

2007 Hawaii as a Model System for Human Ecodynamics. *American Anthropologist* 109(1):8-26.

Komarek, E.V.

1962 The Use of Fire: A Historical Background. *Proceedings of the First Annual Tall Timbers Fire Ecology Conference*:7-10. Tallahasee, Florida.

Krech , Shepard

1999 *The Ecological Indian: Myth and History*. W.W. Norton & Company, New York.

Kroeber, A. L.
1939 Culture Element Distributions: III Area and Climax. In *American Archaeology and Ethnology*. Kraus Reprint Corporation, New York.

Kroeber, A. L.
1956 The Place of Boas in Anthropology. *American Anthropologist* 58(1):151-159.

Kull, Christian A.
2002 Madagascar aflame: landscape burning as peasant protest, resistance, or a resource management tool? *Political Geography* 21(7):927-953.

Kuznar, Lawrence A.
1993 Mutualism between Chenopodium, Herd Animals, and Herders in the South Central Andes. *Mountain Research and Development* 13(3):257-265.

Kuznar, Lawrence A.
2001 Ecological Mutualism in Navajo Corrals: Implications for Navajo Environmental Perceptions and Human/Plant Coevolution. *Journal of Anthropological Research* 57:17-39.

Laris, Paul
2002 Burning the Seasonal Mosaic: Preventative Burning Strategies in the Wooded Savanna of Southern Mali. *Human Ecology: An Interdisciplinary Journal* 30(2):155.

Le Play, Frédéric
1871 *L'organisation de la famille selon le vrai modèle signalé par l'histoire de toutes les races et de tous les temps. Avec trois appendices*. Téqui, Bibliothécaire de l'oeuvre Saint-Michel,, Paris.

Leopold, Aldo
1920 "Piute Forestry" vs. Forest Fire Prevention. *Southwestern Magazine* 2:12-13.

Lewis, Henry T.
1972 The Role of Fire in the Domestication of Plants and Animals in Southwest Asia: A Hypothesis. *Man* 7(2):195-222.

Lewis, Henry T.
1978 Traditional Uses of Fire by Indians in Northern Alberta. *Current Anthropology* 19(2):401-402.

Lewis, Henry T.
1989 Ecological and Technological Knowledge of Fire: Aborigines Versus Park Rangers in Northern Australia. *American Anthropologist* 91(4):940-961.

Lewis, Henry T. and Lowell John Bean
1973 *Patterns of Indian Burning in California: Ecology and Ethnohistory*. Ballena Press, Ramona.

Lewis, Henry T. and T. A. Ferguson
1988 Yards, corridors and mosaics: How to burn a boreal forest. *Human Ecology* 16:57-77.

Liu, J. G., T. Dietz, S. R. Carpenter, C. Folke, M. Alberti, C. L. Redman, S. H. Schneider, E. Ostrom, A. N. Pell, J. Lubchenco, W. W. Taylor, Z. Y. Ouyang, P. Deadman, T. Kratz and W. Provencher
2007 Coupled human and natural systems. *Ambio* 36:639-649.

MacDonald, D., J. R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. Gutierrez Lazpita and A. Gibon
2000 Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* 59(1):47-69.

Malthus, T.
1798 *An Essay on the Principle of Population, as it Affects the Future Improvement of Society with Remarks on the Speculations of Mr. Goodwin, M. Condorcet, and Other Writers.* J. Johnson, London.

Marquardt, William H. and Carole L. Crumley
1987 Theoretical Issues in the Analysis of Spatial Patterning. In *Regional dynamics : Burgundian landscapes in historical perspective*, edited by C. L. Crumley and W. H. Marquardt, pp. xviii, 629 p., [626] p. of plates. Academic Press, San Diego.

Marsh, George Perkins
1865 *Man and nature*. Belknap Press of Harvard University Press, Cambridge.

Mason, Otis Tufton
1894 Technogeography or the Relation of the Earth to the Industries of Mankind. *American Anthropologist* 7(2):137-161.

Mason, S.L.R
2000 Fire and Mesolithic subsistence — managing oaks for acorns in northwest Europe? *Palaeogeography, Palaeoclimatology, Palaeoecology* 164(1–4):139-150.

Maxwell, Hu
1910 The Use and Abuse of Forests by the Virginia Indians. *William and Mary College Quarterly Historical Magazine* 19(2):73-103.

McDonnell, Mark J, Steward TA Pickett, Gene E Likens and William J Cronon
1993 *Humans as components of ecosystems: the ecology of subtle human effects and populated areas*. Springer New York.

McGlade, James
1995 Archaeology and the ecodynamics of human-modified landscapes. *Antiquity* 69:113-132.

McGuire, Randall and Robert McC Netting
1982 Leveling Peasants? The Maintenance of Equality in a Swiss Alpine Community. *American Ethnologist* 9(2):269-290.

Meggers, Betty J.
1954 Environmental Limitation on the Development of Culture. *American Anthropologist* 56(5):801-824.

Métailié, Jean-Paul
1981 *Le feu pastoral dans les Pyrénées centrales : Barousse, Oueil, Larboust*. Editions du C.N.R.S., Paris.

Métailié, Jean-Paul
2006 Mountain Landscape, Pastoral Management and Traditional Practices in the Northern Pyrenees (France). In *The Conservation of Cultural Landscapes*, edited by M. Agnoletti. CAB International.

Minge-Kalman, Wanda
1977 On the Theory and Measurement of Domestic Labor Intensity. *American Ethnologist* 4(2):273-284.

Minge-Kalman, Wanda
1978 Household Economy during the Peasant-to-Worker Transition in the Swiss Alps. *Ethnology* 17(2):183-196.

Minnich, Richard A.
1983 Fire Mosaics in Southern California and Northern Baja California. *Science* 219(4590):1287-1294.

Moore, Jenny
2000 Forest fire and human interaction in the early Holocene woodlands of Britain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164(1–4):125-137.

Moran, Emilio F.
1990 *The Ecosystem approach in anthropology : from concept to practice*. University of Michigan Press, Ann Arbor.

Morgan, Lewis Henry
1985 [1877] *Ancient Society*. University of Arizona Press, Tucson.

Mottet, Anne, Sylvie Ladet, Nathalie Coqué and Annick Gibon
2006 Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agriculture, Ecosystems & Environment* 114(2-4):296-310.

Netting, Robert McC
1974 Agrarian Ecology. *Annual Review of Anthropology* 3:21-56.

Netting, Robert McC
1981 *Balancing on an Alp: Ecological Change and Continuity in a Swiss Mountain Community*. Cambridge University Press, Cambridge.

Netting, Robert McC
1993 *Smallholders, householders : farm families and the ecology of intensive, sustainable agriculture*. Stanford University Press, Stanford, California.

Netting, Robert McC, Richard R. Wilk and Eric J. Arnould
1984 *Households : comparative and historical studies of the domestic group ; edited by Robert McC. Netting, Richard R. Wilk, Eric J. Arnould*. University of California Press, Berkeley.

Ninot, J. M., e. Carrillo, X. Font, J. Carreras, A. Ferre, R. M. Marsalles, I. Soriano and J. Vigo
2007 Altitude Zonation in the Pyrenees. A Geobotanic Interpretation. *Phytocoenologia* 37(3-5):371-398.

Orlove, Benjamin S.
1980 Ecological Anthropology. *Annual Review of Anthropology* 9(1):235-273.

Orlove, Benjamin S. and David W. Guillet
1985 Theoretical and Methodological Considerations on the Study of Mountain Peoples: Reflections on the Idea of Subsistence Type and the Role of History in Human Ecology. *Mountain Research and Development* 5(1):3-18.

Ostrom, Elinor
2000 Collective Action and the Evolution of Social Norms. *The Journal of Economic Perspectives* 14(3):137-158.

Ott, Sandra
1993 *The circle of mountains : a Basque shepherding community*. University of Nevada Press, Reno, USA.

Otto, John Solomon

1983 The Decline of Forest Farming in Southern Appalachia. *Journal of Forest History* 27(1):18-27.

Palu, Pascal

1992 Rapports entre organisation sociale et écosytème dans la société pastorale souletine. *Sociétés contemporaines*:239-264.

Parish, William L., Jr. and Moshe Schwartz

1972 Household Complexity in Nineteenth Century France. *American Sociological Review* 37(2):154-173.

Pasche, F., M. Armand, P. Gouaux, T. Lamaze and A. Pornon

2004 Are meadows with high ecological and patrimonial value endangered by heathland invasion in the French central Pyrenees? *Biological Conservation* 118(1):101-108.

Pickett, S. T. A., J. Kolasa, J. J. Armesto and S. L. Collins

1989 The Ecological Concept of Disturbance and Its Expression at Various Hierarchical Levels. *Oikos* 54(2):129-136.

Pickett, Steward T. and P. S. White

1985 *The Ecology of natural disturbance and patch dynamics*. Academic Press, Orlando, Fla.

Pinchot, Gifford

1911 *A Primer of Forestry Part I: The forest*. Government Printing Office.

Pyne, Stephen J.

1982 *Fire in America : a cultural history of wildland and rural fire*. Princeton University Press, Princton, N.J.

Rappaport, Roy A.

1968 *Pigs for the Ancestors: Ritual in the Ecology of a New Guinea People*. Yale University Press, New Haven, CT.

Redman, C. L.

2008 Introduction. In *Agrarian landscapes in transition: comparisons of long-term ecological and cultural change.* , edited by C. L. Redman and D. R. Foster, pp. 89-121. Oxford University Press, New York, New York, USA.

Redman, C. L. and D. R. Foster (editors)

2008 *Agrarian landscapes in transition: comparisons of long-term ecological and cultural change.* . Oxford University Press, New York, New York, USA.

Redman, Charles L.
1999 Human Dimensions of Ecosystem Studies. *Ecosystems* 2(4):296-298.

Rhoades, Robert E. and Stephen I. Thompson
1975 Adaptive Strategies in Alpine Environments: Beyond Ecological Particularism. *American Ethnologist* 2(3):535-551.

Rica, J. P. Martinez and P. Montserrat Recoder
1990 Biogeographic Features of the Pyrenean Range. *Mountain Research and Development* 10(3):235-240.

Ricardo, David
1891 *Principles of political economy and taxation*. G. Bell and sons, London, UK.

Rius, Damien, Boris Vanniere and Didier Galop
2009 Fire Frequency and Landscape Management in the Northwestern Pyrenean Piedmont, France, Since the Early Neolithic (8000 cal BP). *The Holocene* 19(6):847-859.

Rius, Damien, Boris Vannière and Didier Galop
2012 Holocene history of fire, vegetation and land use from the central Pyrenees (France). *Quaternary Research* 77(1):54-64.

Roseberry, William
1988 Political Economy. *Annual Review of Anthropology* 17:161-185.

Roura-Pascual, N., P. Pons, M. Etienne and B. Lambert
2005 Transformation of a rural landscape in the Eastern Pyrenees between 1953 and 2000. *Mountain Research and Development* 25(3):252-261.

Rudel, Thomas K.
1998 Is There a Forest Transition? Deforestation, Reforestation, and Development. *Rural Sociology* 63(4):533-552.

Russell-Smith, Jeremy, Siliwoloe Djoeroemana, Josef Maan and Petrus Pandanga
2007 Rural Livelihoods and Burning Practices in Savanna Landscapes of Nusa Tenggara Timur, Eastern Indonesia. *Human Ecology: An Interdisciplinary Journal* 35(3):345-359.

Russell-Smith, Jeremy, Diane Lucas, Minnie Gapindi, Billy Gunbunuka, Nipper Kapirigi, George Namingum, Kate Lucas, Pina Giuliani and George Chaloupka
1997 Aboriginal Resource Utilization and Fire Management Practice in Western Arnhem Land, Monsoonal Northern Australia: Notes for Prehistory, Lessons for the Future. *Human Ecology* 25(2):159-195.

Russell, Emily W. B.
1983 Indian-Set Fires in the Forests of the Northeastern United States. *Ecology* 64(1):78-88.

Ruttan, Lore
1998 Closing the Commons: Cooperation for Gain or Restraint? *Human Ecology* 26(1):43-66.

Ruttan, Lore M. and Monique Borgerhoff Mulder
1999 Are East African Pastoralists Truly Conservationists ? *Current Anthropology* 40(5):621-637.

Sahlins, Marshall
1964 Culture and Environment: The Study of Cultural Ecology. In *Horizons of anthropology*, edited by S. Tax, pp. 288 p. Aldine Pub. Co., Chicago,.

Sahlins, Marshall D. and Elman R. Service
1960 *Evolution and Culture*. The University of Michigan Press, Ann Arbor.

Sauer, Carl O.
1950 Grassland Climax, Fire, and Man. *Journal of Range Management* 3(1):16-21.

Sauer, Carl O.
1956 The Agency of Man on the Earth. In *Man's Role in Changing the Face of the Earth*, edited by W. L. J. Thomas, pp. 45-69. University of Chicago Press, Chicago.

Savage, Mellissa and Thomas W. Swetnam
1990 Early 19th-Century Fire Decline Following Sheep Pasturing in a Navajo Ponderosa Pine Forest. *Ecology* 71(6):2374-2378.

Seklecki, M. T., H. D. Grissino-Mayer and T. W. Swetnam
1996 *Fire History and the possible role of Apache-set fires in the Chiricahua Mountains of Southeastern Arizona*. U.S. Department of Agriculture, Forest Service. Copies available from 0277-5786.

Service, Elman R.
1962 *Primitive Social Organization*. Random House, New York.

Shea, John P.
1939 *Man-caused forest fires : the psychologist makes a diagnosis*. USDA. Forest Service. .

Shea, John P.
1940 *Getting at the roots of man-caused forest fires : a case study of a southern forest area*. U.S. Gov. Print. Off., Washington.

Simmons, I. G. and J. B. Innes
1987 Mid-holocene adaptations and later Mesolithic forest disturbance in Northern England. *Journal of Archaeological Science* 14(4):385-394.

Smith, Eric A.
1988 Risk and uncertainty in the 'original affluent society': evolutionary ecology of resource-sharing and land tenure. In *History, Evolution and Social Change: Theoretical and Comparative Approaches*.

Smith, Eric Alden and Mark Wishnie
2000 Conservation and Subsistence in Small-Scale Societies. *Annual Review of Anthropology* 29:493-524.

Spencer, Herbert
1860 The Social Organism. *The Westminster Review, new series* 17:51-68.

Stambaugh, M. C. and R. P. Guyette
2006 Fire regime of an Ozark wilderness area, Arkansas. *American Midland Naturalist* 156(2):237-251.

Steward, Julian H.
1937 Ecological Aspects of Southwestern Society. *Anthropos* 32:87-104.

Steward, Julian H.
1938 *Basin-Plateau Aboriginal Sociopolitical Groups*. United States Government Printing Office, Washington.

Stewart, Omar C.
2002 *Forgotten Fires: Native Americans and the Transient Wilderness*. University of Oklahoma Press, Norman.

Stewart, Omer C.
1951 Burning and Natural Vegetation in the United States. *Geographical Review* 41(2):317-320.

Stoddard, Herbert L.
1962 Use of Fire in Pine Forests and Game Lands. *Proceedings of the First Annual Tall Timbers Fire Ecology Conference*. Tallahassee.

Tacconi, Luca and Yayat Ruchiat
2006 Livelihoods, fire and policy in eastern Indonesia. *Singapore Journal of Tropical Geography* 27(1):67-81.

Trabaud, Loius
1981 Effects of Past and Present Fire on the Vegetation of the French Mediterranean Region. Paper presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, San Diego, California.

Trigger, Bruce G.
1989 *A History of Archaeological Thought*. Cambridge University Press, Cambridge.

Vale, Thomas R
2002 *Fire, Native Peoples, and the Natural Landscape*. Island Press, Washington, DC.

Vankat, John L.
1977 Fire and Man in Sequoia National Park. *Annals of the Association of American Geographers* 67(1):17-27.

Vayda, Andrew P. and Bonnie J. McCay
1975 New Directions in Ecology and Ecological Anthropology. *Annual Review of Anthropology* 4:293-306.

von Thünen, Johann Heinrich and Peter Hall
1966 *Von Thunen's isolated state: an English edition of Der isolierte Staat*. Pergamon, Oxford, UK.

Wiber, Melanie G.
1985 Dynamics of the Peasant Household Economy: Labor Recruitment and Allocation in an Upland Philippine Community. *Journal of Anthropological Research* 41(4):427-441.

Wilk, Richard R. and William L. Rathje
1982 Household Archaeology. *American Behavioral Scientist* 25(6):617-639.

Williams, Gerald W.
2002 Aboriginal Use of Fire: Are There Any "Natural" Plant Communities. In *Wilderness and Political Ecology: Aboriginal Land Management-Myths and Reality*, edited by C. Kay and R. T. Simmons. University of Utah Press, Logan, Ut.

Williams, Gerald W.
2005 *References on the American Indian Use of Fire in Ecosystems*. USDA Forest Service

Wissler, Clark
1926 *The Relation of Nature to Man in Aboriginal America*. Oxford University Press, New York.

Wolf, Eric R.
1955 Types of Latin American Peasantry: A Preliminary Discussion. *American Anthropologist* 57(3):452-471.

Wolf, Eric R.
1957 Closed Corporate Peasant Communities in Mesoamerica and Central Java. *Southwestern Journal of Anthropology* 13(1):1-18.

Wolf, Eric R.
1966 *Peasants*. Foundations of modern anthropology series. Prentice-Hall, Englewood Cliffs, N.J.,.

Wolf, Eric R.
1969 *Peasant Wars of the Twentieth Century*. Harper & Row, New York.

Wolf, Eric R.
1972 Ownership and Political Ecology. *Anthropology Quarterly* 45:201-205.

Wolf, Eric R.
1982 *Europe and the people without history*. University of California Press, Berkeley.

Wu, Jianguo and Orie L. Loucks
1995 From Balance of Nature to Hierarchical Patch Dynamics: A Paradigm Shift in Ecology. *The Quarterly Review of Biology* 70(4):439-466.

Zink, Anne
1969 *Azereix, la vie d'une communauté rurale à la fin du XVIIIe siècle*. Démographie et sociétés, 11. S. E. V. P. E. N., Paris,.

Zink, Anne
1997 *Clochers et troupeaux : les communautés rurales des Landes et du Sud-Ouest avant la Révolution*. Presses universitaires de Bordeaux, Talence.

Zon, Raphael
1920 Forests and Human Progress. *Geographical Review* 10(3):139-166.

CHAPTER 3

ERRAKINA:

PASTORAL FIRE USE AND LANDSCAPE MEMORY IN THE BASQUE REGION OF THE FRENCH WESTERN PYRENEES[1]

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Abstract

People in the French Western Pyrenees have used fire for millennia in order to shape and manage landscapes. This history has left cultural and ecological legacies that both reflect and ensure the relative persistence of landscape patterns and processes. In this paper I draw on ethnographic research, ethnohistorical evidence, and Bayesian spatial analyses of historical fire use locations and land use maps to shed some light on human-fire-landscape dynamics in the Pyrenees for the years 1830 to 2011. I show how cultural and ecological legacies reflect a self-organized fire management regime that emerges from fire use driven by the production goals of individual households. I frame the self-organizing dynamic inherent in Pyrenean pastoral fire use as “landscape memory.” This conclusion has implications for the future direction of fire-related conservation policy for the Pyrenees and for analogous systems characterized by self-organized land management regimes.

Résumé

Dans les Pyrénées occidentales françaises, le feu est utilisé depuis des millénaires pour la gestion des paysages. Cette histoire a laissé un héritage culturel et écologique qui se reflète dans les paysages actuels et qui garantit leur persistance relative. Dans cet article, je m’appuie sur des recherches ethnographiques et ethnohistoriques, sur des analyses spatiales bayésiennes du feu pastoral ainsi que sur des cartes d’usages des sols pour éclairer les relations entre anthropisation, feu et paysage dans les Pyrénées entre 1830 et 2011. Je démontre comment cet héritage culturel et écologique reflète un régime de feu auto-géré. Ce régime se caractérise par une utilisation du feu motivée par les objectifs de production des fermes. Je montre comment cette auto-gestion inhérente à la *pratique du feu pastoral a contribué à la formation d'une « mémoire du paysage » dans les Pyrénées. Cette conclusion a des implications pour l'orientation future des politiques de conservation associées au feu dans les Pyrénées, ainsi que pour d'autres systèmes également caractérisés par des régimes auto-gérés.*

Introduction

People in the French Western Pyrenees have used fire for millennia to shape and manage landscapes (Rius et al. 2009). This history has left cultural and ecological legacies that both reflect and ensure the relative persistence of landscape patterns and processes. Over the last 40 years, the French state has increasingly accepted the beneficial role of fire as a land management tool. At the same time, recent portrayals of pastoral fire in the Western Pyrenees have characterized it as an overly haphazard, self-interested, or degraded practice in need of organized reform in order to meet changing social and environmental conditions (Cummins 2009; Métailié 2006; Tourreuil 2002). These characterizations suggest that present fire management differs from the past. They imply that in the past, traditional values, practices, or institutions controlled behaviors that might have resulted in collateral damages.

Fire is a contagious disturbance in that once ignited, it spreads as a result of dynamic interactions with the landscape (Peterson 2002). In the land management context of the Pyrenees, a mosaic pattern of land use, parcel ownership, and property regimes renders fire potentially problematic since fire is beneficial for pasture but detrimental to other land use types such as woodlands. Thus, alternative fire management policies offer differential costs and benefits to individuals, society at large, and to the environment. For example, self-interested individuals might be tempted to act in ways that run counter to the interests of others: if a farmer lights a pasture fire, the benefits of the fire treatment go to the individual farmer using the pasture, whereas costs of an escaped fire are potentially diffused across society.

Ostrom (2000) and others (Smith and Wishnie 2000) identify this type of situation as a collective action problem where institutionalized cooperation or coordination is needed to curtail potentially harmful actions of self-interested individuals in order to conserve common resources. For fire use, collective action institutions might involve cooperative labor networks for monitoring and controlling fire spread, reliance on authorization and direction from a designated expert, the imposition of sanctions for fire escape, or a combination of these possibilities. Indeed, official policy for pastoral fire use (*ecobuage* in French) formalizes this approach to fire management. An alternative hypothesis with regards to fire use suggests that for some areas, self-limiting fire regimes emerge from practices that time fire ignitions to take advantage of the relationships between fuels, climate, and landscape patterns (Bird et al. 2008; Laris 2002; Russell-Smith et al. 1997). Calculated ignition timing allows for selective burning of specific patches while buffering others in a landscape mosaic.

The question guiding this research is how do Pyrenean farmers achieve pastoral fire management goals without damaging other resources? In order to answer this question, I examined fire management for a village in the Basque region of the French Western Pyrenees from 1830 to the present. I employed a multi-method approach that used ethnographic and archival information of fire use practices to guide and interpret Bayesian spatial analysis of the historical dynamics between fire and land use. I investigated methods of fire control and evaluated evidence for changes in fire use and landscape over the last 180 years. Results suggest that local fire management practices have little in common with collective action solutions promoted in official policy despite a history of protectionist forest management by the French state. Instead, cultural and ecological legacies reflect a self-organized fire management regime that emerges from household level land and fire use patterns. I develop the concept of landscape memory to explain fire practitioners' knowledge and use of the landscape itself as a principal factor controlling fire behavior. I show how this concept is embodied in local knowledge through the Basque word "*errakina*," which refers not only to the practice of burning land, but to the specific land form that is burned.

Study Area

The Pyrenees Mountains follow an east-west orientation along what is today the border between France and Spain. The more eastern and southern portions of the range exhibit a characteristically Mediterranean climate while the western and northern portions tend to exhibit a more humid, Atlantic climate. Forests grade from oak in the lower elevations to a mixture of beech and fir in the middle mountain. Higher elevations are generally dominated by alpine and subalpine grasslands and heaths, but patches of mixed conifer and pine exist in sheltered areas (Ninot et al. 2007). Lightning-caused fire is not a dominant disturbance regime in the western half of the range, but anthropogenic ignitions, common since at least the Neolithic (ca. 6,000 BP), continue to dominate the fire regime (Rius et al. 2009).

The study area consists of a village territory or *commune* situated in the headwaters of the Saison River in the French Western Pyrenees (Figure 3.1). Culturally, people in the area self-identify as Souletin Basque, a deeply rooted ethnolingustic identity that has existed despite cultural imperialism by ruling elites since at least the Middle Ages. Although community members speak French, Basque continues to be the primary language of everyday affairs and cultural identity remains strong. At its peak in the 1860s, the village consisted of about 1600 people with over 100 households practicing mixed agro-pastoral subsistence farming. Today in the village there are about 25 farming households remaining and a total village population of less than 200 people. Farming has transitioned from a diverse mixed agro-pastoralism focused on subsistence to commercial veal and sheep-based dairy production heavily dependent on government subsidies.

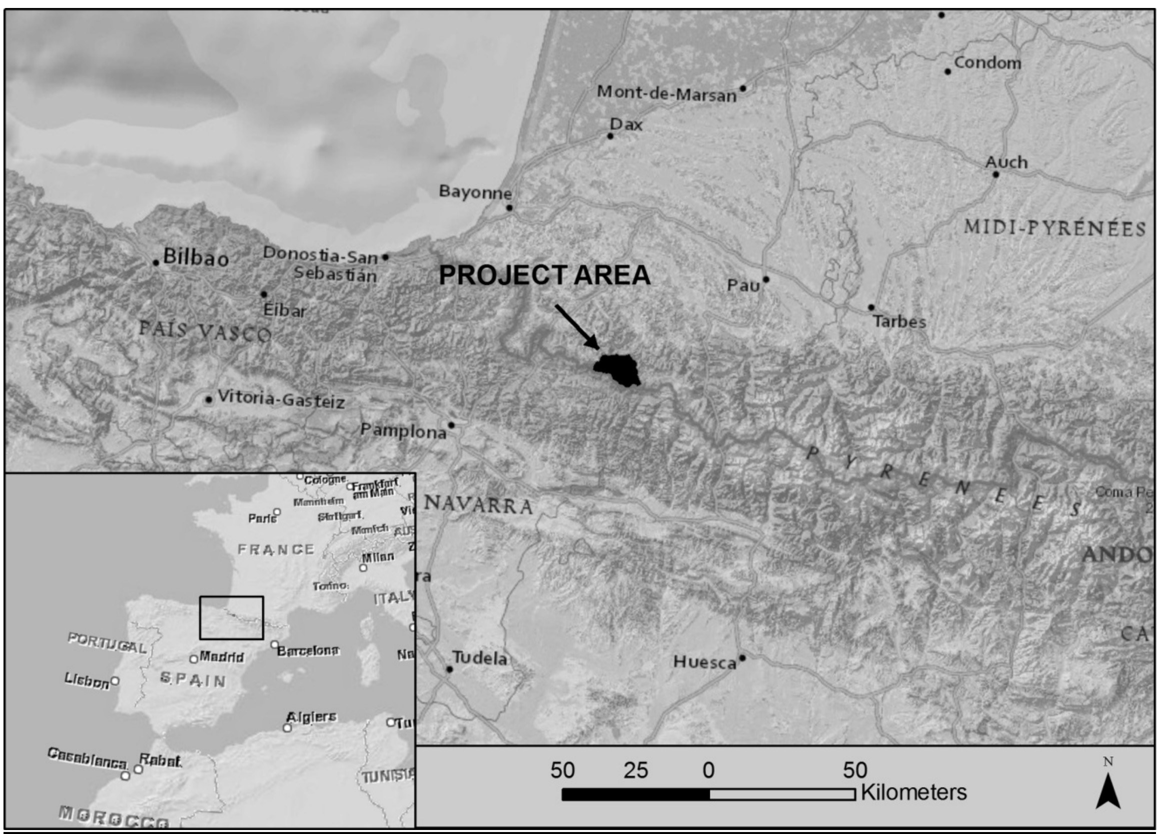

Figure 3.1. Map of project area. Cartography, Michael R. Coughlan. Image courtesy of ESRI, Inc. under creative commons licenses CC By-NC-SA 3.0.

Historically, the household formed the principal unit of domestic production (Fauve-Chamoux 1984), but communally owned woodlands and pastures provided a large share of resources. Spatially, household farm units formed a patchwork of planted fields, hay meadows, woodlots, and pastures that often include in-holdings amidst the mid-elevation forest commons. For the Western Pyrenees, in particular, inter-household cooperative labor networks were extremely important (Ott 1993) and, along with other traditional social institutions, these networks were quite successful in sustainably managing the commons (Cavailles 1931; Gómez-Ibáñez 1975; Murray 2010). Access to the commons was customarily restricted and is now regulated either by the local government or the valley syndicate, a quasi-governmental cooperative land management organization. In order to take advantage of higher elevation summer pastures, households owned shares in an "*olha*" (*cayolar* in French*)*, a grazing and cheese-making cooperative associated with a shepherds' cabin and pasture territory (Ott 1993). Membership in the *Olha* conferred exclusive grazing rights to common lands surrounding the cabin. Neighboring households also shared use and management of communal pastures adjacent to their lands in the mid-mountain forest-pasture matrix. Over the last century, declining population, agricultural intensification, and successive integration with wider political economic spheres of influence have significantly eroded traditional social institutions (Métailié 2006; Murray 2010). Households continue to structure production, but cooperation is much less important. Despite these changes, farmers continue to use fire.

Pastoral Fire Use and Regulation: Regional Overview

Pastoral fires in the Pyrenees are generally low severity surface fires set in late winter and early spring in order to consume dried grasses and small shrubs in pasture lands. The fires thus clear the way for spring growth that is more palatable to livestock, counteract successional trends toward afforestation, and help clear woody barriers to pasture access (Métailié 1981). The historical documentation of agro-pastoral fire use in France, as elsewhere, is extremely rare and is primarily concerned with its prohibition. Prohibitions of fire-use in and around managed forests began under the monarchy as early as the 1660s (Métailié 1981) and were driven by a push to organize forest resources under the direction of a central authority, the newly formed *Administration des Eaux et Forets* (Water and Forest Administration) (Bamford 1955). However, in the Western Pyrenees, the local population largely ignored forest regulations until the French Revolution and the establishment of the modern republic (Gómez-Ibáñez 1975). Specifically, the *Code Forestier* of 1827 updated the forest laws and provided a renewed administrative context for enforcement (Sahlins 1994). Around the same time, in 1830, the Napoleonic cadastral maps were created for the study area. These maps recorded land ownership and use at the parcel level, ostensibly for taxation purposes, but they also proved instrumental to the state's efforts to manage aspects of land and resource use by legally delimiting the boundaries between private and public lands and by codifying land use designations.

The *Code Forestier* excluded grazing and wood cutting on public forest lands and prohibited fire within 200 meters of their borders. The ban shut peasants out of highly managed woodlands called *bois taillis* (coppice woodland). For some households, these woodlands provided the only source of small wood for cooking, heating, and tool making. *Bois taillis* also provided important supplemental food sources for livestock in the form of leaf fodder, acorn and beechnut mast, and forest grasses (Debussche et al.

2001; Métailié 2006; Palu 1992). In 1829, two years after the *Code* took effect, Pyrenean peasants took up arms against the forest guards in a conflict that would become known as *La Guerre des Demoiselles* (Sahlins 1994). Partisans dressed as women terrorized forest agents intensely for four years, but *La Guerre* continued intermittently until about 1872.

In terms of fire use, the more serious conflict concerned the 200 meter buffer established by the *Code Forestier* (Métailié 1981). Ironically, because fire is used to counter woody encroachment on pastures, the very zone that fire is most useful for maintaining was now off-limits. In addition, the 200 meter buffer banned fire use completely for many pastures due to the area to edge ratio and the relatively large number of smaller pastures bordered by forests. For example, while only 34% of 1830 pasture land in the study area fell within 200 meters of woodland boundaries, this area constituted 87% of individual pastures. Compliance meant that farmers would risk losing pasture year by year as forests and scrublands encroached. Although historical archives show that state officials occasionally authorized fire-use for specific times and places, the conditions under which the fire could be conducted was strictly regulated. For example, an 1880 fire use authorization letter from the *Préfecture des Basses-Pyrénées* mandated that the fire be under the surveillance of the forest guard, kept a safe distance from forests, and that fire practitioners provide sufficient personnel to control fire spread.

These regulatory requirements proved difficult to follow and unauthorized fires became the norm. Lefèbvre (1933) reports that clandestine pasture burning was common in the Western Pyrenees region during the late 1920s. In spite of the illegality of the fires, Parrot (1954) reported that for the mid-20th century, wildfires were extremely rare in Soule and that occasional damages were concentrated along the pasture edges. In 1973, the 200 meter ban was lifted, but other regulations became stricter. Clandestine burning remained common in the 1970s (Gómez-Ibáñez 1975;) and continues to be relatively ubiquitous across much of the Western Pyrenees (Pierre Gascouat, Coughlan unpublished field notes 2010).

As outlined above, the historical record has preserved the regulatory context. Yet the actual details of pastoral fire use remain relatively invisible in part because of the marginal legality of the practice itself. However, fire use has left ecological and cultural legacies and is very much alive in certain parts of the Pyrenees. Consequently, it remains possible to delineate the principal means by which farmers achieved fire management while avoiding degradation and abuse of the landscape.

Methods

Data Collection and Transformation

In addition to four shorter visits from June 2008 through June 2012, I spent 10 months living at the field site, from September 2010 through June 2011. I gained a general understanding of local perceptions of fire use, its history, and its regulation through daily conversation with *commune* inhabitants. I participated in, videoed, photographed, and took notes on pastoral fire events. During these participant observation opportunities, I questioned fire practitioners about the cultural rationale, timing, frequency, spatial details, and social relations of fire use. Additionally, because I was living in the *commune* during the entire 2011 burning season, I was able to make observations of pastoral fires on 35 separate days. I recorded time of day, general weather details, spatial area, number of participants, and duration of burn in field notes and photographs. In order to more systematically investigate social aspects of fire use, fire frequencies, and perceptions of fire behavior, I conducted informal interviews with 12 fire use practitioners and mailed a fire use survey to 70 communal pasture users from which I received 22 responses.

In addition to ethnographic data collection, I undertook systematic pedestrian surveys of large sections of the study area recording evidence of fire. I conducted historical investigations at the communal and department archives where I collected a variety of documents including letters pertaining to requests and authorizations for fire use, correspondence concerning wildfires, and a forester's official journal describing daily forest tours for the period 1915 to 1933. I also collaborated with a multidisciplinary research unit at the Université de Pau et des Pays de l'Adour which gave me access to a variety of previously digitized historical maps and documents pertaining to the study area. I developed a geodatabase for storing, integrating, and displaying spatial aspects of the data in a geographic information system (GIS). This geodatabase linked the spatial provenience of fire events with digitized parcel maps and enabled spatial overlay of fire use practices, land use, and topography.

Spatial Analyses

I used a GIS application, ArcSDM for ArcGIS 9.3, to build Bayesian weights of evidence (WoE) probability maps (Bonham-Carter et al. 1989; Sawatzky et al. 2009) for fire use based on topography, historical land use, and the locations of fire use from official prescribed burn authorizations for the years 1969-2011. The objective of this analysis was to quantify the relationships between fire use and the landscape in terms of both topographic characteristics and historical land use. Bayesian methods are well suited to this type of analysis because they are data-driven and able to incorporate prior knowledge and uncertainty into the modeling process (Clark 2005; Dickson et al. 2006). WoE uses Bayes theorem:

$$\mathbf{P\ (D|B) = P\ (B|D)\ P(D)\ /\ P(B)}$$

where **P (D)** is the probability that **D**, which represents a known sample, occurs in a sample space given no other evidence. **P (B)** is the probability that **B** occurs in the same space, and **P (B|D)** is the conditional probability that **B** occurs in a sample space occupied by **D**. Consequently, **P (D|B)** is the posterior probability: the probability that the location of evidence **B**, (e.g., a southeastern aspect), predicts **D** (e.g., fire use occurrence or absence).

In order to operationalize the sample space, I divided the project area (approximately 125 km^2) into a grid of 30 m^2 units. GIS WoE uses training points to represent a sample of a known distribution of the parameter being predicted. For the training points, I plotted the spatial extent of current and recent fires (observed and requested fires 1969-2011) as polygons. To create the training point layer, I transformed the polygon features into 30 m^2 square units and placed a point at each unit's centroid (n=6086). Observations and informant statements suggested that not all pastures are burned with the same frequency and spatial homogeneity, specifically with reference to pastures above 1400 msl. Thus, in order to more accurately reflect this variability in informant's fire use, the sample was split into two groups and randomly thinned: (1) points located at pastures above 1400 msl (n=1554) were thinned by random selection of 5% to reflect > 20 year fire return interval (consistent with informants statements for that elevation) and, (2) points located at elevations below 1400 msl (n= 4532) were thinned by random selection of 20%, to reflect a < 5 year fire return interval. This sampling strategy adjusts for relative patchiness of fire (a consequence of vegetation growth and fire return) by ensuring that fire points are more proportionally representative of observed and reported practices.

Next, sets of binary evidence maps (B_i) are used to build conditional probabilities for the locations of fire events. For topographic evidence maps, I created a 3-category elevation map, an 8-category aspect map, a 3-category slope map, and a 4-category topographic roughness map using a 50-meter resolution digital elevation map (DEM) of the project area (Institut Géographique National 2009). With the exception of aspect, categories were ordinal. These maps were further parsed into binary theme maps for each topographic class. For land use, I created 30-meter resolution binary theme maps with 10 land use classes (pasture, forest, woodland, coppice woodland, hay meadow, crop field, garden, waste land, structure, shrubland) using a previously digitized version of the 1830 Napoleonic Cadaster that details land use at the parcel level.

In the WoE analysis, each predictor variable is weighted based on the statistical strength of association, with positive weights predicting occurrence and negative weights predicting absence. The significance of each evidence layer is determined by "studentizing" the contrast between the positive and negative weights. Levels below the studentized value of 2 (outside the 98% confidence level) are rejected. The ArcSDM GIS application then combines the significant weights to create a posterior probability map that provides the probability of fire occurrence given all evidence layers.

WoE analysis assumes conditional independence (CI) of evidence layers with reference to the training points (Bonham-Carter 1994). I tested CI with the Agterberg-Cheng CI test (Agterberg and Cheng 2002), a one-tailed test in which the difference between the expected number of training points (based on the posterior probability maps) and the observed number of training points is equal to 0. In my initial analysis I found conditional dependence between both land use and topographic evidence layers. While some conditional dependence is likely in all WoE analysis, accuracy of WoE probabilities is highest when CI is maximized (Bonham-Carter 1994). In order to avoid over estimation of fire use probabilities, it is recommended that conditionally dependent layers either be combined (Agterberg and Cheng 2002; Dickson et al. 2006) or dropped from WoE analysis (Romero-Calcerrada et al. 2008). In this analysis, land use layers were conditionally dependent, in part, because woodland and pasture along with their suite of topographic characteristics were mutually exclusive with respect to fire use presence and absence. I dropped the 1830 land use in order to remove this redundancy. To ensure CI for the topographic layers, I combined the slope, topographic roughness, and elevation classes into one layer with 36 binary categories, e.g., SL1R1EL1 = slope 1, roughness 1, elevation 1; SL3R2E2 = slope 3, roughness 2, elevation 2.

I evaluated the predictive power of the WoE analysis using a burned area map from the 2011 fire season. This process transforms the posterior probability map from a continuous probability raster into “prediction classes” and plots them on a prediction efficiency curve (Fabbri and Chung 2008; Porwal et al. 2010). The prediction rate curve is a scatter plot with the proportion of area in the potential predictive class on the x axis and the percentage of “events” captured by that class on the y axis. The curve helps locate potential thresholds of high versus low predictive power. I used thresholds on the prediction rate curve to define high, moderate, and low fire use predictor classes.

For the final stage, I used GIS overlay and intersect functions to compare and contrast maps of the fire use predictor class, 1830 and 2003 land use, and 2011 burned area. To assess potential change and persistence in fire use, I created a map of fire use probabilities for 1830 and 2003 by overlaying respective pasture area on the fire use predictor class map. I then used zonal statistics to compare the maps with a 2011 map of burned area observations.

Results

Fire and Social Institutions

Observation, interview, and survey results suggest that pastures are selectively burned while fire is intentionally excluded from other land uses (Figure 3.2). Although most pastureland is communally owned, the rights of households to restrict and in some cases, monopolize, access to pasture commons brings with it the responsibility to appropriately manage the lands. Pasture burning falls under these management responsibilities, and households (these days often a solitary farmer) generally undertake the burning on their own. *Olhas*, as corporate groups using syndicate land, conduct burning together within the *Olha* territory, but coordination does not involve directing or monitoring fire behavior. Members instead divide the territory amongst themselves in order to more efficiently place ignitions across the landscape. In recent years, the valley syndicate has begun to organize collective, prescribed burning parties for some of the land they manage, but these are limited in number.

During the 2011 fire season, I observed only one fire that was conducted in complete compliance with fire use regulations. This fire, which was conducted in an area that receives high tourist traffic, was organized and led by paid employees of the valley

Figure 3.2. Fires burn dry pastures along the slope, but do not penetrate woodland or hay meadows. Photograph by Michael R. Coughlan.

syndicate. Fires on the other 34 days of observation casually violated the regulations in one way or another. The most common violation involved the failure to provide a burn team; the person responsible for the fire is required to furnish a team of persons for control and surveillance of the fire. Instead, individuals worked alone, setting their fires and moving along. Some informants expressed the notion that more than three or four people conducting a burn could be hazardous since it would be difficult to keep track of each other. Burn teams were considered unnecessary by most informants since they did not think fires needed to be monitored or actively controlled.

This point relates to the other common violation: the failure to stay on site while the fire was active. Nearly every fire I observed was left to burn out on its own without surveillance and without any fire suppression activities. About a third of the fires were conducted clandestinely, including the largest and most publically visible fires. However, unless they had other work to do on site, fire practitioners quickly left the scene of ignition even for those fires that were legally authorized and fire practitioners had little fear of legal repercussions.

Until the mid-1980s, fire use authorizations were issued for higher elevation pastures only, where there was almost no risk of escape , and land management technically fell to the valley syndicate. However, this may reflect the fact that requests for fire use authorizations were simply not filed for other areas. In the mid-1980s, several households began to request authorizations for burning on private property and nearby communal use areas just outside the village. By the mid-1990s, nearly every farm submitted requests for fire use authorizations at high and low elevations. The historical record gives the appearance of an increasing use of fire on lower elevation pasture.

However, it more likely reflects an increasing need for fire users to give the appearance of regulatory compliance. For example, in the mid-1980s, after a new forest guard moved into a refurbished farm house, his neighbors were the first households in the *commune* to request authorizations to burn low elevation pastures.

Fire Use Practice and Control

According to informants, pastures are burned annually, which in practice translates to annual ignitions on most parcels, if not complete burns. I observed several unsuccessful ignition attempts; two of these were in the same location on different days. Informants variously cited the effects of altitude, aspect, exposure, vegetation type, and grazing pressure as contributing to variability in fire frequency. According to 70% of the survey responses, pastures would become unsuitable for grazing after three to five years without fire due to the encroachment of woody vegetation. Another 30% of survey responses indicated a fire free interval between 20 to 100 years would be problematic for grazing, but these responses all referred to pastures above 1400 msl. Portions of these high elevation pastures were nevertheless burned in 2011 and 2012. Two informants stated that fire was not the preferred method for clearing land that had been left fallow for a long period of time since fires could burn too hot, potentially damaging soils. For this reason, many pastures were burned regularly even if not currently in use. Therefore, fire return intervals for burned parcels vary by location, but bellow 1400 msl, they rarely exceed the five-year mark.

Fires are set between the months of January and May, during what might be termed "fire weather opportunities." With the heavy influence of an oceanic climate regime, winter weather in the Western Pyrenees is typically cool and humid with frequent fog, light rain, and snow at higher elevations. However, the area often receives dry southerly, downslope winds similar to foehn winds (Rothermel 1983) that bring clear, sunny skies and low humidity. Fires are set after 3 to 10 days of these low humidity conditions, but also require relatively low wind speeds. Farmers understand thresholds of fuel moistures necessary to contain their fires in pastures: fires set in the winter-dry pasture grasses are timed such that they will not spread to hay meadows, hedgerows, or forests due to residual fuel moistures retained by these other vegetation types. Informants stated that after 10 or more days of drying sun and south wind, fires could burn too hot or escape into fire exclusion zones. Consequently, spread of fire is constrained by higher fuel moistures retained by non-pasture vegetation patches. Streams, ridgelines, and livestock trails also function as firebreaks, some helpful, while others entail additional ignitions in order to facilitate spread of fire to additional pasture.

Buildings such as houses and barns were historically insulated from fires by their placement away from frequently burned communal pastures. Often structures were surrounded by planted fields and hay meadows that do not burn because they either lack fuel or because meadow grasses, in contrast to typical pasture grasses, remain green and humid all winter. In addition, pasture lands immediately surrounding barns and cabins do not easily burn since concentrated grazing, trampling, and manure deposition selects for meadow grass species that remain green and retain moisture during the burning season.

According to the local forest agent, “escaped” fires have been very rare over the past 30 years. During his tenure, he’d given just two citations for fire escape, both to farmers from the neighboring village whose fires had intruded into a forest service pine plantation (*Pinus nigra*) (Arnold 1785). Community members claimed, without qualification, that the beech forests were “impossible to burn.” One informant asked if he was concerned about a fire escaping onto a neighbor’s land replied that if it did, his neighbors would thank him for it. This statement gets at the heart of fire use rationale: if a particular piece of land is flammable under the normal conditions of fire-usage (i.e., appropriate season and weather conditions), it needs to be burned. Under this rationale, escaped fires only occur when the wrong vegetation type burns, i.e., forest.

Escaped fires are rare in the historical archives as well. A 60 ha fire that occurred in 1891 prompted forest authorities to exclude grazing and plant trees. In 1897 the forest office of the Ministry of Agriculture generated a report in response to a request by *commune* inhabitants to reopen the area for local use. The report admits that the surface area of the fire was inflated since there were “enclaves” untouched by fire but that it was important to continue to exclude grazing to ensure the natural regeneration of the forest. An escaped fire in 1974 that occurred near the 1891 location prompted similar action by the forest service: they excluded grazers from the burned area for a period of 10 years.

Historically, most fires were set illegally and therefore not monitored. Despite this fact, a forester’s notebook from the years 1915-1933 recorded just 12 instances of fire trespassing onto land under the forest service control, and only one of these fires did any damage to trees. It is common to find fire scars on hardwood trees within and along the edges of pastures, but scars do not occur in the interior of forest stands.

Change in Fire Management

Informants disagreed about the Basque term for pastoral fire use. Some informants used the term *süeman* which translates as “return the fire.” Older informants used the term *errakina*. *Errakina* is literally translated as “that which is burned,” but figuratively it means burning the type of pasture land that is burned. While this suggests some shifts in pastoral fire knowledge, informants did not differ in their description of the practice, nor did I observe differences in actual techniques.

Farmers perceive change in fire management as a result of the "*déclin de l'agriculture de montagne*" (the decline of mountain agriculture), but the change is never articulated as a change in the practice itself. Rather, farmers perceive changes in fire management, both potential and actual, as tied to the changes in land use that have accompanied population decline and farm abandonment. For example, on separate occasions, four different community members pointed to a hillside where the non-resident landowners were in disagreement about its use and management. The hillside had gone unburned for an unspecified amount of time and, as a consequence, was covered in tall shrubs. Community members suggested that the hillside looked "dirty" and posed a fire hazard for neighboring properties. They perceived this hillside as exemplifying a growing fire management problem. The number of "abandoned" properties has steadily increased and some farmers reported that they burn the pastures of absentee neighbors. These farmers are not merely providing a public service since, at a relatively low cost to themselves, they maintain the productive potential of land they may profit from in the future.

Other significant changes include shifts in pasturing practices from active shepherding of herds to *laissez-faire* pasturing as well as shifts from sheep dominant to cattle dominant herds. As one informant put it, cows take less work. These shifts also entail changes in the fire regime. For example in 2011, homogenous, complete burns occurred on slopes too steep to accommodate cattle whereas patchy, incomplete burns often occurred on slopes dominated by cattle (Figure 3.3). Heavy cows grazing in moist pastures sometimes cause the development of grass "hummocks" that hinder fire spread. One informant described an attempt to build a flame thrower in order to burn the small hummocks of grass, but eventually he gave up burning the pasture.

Weights of Evidence Analysis

The initial WoE analysis (prior to the CI test) determined that 3 land use classes, 2 elevation classes, 2 topographic roughness classes, 2 slope classes, and 6 aspect classes were statistically significant predictors for presence or absence of fire use (Table 3.1). The 1830 land use classes for pasture and woodlands and both southern and northern aspects displayed high contrast between positive and negative predictors for fire use. The lack of conditional independence confounds the accuracy of the resulting probability map, but it does not invalidate the spatial associations between 1830 land use and current fire use practice.

The final WoE analysis, which excluded land use, found 5 classes of the combined topographic layers (topo combo) to be significant predictors for presence or absence of fire use (Table 3.2). This analysis included aspect and SLREL classes for an overall conditional independence of 77.3%. Prediction rate curve analysis translated the WoE probability thresholds into three predictor classes: high probability, > 0.42, moderate, 0.26 to 0.42, and low, < 0.26 (Figure 3.4). High fire use probabilities appear on south facing, rough, and steep areas and low fire use probability on north facing, level ground. Although not specifically quantified, field notes and photographs suggest that many of these areas burned homogenously in 2011 and again in 2012. The moderate class

Figure 3.3. Effects of grazing type and intensity on vegetation and fire behavior. Arrows point to a barbed wire fence excluding cattle from the lower slope which remains accessible to sheep. Note that below the fence the burned area is darker and relatively homogeneous and above the fence the burned area is patchy and incomplete. Photograph by Michael R. Coughlan.

Table 3.1. Initial WoE results for significantly correlated evidence classes. See Table 3.2 for significant aspect layers. For weights (W±) and contrast, positive values indicate higher probability of fire occurrence while negative values indicate higher probability of fire non-occurrence. Significance is defined as a "studentized" contrast (student C) value of > ±2 indicating it lies outside the 98% confidence envelope.

Layer	Evidence Class	Area (Ha)	Training Points	W+	W-	Contrast	Student C
1830 Land Cover	Pasture	6335	747	0.592	-0.917	1.509	17.882
1830 Land Cover	Woodland	1293	23	-1.682	0.112	-1.794	-8.246
1830 Land Cover	Forest	1784	90	-0.530	0.074	-0.605	-5.004
Elevation	2 (800-1400 msl)	7067	647	0.223	-0.338	0.561	7.297
Elevation	3 (>1400 msl)	2223	98	-0.687	0.118	-.8047	-6.978
Roughness	1 (< 8%)	1883	122	-0.228	0.038	-0.1083	-2.452
Roughness	4 (>12%)	1656	166	0.350	-0.059	0.4095	4.051
Slope	1 (< 20%)	2526	161	-0.248	0.058	-0.356	-3.169
Slope	3 (> 29%)	4319	362	0.0103	-0.057	0.160	2.101

Table 3.2. Final WoE results for significantly correlated evidence classes. "Topo Combo" layer represents the combined presence of slope, roughness, and elevation classes (Table 3.1) for a given location. For weights (W±) and contrast, positive values indicate higher probability of fire occurrence while negative values indicate higher probability of fire non-occurrence. Significance is defined as a "studentized" contrast (student C) value of > ±2 indicating it lies outside the 98% confidence envelope.

Layer	Evidence Class	Area (Ha)	Training Points	W+	W-	Contrast	Student C
Topo Combo	SL3R4EL3	280	7	-1.319	0.020	-1.339	-3.392
Aspect	SSE	1340	214	1.110	-0.174	1.284	12.457
Aspect	NWN	1921	59	-1.093	0.138	-1.232	-8.676
Topo Combo	SL1R1EL1	482	15	-1.078	0.031	-1.109	-4.052
Aspect	NNE	2304	91	-0.812	0.139	-0.952	-8.045
Aspect	SSW	1481	197	0.784	-0.130	0.915	9.107
Topo Combo	SL3R4EL2	896	104	0.568	-0.051	0.619	4.854
Topo Combo	SL3R4EL1	480	55	0.547	-0.025	0.572	3.350
Topo Combo	SL1R1EL3	464	23	-0.551	0.018	-0.569	-2.482
Aspect	ESE	1351	145	0.449	-0.062	0.510	4.713
Aspect	WNW	1286	69	-0.457	0.046	-0.503	-3.672

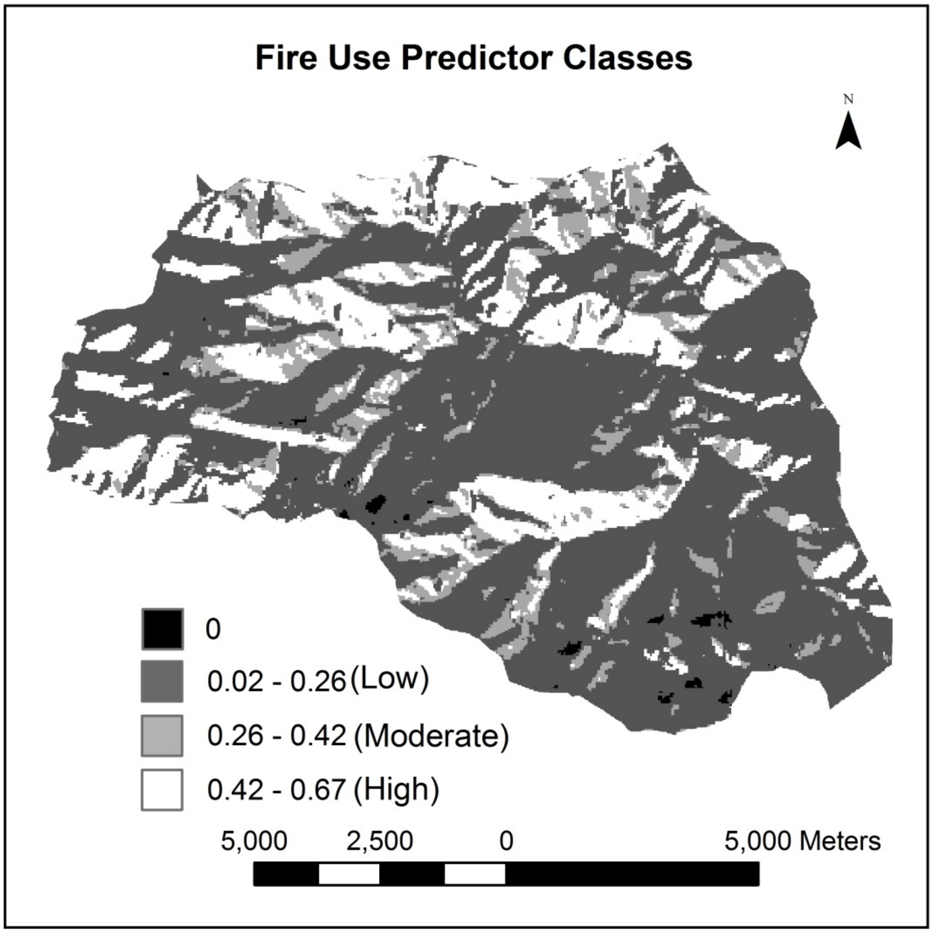

Figure 3.4. Fire use predictor classes derived from a prediction efficient curve of WoE posterior probability of fire use for the project area.

appears in areas where the influence of topography is not clear. Many areas of moderate and lower probability burned patchily in 2011.

Zonal statistics analyzing the intersection of predictor classes, 1830 and 2003 land use and 2011 burned area, (Table 3.3) suggest strong associations between pasture persistence and fire use (Figure 3.5). Of the 1830 pasture, 85% remained classified as pasture land in 2003, and of the area burned in 2011, 82% was classified as pasture land in 1830. Although only about a third of the 1830 pasture land is captured within the highest fire use predictor class, this same area (1830 pasture + high probability fire use) constitutes 43% of the total 2011 burned area and 52% of the 2011 burned area intersecting 1830 pasture.

Discussion

Errakina, Fire Control, and the Persistence of Process and Pattern

Theory in historical ecology defines the term landscape as the material manifestation of human-environment interaction (Crumley 1994). Indeed, with respect to the material manifestation of fire use, social and ecological processes cannot easily be disentangled. The Basque term *süeman* describes how fire practitioners use ignition timing and placement to return fire to the landscape. But the term *errakina* more accurately reflects the historical ecological importance of the fire-maintained landscape itself to the practice of fire use. Iniguez et al. (2008) suggest the term “fire habitat” to describe topographic and vegetative characteristics that encourage or facilitate a specific fire regime. The term *errakina* describes both the fire use process and the pattern of fire habitat it maintains. Fire practitioners simultaneously draw on and reproduce fire habitat

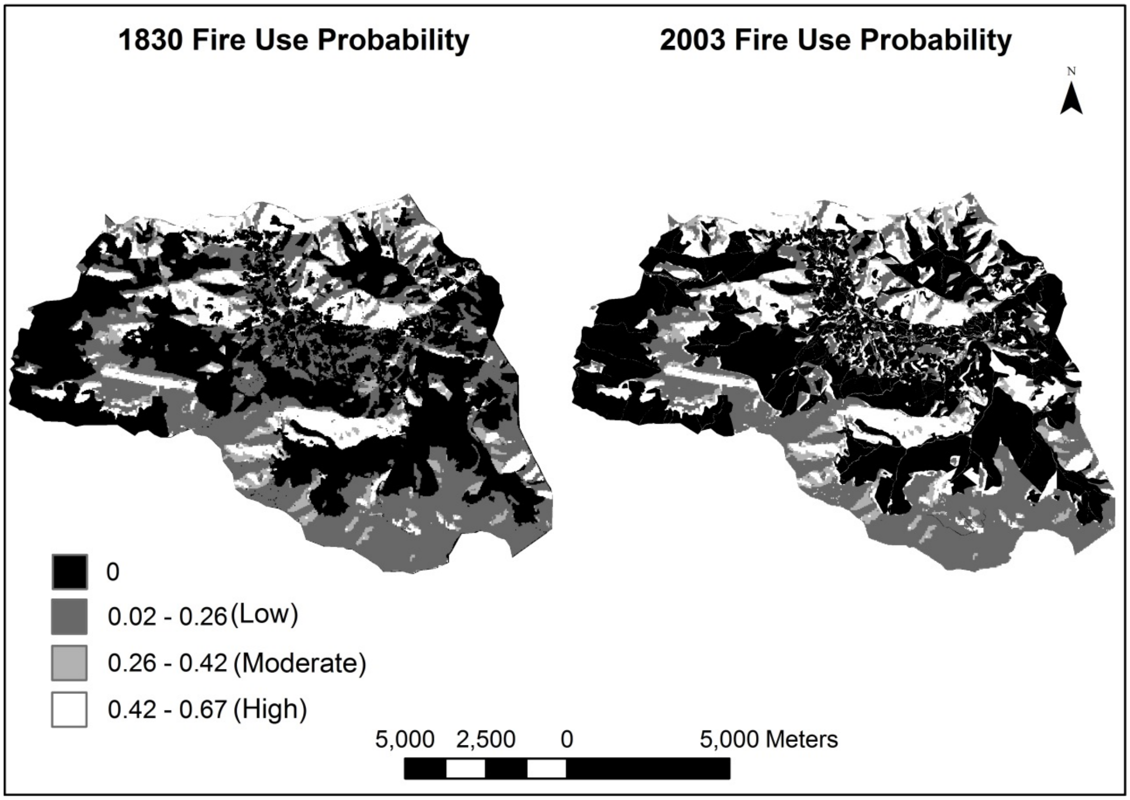

Figure 3.5. Fire use predictor classes for 1830 and 2003 pasture area.

Table 3.3. Analysis of fire use predictor zones.

Predictor Class	% Total Area	% 1830 Pasture Area	% 2011 Burned Area	% 2011 Burned Area (1830 Predictors)	% 2011 Burned Area w/in 1830 Pasture Area
High	22.3	28.0	50.6	42.8	52.3
Moderate	11.3	12.4	14.8	12.2	14.9
Low	66.4	59.6	34.6	26.8	32.8
Total	100	100	100	81.8	100

through a socioecological dynamic inscribed in both landscape and social memory by relying on an intimate knowledge of time- and place-specific fire behavior.

Understanding the dynamic represented by the word *errakina* requires a theoretical concept that can encapsulate both pattern and process: landscape memory. Related concepts, including ecological memory and anthropogenic memory, have been used to refer to the way in which disturbance history shapes successive disturbance (Brierley 2010; Peterson 2002). Landscape memory, as applied here, expands on the concept of land use legacy that describes the long term ecological effects of past land use (Foster et al. 2003; Gragson and Bolstad 2006). Spatial analysis demonstrates that land use legacies that go back at least 180 years play an important role in where and how fire is used today. *errakina* (process and pattern) exists as a consequence of the continuation of land use that requires low severity fire disturbance. *Errakina* functions as part of a land management mosaic because of the continuation and legacy of land uses that require fire exclusion. Knowledge of the implications of fire weather for fire behavior facilitates the ignition of fires at specific times when *errakina* is combustible and other landscape types are not. Thus, the practice itself limits risk of fire escape. Fire practitioners are confident in their shared understanding that control of fire is accomplished in this act of ignition timing because of their knowledge of the landscape. Consequently, landscape memory is the reciprocal interaction of social and ecological memory manifest in the landscape through long term land use and management.

The ethnographic and historical evidence suggest that the landscape memory, rather than collective action institutions, furnishes the principal guide and constraint for fire behavior. In conjunction with appropriate fire weather, farmers count on legacy land use patterns to guide management fires that maintain the productive capacity of pastures. The legacy of landscape memory enables farmers to set fires and leave them unattended. Ribet (2005) characterizes traditional fire use practice in the Pyrenees as using the logic of fire in juxtaposition to the prescribed fires or fire management institutions that use the logic of fire suppression. This observation gets at the cultural biases that impede understanding between fire management institutions and traditional fire users: the traditional cultural approach to fire use inverts the logic that fire must be contained and controlled in order to minimize damage to natural resources. Instead, given the appropriate timing, fire is set free to do its work.

Changes in Process and Pattern

Despite relative constancy with regards to the technical aspects of the practice of pastoral fire use itself, persistence in technique has not resulted in a homogenous fire regime. The primary cause of changes to the fire regime appears to be land use change. This is especially apparent in the case of land abandonment. However, in addition to abandonment, the selective grazing patterns that result from recent shifts in pasturing practices can be significant for vegetation (Garcia-Gonzalez et al. 1990). These changes in vegetation patterns have differential consequences for fire behavior. Because grazing and fire affect vegetation structure differently but also interactively (Noy-Meir 1995), changes in land use may have synergistic effects on the fire regime at fine scales. These factors likely affect the strength and role of landscape memory. Informants implied that fire spread homogeneity and severity is, in part, a function of the dynamic between grazing intensity, time since last fire, and topography. This means that the sensitivity of the landscape to land use change will vary by location. Given the WoE results, it appears that locations of higher fire use probability insulate against fire regime change whereas locations of moderate and low probability are most sensitive to the effects of land use changes. With very few ignition opportunities, abandonment of pastures in low fire use probability locations (i.e., sheltered, north facing slopes) will likely reforest relatively rapidly, becoming dense, impenetrable tangles of holly and beech. Shrub and tree encroachment in abandoned pastures with moderate fire use probabilities will have increased risk of accidental ignition, especially during drought.

Conclusions

Conventional notions of fire management suggest the need for institutionalized cooperation or coordination as a solution to the potential threats pastoral fire use poses for the common good. This case study found no evidence of the regulation of fire use by extra-household social institutions. Nor has the degradation of cooperative labor networks had a direct impact on fire use practices, since cooperative labor networks functioned to facilitate ignition, not to actively control fire behavior. This suggests that extra-household sociopolitical factors have had little impact on the practice of fire use techniques. Indeed, historical attempts by the French state to regulate pastoral fire use in order to manage forests for timber production and watershed protection appear largely extraneous: destructive fires were extremely rare despite disregard for regulations designed to mitigate fire escape.

The principal constraint on fire behavior, then, is an emergent and relatively persistent socioecological dynamic between landscape and humans. While the mechanisms governing fire control inother emergent, human driven regimes operate on seasonal (Laris 2002) or decadal (Bird et al. 2008) scales, in the Pyrenees they are on a centennial or perhaps millennial scale. I describe this dynamic as landscape memory because it is contingent on a long term disturbance history intimately tied to a continuing tradition of land use and local knowledge.

Basque pastoral fire use is an enduring tradition, but human-landscape interactions in the Western Pyrenees are dynamic and the region currently faces some unprecedented changes. Local knowledge of fire ecology inherent in the cultural rationale of fire use continues to rely on landscape memory in order to manage fire spread and severity. However, since household level land use actually maintains landscape memory through continual renewal, this dynamic is certainly under threat if land abandonment progresses. This suggests that while collective action fire management solutions were unnecessary in the past, areas with high potential for weakened landscape memory may require new forms of social cooperation and coordination that reach beyond household level economic interests.

Nevertheless, future fire use policy and management actions should focus on mitigating land use changes that impact landscape memory and should be less focused on directly regulating fire use practices. Conservation policy must focus on facilitating social and economic conditions conducive to pastoral land use. Increasingly stringent regulation of pastoral fire that attempts to further circumscribe fire timing, acceptable fire spread, and privatize risk and responsibility of fire use is not likely to be effective in managing fire behavior.

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References

Agterberg, F.P. and Q. Cheng
2002 Conditional Independence Test for Weights-of-evidence Modeling. *Natural Resources Research* 11(4):249-255.

Arnold, J. F.
1785. *Reise nach Mariazell in Steyermark*. Wien

Bamford, Paul Walden
1955 French Forest Legislation and Administration, 1660-1789. *Agricultural History* 29(3):97-107.

Bird, R. B., D. W. Bird, B. F. Codding, C. H. Parker, and J. H. Jones
2008 The "Fire Stick Farming" Hypothesis: Australian Aboriginal Foraging Strategies, Biodiversity, and Anthropogenic Fire Mosaics. *Proceedings of the National Academy of Sciences of the United States of America* 105:14796-14801.

Bonham-Carter, G.F.
1994 *Geographic Information Systems for Geoscientists: Modelling with GIS*. Computer Methods in the Geosciences. Pergamon, Tarrytown.

Bonham-Carter, G.F., F.P. Agterberg, and D.F. Wright
1989 Weights of Evidence Modelling: A New Approach to Mapping Mineral Potential. In *Statistical Applications in the Earth Sciences*, eds. F. P. Agterber and G. F. Bonham-Carter, pp.171-183. Geological Survey of Canada, Ottawa.

Brierley, Gary John
2010 Landscape Memory: The Imprint of the Past on Contemporary Landscape Forms and Processes. *Area* 42(1):76-85.

Cavailles, Henri
1931 *La Transhumance Pyrénéenne et la Circulation des Troupeaux dans les Plaines de Gascogne*. Armand Colin, Pariscity?

Clark, James S.
2005 Why Environmental Scientists are Becoming Bayesians. *Ecology Letters* 8:2-14.

Crumley, Carole L.
1994 Historical Ecology: A Multidimensional Ecological Orientation. In *Historical Ecology: Cultural Knowledge and Changing Landscapes*, ed. C. L. Crumley, pp.1-16. School of American Research Press, Santa Fe.

Cummins, Bryan
2009 *Bear Country: Predation, Politics, and the Changing Face of Pyrenean Pastoralism*. Carolina Academic Press, Durham.

de St. Albert, M., Secrétaire Général, Prefet des Basses-Pyrénées
1880 Letter to Mairie de Larrau, 6 March. Archives Communales, Secrétaire de Mairie, Larrau, France.

Debussche, Max, Geneviève Debussche, and Jacques Lepart
2001 Changes in the Vegetation of Quercus pubescens Woodland after Cessation of Coppicing and Grazing. *Journal of Vegetation Science* 12(1):81-92.

Dickson, Brett, John Prather, Yaguang Xu, Haydee Hampton, Ethan Aumack, and Thomas Sisk
2006 Mapping the Probability of Large Fire Occurrence in Northern Arizona, USA. *Landscape Ecology* 21(5):747-761.

Fabbri, Andrea and Chang-Jo Chung
2008 On Blind Tests and Spatial Prediction Models. *Natural Resources Research* 17(2):107-118.

Fauve-Chamoux, Antoinette
1984 Les Structures Familiales au Royaume des Familles-souches: Esparros. *Annales. Histoire, Sciences Sociales* 39(3):513-528.

Foster, David, Frederick Swanson, John Aber, Ingrid Burke, Nicholas Brokaw, David Tilman, and Alan Knapp
2003 The Importance of Land-Use Legacies to Ecology and Conservation. *BioScience* 53(1):77-88.

Garcia-Gonzalez, Ricardo, Rafael Hidalgo, and Catalina Montserrat
1990 Patterns of Livestock Use in Time and Space in the Summer Ranges of the Western Pyrenees: A Case Study in the Aragon Valley. *Mountain Research and Development* 10(3):241-255.

Gómez-Ibáñez, Daniel Alexander
1975 *The Western Pyrenees: Differential Evolution of the French and Spanish Borderland*. Oxford research studies in geography. Clarendon Press, Oxford.

Gragson, Ted L. and Paul V. Bolstad
2006 Land Use Legacies and the Future of Southern Appalachia. *Society & Natural Resources* 19:175-190.

Iniguez, Jose M., Thomas W. Swetnam, and Stephen R. Yool
2008 Topography Affected Landscape Fire History Patterns in Southern Arizona, USA. *Forest Ecology and Management* 256(3):295-303.

Institut Géographique National
2009 BD ALTI: La modélisation altimétrique de vos grands projets, Dep-64. Institut Géographique National (IGN). Paris, France.

Laris, Paul
2002 Burning the Seasonal Mosaic: Preventative Burning Strategies in the Wooded Savanna of Southern Mali. *Human Ecology:An Interdisciplinary Journal* 30:155.

Lefèbvre, Theodore
1933 *Les Modes de Vie dans les Pyrénees Atlantiques Orientales*. Armand Colin, Paris.

Métailié, Jean-Paul
1981 *Le Feu Pastoral dans les Pyrénées Centrales : Barousse, Oueil, Larboust*. Editions du C.N.R.S., Paris.

2006 Mountain Landscape, Pastoral Management and Traditional Practices in the Northern Pyrenees (France). In *The Conservation of Cultural Landscapes*, ed. M. Agnoletti, pp.108-123 CABI, CAB International, Wallingford, UK.

Murray, Seth
2010 The Presence of the Past: A Historcal Ecology of Basque Commons and the French State. In *Social and Ecological History of the Pyrenees: State Market, and Landscape,* eds. I. Vaccaro and O. Beltran, pp. 25-41. Left Coast Press, Walnut Creek.

Ninot, J. M., e. Carrillo, X. Font, J. Carreras, A. Ferre, R. M. Marsalles, I. Soriano and J. Vigo
2007 Altitude Zonation in the Pyrenees: A Geobotanic Interpretation. *Phytocoenologia* 37(3-5):371-398.

Noy-Meir, Imanuel
1995 Interactive Effects of Fire and Grazing on Structure and Diversity of Mediterranean Grasslands. *Journal of Vegetation Science* 6(5):701-710.

Ostrom, Elinor
2000 Collective Action and the Evolution of Social Norms. *The Journal of Economic Perspectives* 14(3):137-158.

Ott, Sandra
1993 *The Circle of Mountains : A Basque Shepherding Community*. University of Nevada Press, Reno.

Palu, Pascal
1992 Rapports entre Organisation Sociale et Écosytème dans la Société Pastorale Souletine. *Sociétés Contemporaines* 11(11-12):239-264.

Parrot, Aime G.
1954 L'Incineration des Landes au Pays Basque Francais. *Société des Sciences, Lettres & Arts de Bayonne* 66.

Pasche, F., M. Armand, P. Gouaux, T. Lamaze and A. Pornon
2004 Are Meadows with High Ecological and Patrimonial Value Endangered by Heathland Invasion in the French Central Pyrenees? *Biological Conservation* 118(1):101-108.

Peterson, Garry D.
2002 Contagious Disturbance, Ecological Memory, and the Emergence of Landscape Pattern. *Ecosystems* 5(4):329-338.

Porwal, A., I. González-Álvarez, V. Markwitz, T. C. McCuaig, and A. Mamuse
2010 Weights-of-evidence and Logistic Regression Modeling of Magmatic Nickel Sulfide Prospectivity in the Yilgarn Craton, Western Australia. *Ore Geology Reviews* 38(3):184-196.

Ribet, Nadine
2005 La Maitrise du Feu: Un Travail en Creux qui Façonne les Paysages. Le Travail et les hommes: actes du 127e congrès du CTHS, Paris, France.

Rius, Damien, Boris Vanniere and Didier Galop
2009 Fire Frequency and Landscape Management in the Northwestern Pyrenean Piedmont, France, Since the Early Neolithic (8000 cal BP). *The Holocene* 19(6):847-859.

Romero-Calcerrada, Raul, C. Novillo, J. Millington, and I. Gomez-Jimenez
2008 GIS Analysis of Spatial Patterns of Human-caused Wildfire Ignition Risk in the SW of Madrid (Central Spain). *Landscape Ecology* 23(3):341-354.

Rothermel, Richard C.
1983 *How to Predict the Spread and Intensity of Forest and Range Fires*. USDA Forest Service.

Russell-Smith, J., D. Lucas, M. Gapindi, B. Gunbunuka, N. Kapirigi, G. Namingum, K. Lucas, P. Giuliani, and G. Chaloupka
1997 Aboriginal Resource Utilization and Fire Management Practice in Western Arnhem Land, Monsoonal Northern Australia: Notes for Prehistory, Lessons for the Future. *Human Ecology* 25:159-195.

Sahlins, Peter
1994 *Forest Rites : The War of the Demoiselles in Nineteenth-Century France*. Harvard Historical Studies vol. 115. Harvard University Press, Cambridge.

Sawatzky, D.L., G.L. Raines, G.F. Bonham-Carter, and C.G. Looney
2009 Spatial Data Modeller (SDM): ArcMAP 9.3 Geoprocessing Tools for Spatial Data Modelling Using Weights of Evidence, Logistic Regression, Fuzzy Logic and Neural Networks. Available at: http://arcscripts.esri.com/details.asp?dbid=15341 (verified 16 March 2013).

Smith, Eric Alden and Mark Wishnie
2000 Conservation and Subsistence in Small-Scale Societies. *Annual Review of Anthropology* 29:493-524.

Tourreuil, David
2002 La Commission Syndicale du Pays de Soule et la Gestion des Feux Pastoraux. Memoire de fin d'études pour l'obtention du titre d'Ingenieur des Techniques Agricoles. École Nationale d'Ingenieurs des Travaux Agricoles de Bordeaux, Gradignan.

CHAPTER 4

FARMERS, FLAMES AND FORESTS: HISTORICAL ECOLOGY OF PASTORAL FIRE USE AND LANDSCAPE CHANGE IN THE FRENCH WESTERN PYRENEES 1830-2011[2]

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Abstract

The human use of fire is a major disturbance factor shaping the long term composition and patterning of temperate forest landscapes. Yet, knowledge of the role of human agency in the historical dynamics of fire in temperate forests remains vague. This paper presents a cross-scale Bayesian Weights of Evidence analysis of change in the spatial patterns of fire use over the last 180 years for a village territory in the Basque portion of the French Pyrenees. Research investigated the historical relationships between social institutions that control land use, the spatial patterning of fire use, and landscape change. Analysis considered the spatial contexts within which humans use and manage land: the household institution and the parcel unit of land management. Bayesian methods established statistically significant associations between social and ecological factors driving fire use and landscape change. These associations suggest that social institutions differentially affected fire use patterns through inherited constraints. The resulting socioecological legacies helped to explain the spatial patterns of landscape change. Uncertainty highlighted in the modeling process suggests that we need a better understanding of the historical ecological dynamics of household institutions and land use change in order to better explain relationships between variability in land use intensity and the fire regime.

Résumé

L'usage humain du feu c'est un grand facteur de perturbation qui détermine la composition et les modélisations des paysages de forêts tempérées. Cependant, la connaissance du rôle de l'agence humaine dans les dynamiques historiques du feu dans les forêts tempérées reste vague. Cet article présent une analyse spatiale bayésienne à *travers d'échelle de change dans les modélisations spatiales de l'usage du feu pendant les dernières 180 années dans un territoire de village dans la portion Basque des Pyrénées françaises. La recherche a investigué les relations historiques entre les institutions sociales qui contrôlent l'usage de sol, les modélisations spatiales de l'usage du feu, et le changement du paysage. Cette analyse a considéré les contextes spatiales dans lesquels les humains utilisent et gèrent la terre : l'institution de la maison et l'unité parcellaire de régime. Des méthodes bayésiennes ont établi des associations statistiquement significatives entre les facteurs sociales et écologiques qui gèrent l'usage du feu et le changement du paysage. Ces associations suggèrent que les institutions sociales affectent les modélisations des façons différentes à travers des contraintes héritées. L'héritage socioécologique qui a résulté aide à expliquer les modélisations spatiales du changement du paysage. De l'incertitude soulignée dans le processus suggère qu'on a besoin d'une meilleure compréhension des dynamiques écologiques historiques des institutions de la maison et du changement de l'usage de sol, pour mieux expliquer les relations entre la variabilité de l'intensité de l'usage de sol et de la régime de feu.*

Introduction

The human use of fire is a major disturbance factor shaping the long term composition and patterning of temperate forest landscapes (Delcourt, et al. 1998; Foster, et al. 2002; Tinner, et al. 2005; Vanniere, et al. 2008). Historical and ecological implications of fire use patterns are especially notable in the mesic, broadleaf-dominated forest landscapes of the western portion of the Pyrenees Mountain range, where non-anthropogenic fires are rare and farmers continue to use pastoral fire (Métailié 2006; Rius, et al. 2009). Previous research on the historical ecology of human driven fire regimes focuses attention on changes in fire frequency, correlating these with shifts in human population densities or broadly-defined sociocultural attributes (Colombaroli, et al. 2010; Delcourt, et al. 1998; Guyette, et al. 2002; 2006; Rius, et al. 2009; Tinner, et al. 1999). However, despite these efforts, knowledge of the role of human agency in the historical dynamics of fire in temperate forests remains vague. This is due, in part, to methodologies and research designs that lack analytical reference to the levels of social and ecological organization that link humans, fire use, and landscape: the household institution and the parcel unit of land use and management.

This paper presents a cross-scale Bayesian Weights of Evidence (WoE) analysis of change in the spatial patterns of fire use over the last 180 years for a village territory in the Basque portion of the French Pyrenees. Research investigated the historical relationships between social institutions that control land use, the spatial patterning of fire use, and landscape change. The research draws on an historical ecology approach that seeks to understand how past human-environment interaction shapes contemporary landscapes (Crumley 1994; Gragson 2005).

Research in historical ecology often requires inference from diverse and indirect forms of evidence in order to link social and ecological parameters through time and space (Russell 1997). This analysis quantified spatial associations between current fire use patterns, topography, land use change, and historical household land use strategies. Associations between variables contribute to a spatially explicit understanding of how institutionally structured land use strategies influenced fire use patterns and how, in turn, those patterns influenced landscape change. WoE is well suited to historical ecological analyses because the method is quantitative, spatially explicit, data driven, and capable of incorporating diverse categorical data. While others have used WoE for modeling the spatial patterning of disturbance events (Dickson, et al. 2006; Dilts, et al. 2009; Poli and Sterlacchini 2007; Romero-Calcerrada, et al. 2008), I use WoE to establish probabilities of associations between factors influencing the processes of landscape change.

Farmers, Flames, and Landscape Change

Pastoral fires in the Pyrenees are relatively small (mean of 10 hectares), low severity, running surface fires. Livestock raising farmers use these fires to maintain pasture size and quality of forage. Farmers set fires in late winter and early spring during fire weather windows when fuel moistures remain high in non-pasture land use but are sufficiently dry to permit the incineration of winter-cured grasses, shrubs, and dead wood in pastures.

The practice of using fire to maintain pasture is thought to have originated in the Levant (Naveh 1975), spreading to Western Europe in association with a suite of agropastoral practices, including slash and burn techniques of crop field and pasture creation (Kuhnholtz-Lordat 1939; Métailié 2006; Sigaut 1975; Trabaud 1981). Paleoecological records from the Pyrenees suggest that since at least ca. 3,000 before present (BP), human land and fire use strongly dictated the regional fire regime (Bal, et al. 2011; Rius, et al. 2009; Rius, et al. 2012). By the Early Medieval period (ca.1400 BP), these same records show a sharp decline in forest clearance and a probable transition to a fire regime dominated by pastoral fire use. Around the same time, the development of social organization in the Pyrenees centered on autonomous household farm units, most of which were established before ca. 800 BP (Bortoli and Palu 2009; Cursente 1998).

From the Late Medieval period (ca. 15th century) until the 19th century, historical and paleoecological archives evidence a gradual expansion of pastures at the expense of woodlands throughout the Pyrenees (Métailié 2006; Rius, et al. 2009). While fire use is not implicated as a cause of pasture expansion, such expansions likely increased the surface area under pastoral fire management. Over the last 50 years, demographic and socioeconomic changes resulted in regionally variable agricultural extensification and abandonment (Mottet, et al. 2006). Analyses of these land use and management changes in the eastern and southern portions of the Pyrenean range, where agricultural abandonments occurred earliest, show increases in shrub and forest cover at the expense of cultivated lands (Vicente-Serrano, et al. 2004) and decreases in landscape heterogeneity (Roura-Pascual, et al. 2005). Declining use of fire is likely a proximal driver of landscape changes (Métailié 2006), but the specific relationships between changes in the spatial patterning of fire use and the landscape remain unexplored.

The Social Context of Farmers' Flames

Farmers cyclically initiate pastoral fires as part of a land use and management regime that ultimately serves dynamic social and economic demands. Rule-based pastoral fire frequencies have been inferred for particular biogeographic vegetation associations (Métailié 1981) and specific land uses (Métailié 2006). However, these do not address variability in fire management with regards to the social processes and patterns driving fire use.

In the Western Pyrenees, as in many other agropastoral landscapes, the household institution represents the principal unit of economic production and decision making over land use (Arrizabalaga 1997; Gómez-Ibáñez 1975; Ott 1993). Pyrenean farming households have usufruct rights to and decision making powers over a biophysically heterogeneous and often discontiguous set of land plots called parcels. Parcels are physically delineated by natural or manmade boundaries and defined through their use and management, e.g. crop field, hay meadow, pasture, woodland. The spatial patterning of fire use emerges through a cross-scale interaction between households and parcels. However the long term relationships between individual farming households and landscape-level fire regime have never been modeled with empirical evidence.

As members of households, farmers make parcel level land use decisions within the context of specific sociocultural institutions and arrangements that determine patterns of ownership, access, and inheritance of land, capital, and other productive assets (Barlett 1976, 1980; Cole 1969, 1973; Durrenberger 1980; Netting 1974, 1993). Changes in the patterns of land use are driven by householder decision making constrained by the intersection of spatially heterogeneous social and biophysical contexts (Mottet, et al. 2006). In this sense, a household’s land use strategy can be measured as the cumulative outcome of parcel level land use decisions. When changes in a household’s land use strategy cause changes in householder preferences for land use and parcel ownership, land use “intensity” also changes. Modeling the spatially explicit relationships between household level land use intensity and parcel level change in land use and fire management holds promise for a more complete understanding of how human history is inscribed in landscape patterns and processes.

Research Questions

Despite ample documentation of the relationship between land use change and landscape transformation, changes in the spatial patterning of fire use remain largely undescribed. Further the differential effects of the social institutions that structure land use and fire management have not been established. This analysis addressed two specific questions: (1) Are land use changes between 1830 and 2010 associated with historical changes in the spatial distribution of fire use? (2) Does the historical institutional context of land use account for spatial variability of inferred changes in landscape and fire use?

Materials and Methods

Biogeographical Setting

The Pyrenees are an east-west trending mountain range dividing the Iberian Peninsula from the rest of Europe and forming the border between France and Spain. The western portion of the range is characterized by a humid, oceanic climate, with mild temperatures and relatively high amounts of precipitation (Gómez-Ibáñez 1975). Forests at lower elevations (up to 900 msl) are dominated by oak, transitioning to a mixture of beech and fir (800 to 1300 msl) , while upper elevations (above 1300 msl) tend to be dominated by alpine and subalpine grasslands and heaths with patches of mixed conifer and pine (Gómez-Ibáñez 1975; Ninot, et al. 2007). Due to the temperate climate and the east-west orientation of the mountains, biogeographic differences exist between cooler, wetter, north-facing slopes and dryer, warmer, south-facing slopes (Rica and Recoder 1990).

Field Site

I selected a field site in the Basque portion of the French Western Pyrenees where farmers continue to use pastoral fires (Figure 4.1). The field site covers approximately 125 square km and is located in the upper Soule Valley with elevations ranging from 300 and 2000 meters above sea level. Rainfall averages approximately 1700 mm per year[3]. The local population continues to embrace the Basque ethno-linguistic identity, with the majority claiming *Soulitine,* the local Basque dialect, as its first language (Ott 1993; Peaucelle 1977).

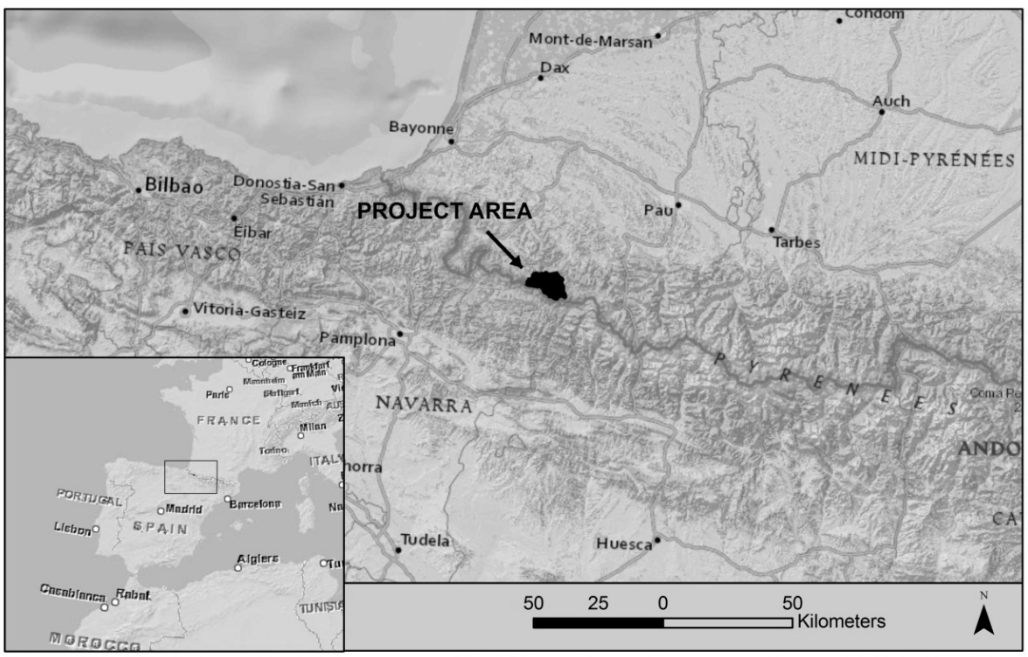

Figure. 4.1. Map of field site. Cartography, Michael R. Coughlan. Imagery courtesy of ESRI, Inc. under creative commons license CC By-NC-SA 3.0.

[3] Data: Meteo France 1956-2011

Prior to changes initiated in the 1980s, farming centered on dairy sheep and cheese production, but kitchen gardens, grain crops, cows, and pigs were also important sources of sustenance and income (Lefèbvre 1933; Ott 1993; Peaucelle 1977). Farmers practiced seasonal transhumance, shepherding animals to communally owned, high elevation pastures (*estives,* French) in summer (Cavailles 1931; Gómez-Ibáñez 1975; Lefèbvre 1928). In winter, farmers kept animals in infield fallows and barns (*borda*, Basque) where they bedded on bracken fern and ate hay and leaf fodder harvested from both private and communal lands. Farmers used mid-elevation pastures, located in the forest matrix, for transitional forage in spring and fall (Palu 1992). Because of their location in the forest matrix, mid-elevation pastures and the lower edge of the *estives* constitute the zone in which farmers use running fires to prepare pastures for the spring.

The Pyrenean householder system was anchored in privately owned crop and hay infields surrounding the physical infrastructure of house and barns (Palu 1992). Spatially contiguous as well as "islet" outfield hay and bracken meadows, pastures, and woodlands also formed a part of the estate. Usufruct relationships of specific households to specific parcels have been systematically preserved in the historical record since 1830 through official cadastral parcelization (Bortoli and Palu 2009; Mottet, et al. 2006). Recorded changes in parcel ownership and use represent reliable and spatially explicit proxies for mapping both parcel level land use and household level land use strategy.

Importantly, household membership also conferred inheritable usufruct rights to communal property adjacent to the homesite and to higher elevation communal pastures. Rights to communal areas were not exclusively held by individual households, but shared through participation in inter-household cooperative labor networks: the *aizoak* (Basque), first neighbor institution and the *olha (*Basque*) or cayolar* (French), pastoral institution (Ott 1993). Households proportionally influenced land use on communal parcels through these networks. In theory, the *aizoak* was based in didactic reciprocity (Ott, 1993), thus, neighboring households had equal rights to the resources of adjacent commons. For *olha* memberships (*txotx*, Basque), a household was obliged to provide a set number of sheep for summer cheese production in the *estives*. Therefore, a *txotx* could be split to allow for the participation of less wealthy households (Ott, 1993). However, historical records linking specific households with particular communal parcels are incomplete. In addition, households from villages throughout the valley participated in *olha* pastoral institutions using communal lands within the study area.

Population in the commune declined steadily following a peak in the mid-nineteenth century (Peaucelle 1977). Over this same time period, farming households in the village substantially decreased in number and size while remaining households increased their landholdings by absorbing those abandoned by neighbors and relatives (Table 4.1). This process of household land use transformation is consistent with other communes in the Western Pyrenees and appears to be most drastic for the period following the 1960s (Mottet, et al. 2006; Welch-Devine 2010). By the 1980s farmers adopted tractors and many transitioned from raising dairy sheep to raising cattle and horses for meat. The 1980s also marked the end of crop cultivation outside of kitchen gardens with farmers converting formerly plowed fields into mechanically cut hay meadows, pastures, or “abandoned” fallow.

Table 4.1. Household extensification trends for households occupied between 1830 and 2010, standard deviations shown as (*10*).

	1830[a]	1862	1931[b]	1963[b]	1977[c]	1990[c]	2010[c]
Actively Farming Households	102	~111[d]	70	60	43	31	24
Average Household Landholdings (ha)	13.83 (11.01)		21.5 (10.02)		19.28 (8.12)	28.75 (9.83)	32.70 (15.31)
Average Household Landholdings, for those extant in 2010 (ha)	17.68 (10.23)				21.74 (8.33)	31.5 (9.34)	32.70 (15.31)
Average Number of Sheep per Household			56		77 (61)	82 (73)	165 (118)
Average Number of Cattle per Household			9		14 (15)	17 (13)	36 (21)

[a] Landowning households only, figure does not include sharecropping households. Source: *Cadastre Napoléonien*.
[b] All actively farming households. Source: *Liste Electorale, Chambre Départemental d'Agriculture* and *Recensement de l'Agriculture et du Betail*.
[c] All actively farming households. Source: French agricultural subsidy records.
[d] Estimate based on the sum of 1830 farming households and difference between the total number of house structures built and the number demolished between 1830 and 1862, multiplied by the percentage of total houses (173) to farming households (102) in 1830.

Data Collection and Transformation

Fire Use

I collected fire use permit requests and authorizations for the years 1969-2010 from communal archives. Permit requests contained parcel level spatial information corresponding with the 2003 cadastral survey. I entered this information into a database and linked the spatial information to a digitized version of the 2003 survey. I also observed, photographed, and point located pastoral fire use on 35 separate days during the 2011 burning season. I used photographs, GPS points, and field notes on paper topographic maps to create a GIS layer of the 2011 burned area. In order to create a map layer of fire use for the years 1969 through 2011, I combined the 2011 burn area map with fire use permit map.

Topography

I used ArcGIS Spatial Analyst to construct elevation, slope steepness (slope), topographic roughness (standard deviation of slope), and slope aspect (aspect) raster layers from a 50m resolution digital elevation model (DEM) of the study area.

Land Use Change

Land survey maps from 1830 and 2003 provided parcel level spatial data with land use attributes. Maps from 1830 and 2003 were scanned, digitized into shapefiles using ArcGIS, and linked to attribute data. The parcel “nature” attribute is part of a fiscal taxation system that assigns each parcel a stratified tax value based on the surface area by hectare (ha) and a predefined land use typology. Beginning with the *Napoleonic Cadastre* of 1830, there were 41 fiscal land use designations for the study area. However, in order to simplify and match 2003 land use categories, these were consolidated into 10 classes (Table 4.2). This classification was further consolidated into four “change analysis” groups in order to ensure the capture of landscape changes that are significant for fire use patterning.

I created a map showing areas of land use change between the two time periods by overlaying the 1830 and 2003 land use maps and intersecting them (Figure 4.2). Land use change categories therefore include categories of no change, i.e. pasture to pasture. I verified and edited land use change categories using aerial photos from 2003 in order to ensure validity of change classes.

Table 4.2. 1830 and 2003 Cadastral land use and land use change analysis categories.

Land Use Categories (French)		Explanation	Analysis Categories
1830	**2003**		
Bois	B (Bois)	General Woodland	Woodland
Bois futaie	BF (Bois Futaie)	Forest (timber production)	Woodland
Bois taillis, haut taillis, chataigneraie	BT (Bois Taillis)	Copice & Pollard woodland (small wood production), Chestnut grove	Woodland
Broussaille	NA	Shrubland	Other
Jardin, Verger	J,VE (Jardin, Verger)	Garden, Orchard	Other
Labour	T (Terre)	Plowed crop field	Field
Pré	P (Pré)	Cut hay meadow	Field
Pâture	L (Lande)	Pasture	Pasture
Terre vague, vaine	L (Lande)	Waste land, low quality pasture	Pasture
Bâtiment*, cour et sol, canal	S (Sol)	Structural footprint, including modern roads and paved areas	Other

*Bâtiment = maison, grange, cabane, and moulin.

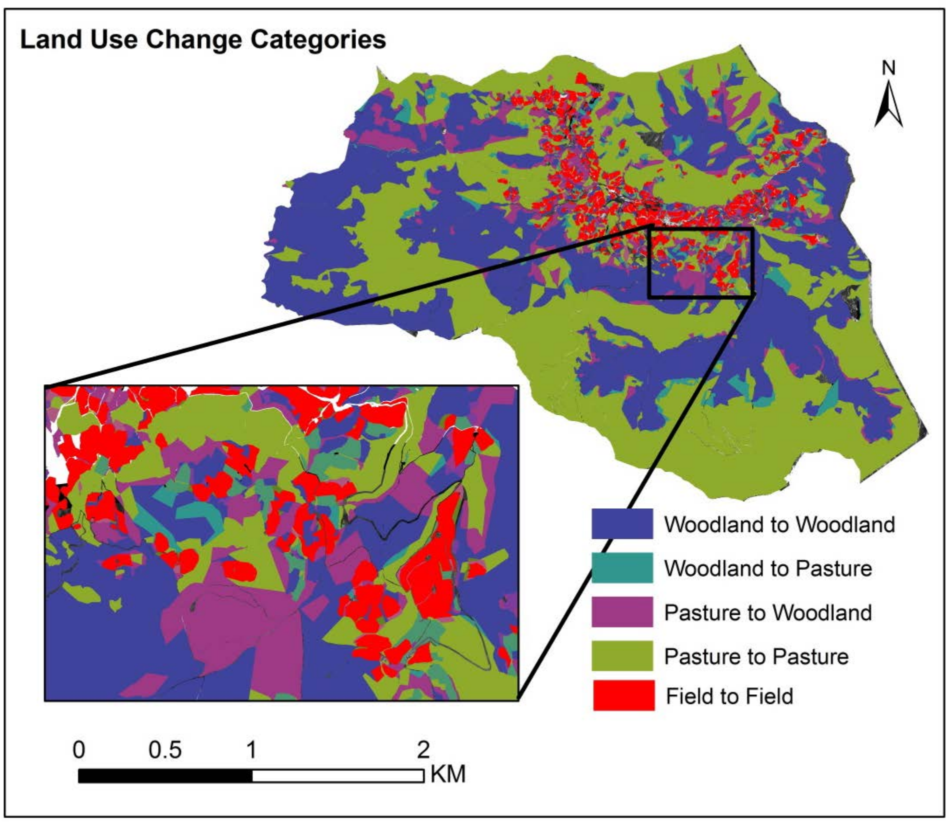

Figure 4.2. Land use change by analysis categories. Cutout for illustration of detail only.

Institutional Context of 1830: Household Land Use Strategy

Land uses form a gradient of intensity in terms of labor and nutrient inputs and biomass outputs (Mottet, 2006). For example, crop fields are more intensive than hay meadows and hay meadows are more intensive than pastures. The cadastral land use tax captured this variability in order to more accurately tax the potential income generating output of land. Consequently, I calculated the average per ha tax value by land use category for 1830. For each farming household, I summed the area of each land use owned and multiplied this by the average tax value for the corresponding land use category. I operationalized the intensity of a farming household's land use strategy as a function of that household's total land use tax divided by the total surface area owned. This provided an index of land use intensity by household that could be assigned as an attribute to the GIS features representing the spatial footprints of households. Parcels owned by non-farming households, including some parcels owned by large landholders, were excluded from the analysis.

Due to the difficulty in linking households with communal land, I grouped communal land into one feature class. I similarly grouped multi-owner private parcels ("indivisible" properties) associated with *olha* institutions. These parcels occur in the mid-mountain area and the *estives* and are often partly owned by households from other villages. Communal and indivisible lands are both collectively owned and represent two types of inter-household land use strategies associated with extensive land use.

WoE

Analysis Overview

WoE uses the known spatial distribution of dependent variable occurrence, e.g. fire use locations, to create a conditional probability map of occurrence given spatial associations between the dependent variable and any number of evidence maps (Bonham-Carter, et al. 1989). For this analysis, I used a GIS application, ArcSDM (Sawatzky, et al. 2009), to generate probability maps of fire use and land use change, given evidence derived from fire use, topographic, and cadastral maps of the study area. WoE is a multivariate analysis method that uses known locations of particular occurrences to derive conditional probabilities of association between the dependent variable and conditionally independent evidence (Bonham-Carter, et al. 1989). The WoE use Baye's Theorem to calculate posterior probabilities of conditional association:

$$P\ (D|B) = P\ (B|D)\ P(D)\ /\ P(B)$$

The method is well tested and described for a variety of spatial analysis applications (Agterberg 1992; Bonham-Carter 1994; Dickson, et al. 2006; Mensing, et al. 2000; Poli and Sterlacchini 2007).

I used a three step approach to answer the research questions (Figure 4.3). The stepped analysis built progressively on spatial associations between layers. Therefore, I used a consistent sample space (n= 138,918, 30 m^2 units) for all three steps.

Step 1 provides a probability map for backcasting fire use in the landscape for any given time period. The research assumes uniformitarianism in "bottom up" controls on fire (Heyerdahl, et al. 2001), such that topographic conditions conducive to fire use in 2003 are likely to be the same for 1830. I chose topographic characteristics as independent conditions because they represent a major biophysical constraint on both mixed mountain agriculture (Netting 1972) and fire ecology (Métailié 1981). In addition, topography remains spatially fixed at the human time scale.

Step 2 uses the topographic fire use probability map to infer associations between land use changes from 1830 to 2003. Interpretation of the results of this step relies on logical consistencies with ecological theories of disturbance and successional processes (White and Pickett 1985). The results provide probability maps for changes in the spatiotemporal patterns of fire use.

Step 3 uses significant associations between topographic fire use probabilities and land use change to establish probable relationships between the institutional context of 1830 and the inferred changes in fire use patterns. The results of Step 3 provide maps indicative of the historical legacy of social institutions on changes in the fire management regime at the level of individual land management units.

Procedure

The ArcSDM GIS application uses a set of “training” points representing a sample of known occurrences or events and a set of thematic evidence raster maps of potential predictive conditions. For step 1, I extracted training points from the 1969-2011 fire use location map. Parcels in which fires occur average about 4 ha but range from 95 to 0.006 ha. In order to create a point layer without losing spatial significance of the parcel area, I transformed the fire use polygon layer into a 30m spaced point layer (n=6089). I then took a 10% random sample of the original points for use as the training point layer, thinning points to ensure 1 per 30 m^2 sample unit.

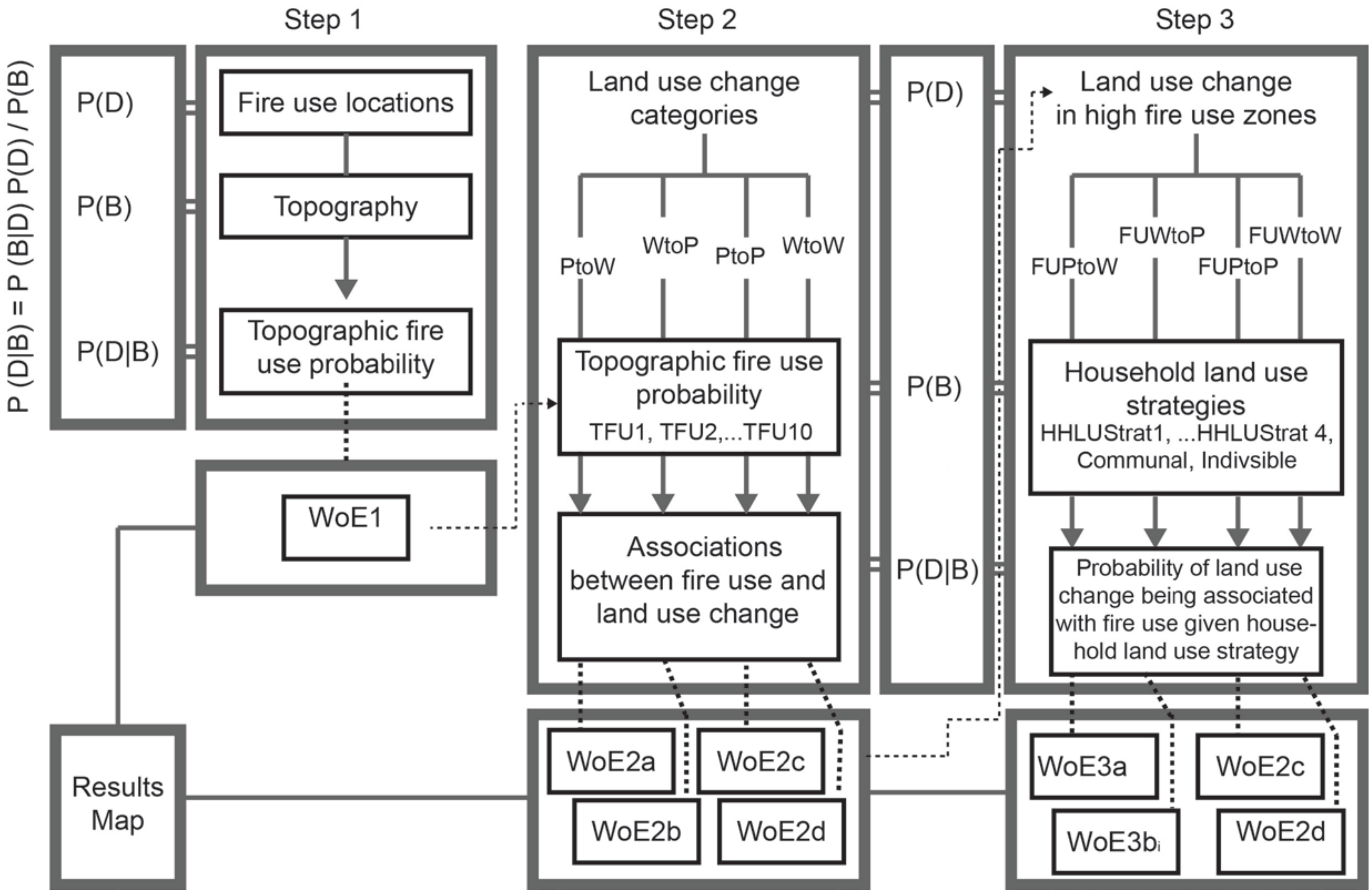

Figure 4.3. Diagram of analysis steps showing the dependent variable (D), Independent variables (B), posterior probability parameter (D|B), and results maps (WoE$_i$).

For topographic evidence layers, I divided elevation, slope, and topographic roughness into categorical ranges using the Jenks natural breaks method: 3 categories each for elevation and slope and 4 categories for roughness. The Jenks method minimizes variance within classes and maximizes variance between them (Jenks 1967). I divided aspect into 8 categories representing aspect ranges located between the 4 cardinal and 4 intercardinal points (e.g. NNE, ENE, ESE, etc.). Slope, topographic roughness, and elevation were combined in the final analysis to ensure conditional independence between layers: e.g. slope (SL_b)+ roughness (R_b)+ elevation (EL_b)= SL1R1EL1, E1S1TR2, … etc. This resulted in 44 binary topographic evidence layers (36 $SL_bR_bEL_b$ and 8 aspect layers). I used ArcSDM to test spatial associations between fire use training points and the topographic layers derived from the DEM. The analysis created a raster map (WoE1) of the conditional probability of fire use, given topography.

In step 2, I used the step 1 map (WoE1) to analyze the probable association between fire use probability and the 1830 to 2003 land use change categories. In order to assess the significance of the WoE1 map for each land use change category, I conducted four separate analyses (Table 4.3). I derived four sets of training points from the Pasture to Woodland (PtoW), Woodland to Pasture (WtoP), Pasture to Pasture (PtoP), and Woodland to Woodland (WtoW) land use change categories. I converted each land use change polygon into a 30 m spaced point layer and randomly selected 1000 points from each layer. I then thinned the point layer to ensure one point per unit area (30 m^2).

Table 4.3. WoE Steps and analyses.

Step	Analysis	Training Points	Evidence
1	WoE1	Fire Use 1969-2011	Topography
2	WoE2a WoE2b WoE2c WoE2d	PtoW WtoP PtoP WtoW	WoE1
3	WoE3a WoE3b WoE3c WoE3d	FU PtoW FU WtoP FU PtoP FU WtoW	HH Land Use Strategy

I selected these four categories of land use change because they most clearly represent potential change and persistence in fire use patterns in terms of spatial distribution and fire return interval (FRI): e.g. PtoW = longer FRI, WtoP = shorter FRI, PtoP = short FRI, low variability, WtoW = long FRI, low variability. Other land use change categories are more likely to have experienced multiple changes over the time period (Mottet 2006), while pasture and woodland land uses offer more concrete evidence of disturbance frequency and severity.

For the binary evidence layers, I used Jenks natural breaks to create 10 categorical probability maps from WoE1 to create “topographic fire use” classes (TFU1 … TFU10, ranging from low probability to high probability). The Step 2 analysis produced four probability maps (WoE2a, WoE2b, WoE2c, WoE2d) corresponding with associations between each land use change category and the TFU categories from WoE1. It thus provided a potential measure of the relative importance of changes in fire management to land use change processes.

In Step 3 I analyzed the relationships between household level land use strategies from 1830 and land use changes associated with fire use or disuse. I derived four sets of training points from the Step 2 training point sets. With the exception of WtoP points, I selected points with associated WoE probability values above thresholds determined by the value at which a fitted trend line modeling the weighted association between the land use change and TFU evidence classes is equal to 0 (Figure 4.4). This provided points from WoE2 probability classes that were positively weighted. WtoP points did not display a linear association. Consequently, for WoE3b$_1$, I selected WtoP training points in WoE2 locations above the 1st standard deviation above the mean probability. This provided training points most strongly associated with TFU classes, regardless of consistence between classes. For WoE3b$_2$, I selected a second WtoP training point set from points that only intersected with TFU7 (WoE1 0.32 - 0.37 probability). This provided training points for WtoP that were significantly associated with higher probability for fire use, excluding the rest. In the results section I compare the associations derived from both WtoP training point sets.

I derived binary evidence layers from the map of 1830 household land use intensity. I used Jenks natural breaks to divide household land use intensity into 4 ordinal classes ranging from high to low intensity. Communal and indivisible parcels were also included as evidence classes, resulting in a total of 6 classes. The results of Step 3 (WoE3a, WoE3b, WoE3c, WoE3d) provide probability maps for changes in fire and land use localized around land use intensity at a scale relevant to social processes. It thus demonstrates associations between linked land-fire use changes and specific household and inter-household land use strategies.

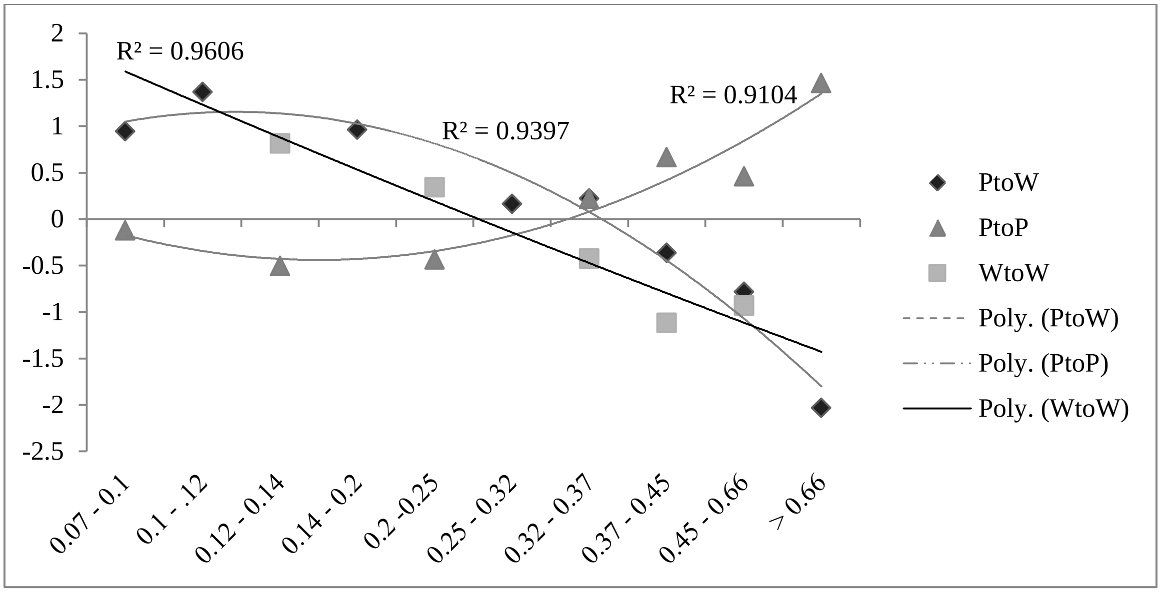

Figure 4.4. Evidential weights for land use change categories. X-axis: WoE1 probability categories. Y-axis: weights assigned in WoE2 analyses. Significance of R^2 values not calculated due to small sample size.

Significance

I evaluated importance and significance of each evidence class to WoE model by examining the contrast (C) positive and negative weights (Bonham-Carter 1994). A positive C indicates that presence of the evidence layer increases chances of training point occurrence, while a negative C indicates the inverse conclusion. Importance of the evidence class to the model increases as positive and negative C values move away from 0. Contrast significance is determined with a “studentized” test of significance. Evidence layers whose studentized C value falls outside the 95% confidence interval (a studentized C value of < 1.64) do not contribute to the probability raster map.

ArcSDM also uses the studentized value of the posterior probability to generate a confidence map. I used this map to identify spatial locations with values below 1.64 (95% confidence interval) for all WoE analyses, to assess the potential effects of this uncertainty on the results, and to ensure that uncertainties did not confound results of successive analyses.

Lastly, WoE assumes conditional independence (CI) of the evidence layers with respect to the training points. Although some conditional dependence is expected, it should be minimized to ensure that probabilities are not inflated (Bonham-Carter 1994). I used the Agterberg-Cheng test in ArcSDM to assess the degree of CI (Agterberg and Cheng 2002). This test uses the training points, posterior probability map, and a map of standard deviation of the posterior probability to measure the significance of the difference between the number of expected sum of all posterior probabilities (T) and the actual number of training points used (*n*). Conditional dependence is present when a one-tailed test finds T to be significantly greater than *n*. Conditional dependence is generally mitigated by dropping some layers and combining others (Agterberg and Cheng 2002; Dickson, et al. 2006). I used tests for conditional dependence on preliminary analyses to inform the 3 step design of the final analysis. Specifically, I dropped the communal land use class in WoE3a and WoE3b, and I combined the elevation, slope, and topographic roughness evidence layers for WoE1.

Results

Step 1

WoE1 results produced a CI value of 90.4%. eight out of 44 topographic evidence layers were significant (Table 4.4). Confidence in the posterior probability was high with studentized value of > 3.2. High elevation, flat and even areas displayed highest contrast and are, therefore, the most important topographic characteristics associated with fire use. Southern aspects weigh in next as positively associated, followed by northern aspects and low elevation, flat areas as negatively associated. The final posterior probability map shows that fire use is largely consistent with topographic features of the landscape (Figure 4.5).

Table 4.4. Fire Use WoE1 results for significantly associated topographic classes. Positive weight and contrast values indicate strength of positive association while negative values indicate strength of negative association. Significance is defined as a studentized contrast value > ±1.64, 95% confidence envelope.

Evidence Class	Area (Ha)	Training Points	W+	W-	Contrast	Student C*
SL1R1EL3	464	69	1.002	-0.048	1.051	6.322
SSW	1481	188	0.733	-0.12	0.853	8.426
SSE	1340	158	0.616	-0.088	0.703	6.589
ESE	1351	122	0.0228	-0.03	0.039	2.275
WNW	1286	77	-0.301	0.031	-0.332	-2.523
NNE	2304	119	-0.478	0.092	-0.57	-5.303
NWN	1921	75	-0.802	0.111	-0.913	-7.079
SL1R1EL1	482	16	-0.982	0.029	-1.011	-3.801

Step 2

Land use changed on less than 12% of the study area between from 1830 to 2003. Most land use change concerned a transition to woodland. PtoW represented 73% of land use change used in Step 2 while WtoP represented only 27%. PtoP represented 86% of 1830 pasture land use and WtoW represented 91% of 1830 woodland land use.

All of the land use change categories were significantly associated with two or more WoE1 evidence classes (Table 4.5). WoE2a (PtoW) and WoE2c (PtoP) displayed a gradient in strength of associations in directions consistent with the known effects of fire disturbance on land cover (Figure 4.4). For example, the high topographic fire use probability classes were strongly and positively associated with pasture persistence (PtoP). These same topographic fire use probability classes were strongly negatively associated with pasture to woodland transition (PtoW). PtoW was positively associated with topographic fire use probability class below 0.37, but levels below 0.2 were more strongly associated. WoE2b (WtoP) and WoE2d (WtoW) did not follow a pattern consistent with what we might expect in terms of fire management (Table 4.5). However, inconsistencies found for WoE2d include TFU1, 2, and 4. These were located in lower elevation, flat areas with higher intensity land uses, including most of the major roads and the main cluster of village houses. Once these values were removed, WoE2d displays negative associations at higher topographic fire use probability classes and positive associations at lower probability classes (Figure 4.4). Inconsistencies with WoE2b were positive at low probability classes, negative at moderate classes, positive again, then negative at high classes. I discuss the relevance of these inconsistencies in Step 3 results.

Confidence in the posterior probability maps was high for WoE2b and WoE2c. WoE2a and WoE2d both showed small areas of high uncertainty (studentized posterior probabilities < 1.64), found along parcel edges. This uncertainty appears to be linked with inaccuracies in data transformation, for example in the overlay and intersection of the 1830 and 2003 land use maps and through rasterization of land use change polygons.

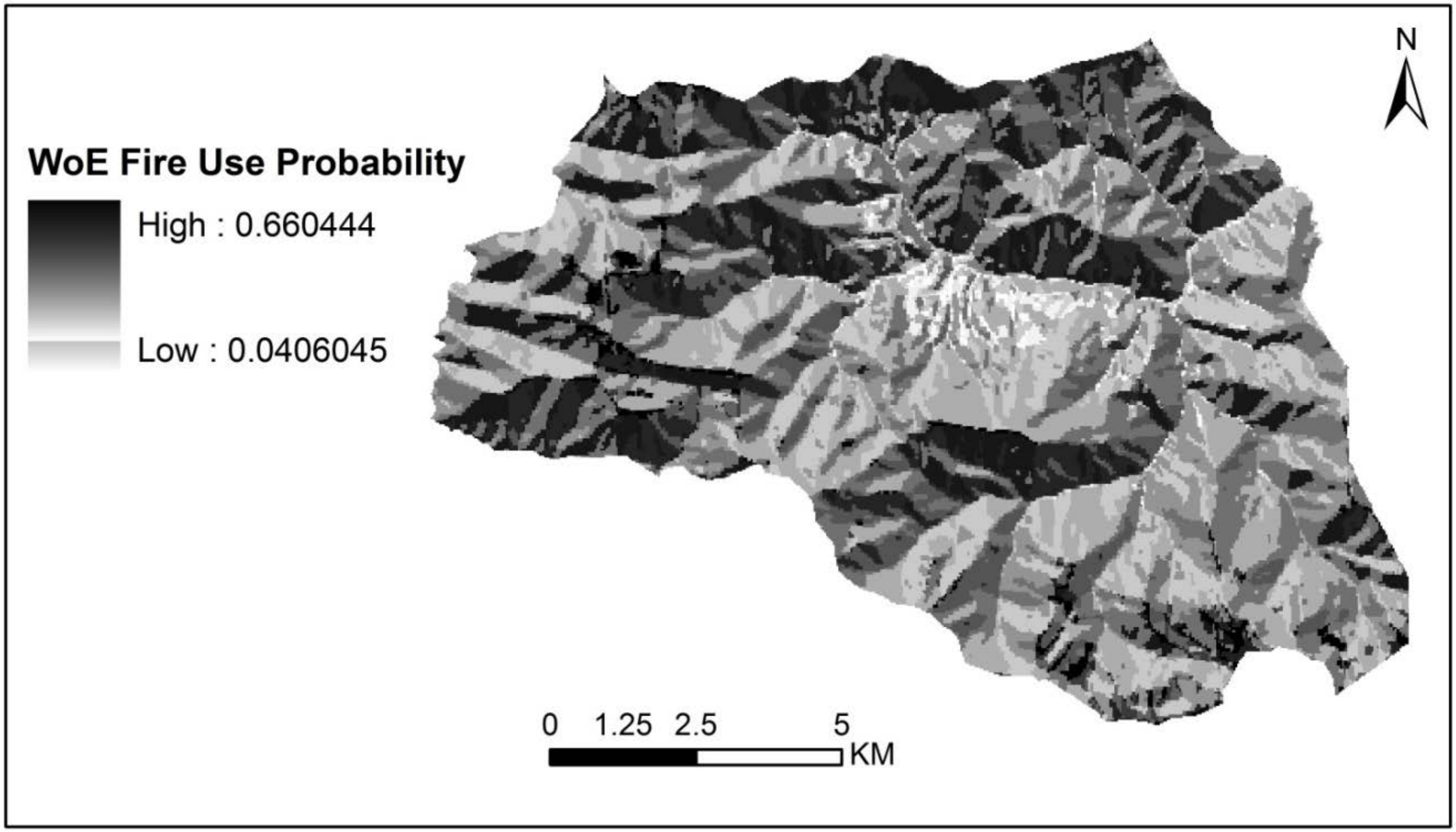

Figure 4.5. WoE fire use probability.

Step 3

1830 land use intensity is significantly associated with land-fire use change associations (Table 4.6). WoE3a (Low fire use, PtoW) was most strongly and positively associated with households in the highest land use intensity class. The strength of association gradually diminishes as land use intensity lessens, transitioning to a weak, negative association for communal and indivisible properties. The communal class adds to conditional dependence of the model and is removed from the final probability map (WoE3a).

$WoE3b_1$ is significantly and negatively associated with communal lands and positively associated with indivisible lands and household land use intensity class 2. As with WoE3a, communal lands added to conditional dependence between variables. $WoE3b_2$ is similarly positively associated with indivisible lands, but significantly negatively associated with household land use intensity level 3. Communal lands were not significant. In comparison, given that $WoE3b_2$ uses training points significantly associated with only high fire use probabilities, $WoE3b_2$ provides a stronger and more consistent link between land use strategy and changes in land-fire use associations.

However, the $WoE3b_1$ confidence map showed very low uncertainties at all probability levels, while uncertainties for $WoE3b_2$ probabilities were high (studentized probabilities of < 1.64) for the significant negative associations with household land use intensity. Thus, woodland to pasture transitions linked with fire use are most likely associated with lower land use intensities (indivisible lands), but uncertainty exists for this change category on all other land use strategies.

Table 4.5. WoE2 contrasts for significantly associated TFU classes. Positive values indicate strength of positive association while negative values indicate strength of negative association. Significance is defined as a studentized contrast value > ±1.64, 95% confidence envelope. NS = not significant. * Values not used in calculating probability threshold for WoE3d training points.

Evidence Class	**Probability Range**	**WoE2a (PtoW)**	**WoE2b (WtoP)**	**WoE2c (PtoP)**	**WoE2d (WtoW)**
TFU1	0.07 - 0.1	0.9638	NS	-1.2377	-0.7018*
TFU2	0.1 - .12	1.3892	0.7045	NS	-1.2035*
TFU3	0.12 - 0.14	NS	0.3509	-0.5735	0.9817
TFU4	0.14 - 0.2	0.9684	NS	NS	-1.7143*
TFU5	0.2 -0.25	NS	-0.2004	-0.575	0.4888
TFU6	0.25 - 0.32	0.2095	NS	NS	NS
TFU7	0.32 - 0.37	0.2515	0.2923	0.2485	-0.4742
TFU8	0.37 - 0.45	-0.4023	NS	0.7608	-1.2083
TFU9	0.45 - 0.66	-0.8653	-0.5845	0.5316	-1.0265
TFU10	> 0.66	-2.0419	NS	1.4803	NS

Table 4.6. WoE3 weight contrasts for significantly associated fire-land use change classes. Positive values indicate strength of positive association while negative values indicate strength of negative association. Significance is defined as a studentized contrast value > ±1.64, 95% confidence envelope. NS = not significant. *Removed from final analysis due to conditional dependence.

Evidence Class	**WoE3a (↓TFU,PtoW)**	**WoE3b$_1$ (±TFU,WtoP)**	**WoE3b$_2$ (↑TFU,WtoP)**	**WoE3c (↑TFU, PtoP)**	**WoE3d (↓TFU,WtoW)**
Communal	-1.2071*	NS	-0.6248*	0.5623	0.3444
Indivisible	-0.4389	1.0255	1.0329	0.5097	-1.7406
HHLUStrat1	1.0738	NS	NS	NS	NS
HHLUStrat2	1.4579	NS	0.6394	-0.6592	-0.7725
HHLUStrat3	1.4799	-1.7961	NS	-1.2502	NS
HHLUStrat4	1.5481	NS	NS	NS	NS

NS = not significant
*Removed from final analysis due to conditional dependence between variables.
HHLUStrat = Household land use strategy (intensity categories 1-4)
↑TFU = Association with high topographic fire use probability.
↓TFU = Association with low topographic fire use probability.
±TFU = Non directional association with fire use probability.

WoE3c shows that pasture persistence coupled with high TFU is significantly associated with inter-household land use strategies on communal and indivisible lands. Pasture persistence is negatively associated with higher intensity household land use strategies. WoE3d shows a similar result for woodland persistence, which is positive on communal lands, but negative for the one significant household land use strategy class. However, unlike pasture persistence, woodland persistence is negatively associated with indivisible properties.

Discussion

Consideration of the spatial contexts within which humans use and manage land proved fruitful for modeling the effects of social institutions and fire use practices on landscape change. Analysis established statistically significant associations between the spatiotemporal patterning land use change, fire use, and historical social institutions. These associations suggest that the institutional context strongly determined the relationship between fire use and landscape change. For example, households differentially affected fire use patterns through inherited constraints concerning the flexibility of their land use strategies. Further, shifting household land use preferences are not only subject to the spatial constraints of socially controlled access, but also the topographically defined flammability of the landscape. These combined factors helped to define the spatial patterning of fire and land use through time. Uncertainty highlighted in the modeling process suggests that we need a better understanding of the historical ecological dynamics of individual households and land use change in order to explain the relationship between the intensity of land use and the variability in fire use. Four key aspects of the analysis bear further explanation.

Firstly, topography appears to provide a reliable template for backcasting the potential distribution of fire use. While topography does not “control” fire use patterning *per se*, it does furnish a significant constraint on both fire and land use. Some topographic constraints are inherent in the functioning of mixed mountain agricultural land use across mountain ranges and cultures (Rhoades and Thompson 1975), e.g. higher elevations are not suitable for infield cultivations and are better suited to extensive pastoral uses. However, farmers show a clear preference for fire use management on southern aspects. This preference is consistent with physiographic controls on vegetation (Ninot, et al. 2007) and with vegetation-fire dynamics in areas as diverse as Corsica (Mouillot, et al. 2003), Appalachia (Flatley, et al. 2011) and the Northwestern US (Heyerdahl, et al. 2001).

Increased insolation and exposure to warm, southern winds during the burning season provides farmers with significantly more ignition opportunities on south-facing slopes. As an index for ignition opportunities, topographic fire use probabilities may also represent an index of fire frequency since the most “flammable” areas provide for the most efficient use of time allocation in maintaining pastures. These south-facing pastures burn more uniformly, require less ignition points, and exhibit more predictable fire behavior. The conversion of gorse shrublands to grass-dominant systems is linked with higher fire frequency through the positive feedback effects of grassy fuels (Santana, et al. 2012).

Over the short term, patch level interactions between vegetation dynamics and grazing likely help determine the frequencies with which farmers burn pastures (Kerby, et al. 2007). Yet, for domestic animals, grazing pressure is a function of household grazing strategies which differentially affects vegetation (García-González, et al. 1990). Positive feedbacks between pasture preference, grazing strategies, and topographic constraints on fire use may encourage a higher shrub-to-grass ratio on north-facing slopes and a lower shrub to grass ratio on south-facing slopes. Field observations from 2011 certainly support this notion. Thus, in labor limited situations, north-facing slopes provide lower quality pastures.

Secondly, given topographic constraints on fire use, land use persistence and change was largely directionally consistent with preferences for more efficient use of land under the rationale of fire management. For example, pastures less conducive to fire use were more likely to convert to woodlands. Long term pasture persistence (PtoP) was more likely in areas conducive to efficient fire management, i.e. slopes with southern aspects. Inversely, woodlands persisted on north-facing slopes, in part because ignition opportunities are rare. The exclusion of fire from northerly aspects is facilitated by the microclimatic reality of the location. The one exception to this rule was woodlands that converted to pasture (WtoP). These changes were less clearly linked with fire use preferences, indicating stronger influence of social contexts (discussed below).

Thirdly, the importance of topographic constraints on fire use is relative to a gradient of land use strategies structured through social institutions. Land use strategies ranged from “extensive” on communal and indivisible lands where topography was more important to persistence of land use to “intensive” on private household lands where topography proved more important to land use change. The 1830 land management institutions provide a legacy of social constraint that resonates through time by modulating the effects of topography on land use decisions.

The dynamics of agricultural abandonment were such that estates that persisted absorbed the lands of abandoned households. This transition entailed fewer workers per ha; hence the socioecological dynamic shifted toward a less labor intensive land use regime. During the early 20th century, birthrates declined, exacerbating the deficit of laborers to farm surface area. Households preferentially adjusted the intensity of land use within the constraints of the surface area and diversity of land they could access. The type and amount of land that a household decided to let afforest or actively reclaim depended, in part, on these particular ratios. The importance of the legacy of land use strategies ca. 1830 is reflected in the associations between households and changes in coupled land-fire use patterns.

For example, a household with suboptimal pasture may obtain new pastures through purchase or inheritance. However, limited access to summer communal lands still constrains the household's ability to increase the number of animals it manages. Thus, the household may stop burning the suboptimal pasture and allow it to afforest, perhaps meeting demands for firewood or other woodland services. Oral histories collected in 2011 suggest that farmers planted chestnut trees (*Castanea sativa*) for leaf fodder and mast on some north-facing pastures ca. 1900 (Coughlan, unpublished data).

Fourthly, inter-household institutions supporting collective land use strategies insulated parcels from extensification processes. As Netting points out, in the Alps, such institutions exist to promote, "an efficiency of utilization that would be threatened by fragmented private ownership; the potential for maintaining yields by enforced conservation; the equitable sharing of necessary resources by all group members" (Netting 1981:64). However, privately owned indivisible parcels were associated with some woodland to pasture changes. This intensification of land use is likely a long term result of the proximity and function of the parcel to the *olha* shepherd cabin. Enclosure of communal woodlands by the French state in 1828 resulted in the imposition of a strict rationing of fire wood to the *olhas.* Private lands were not subject to this stricture and likely faced the pressures of increased wood collection. Wood collection in combination with grazing and fire use probably converted the indivisible woodlands to pastures.

<u>Conclusion</u>

The changes in coupled land and fire use patterns analyzed above highlight a give-and-take relationship where fire use is situated between household economic demand, historically contingent social constraints, and the ecological template. As the number of households decreased and access to land opened up, decreasing land use intensity resulted in land use strategies more in line with topographic constraints. This implies that topographic constraints on fire use played a role in household strategies concerning the maintenance or transformation of land use in specific locations. However, equally important to determining fire use patterns were the social constraints imposed by the historical institutional context governing the means of production and distribution.

The implications of this historical ecological dynamic are that certain areas were more likely to have cycles of use, abandonment, and reclamation in response to socioeconomic changes at larger scales. Human influences on the landscapes of temperate forests were never monolithic, but involved the dynamic and complex interplay of human decision making, institutionally defined land use strategies, and social and ecological constraints. While much work remains to be done, the findings presented here suggest that research on the history and evolution of human-fire-landscape interaction should scrutinize the levels of social and ecological organization at which human-fire-landscape interaction occurs. For regions where sufficient information exists for modeling the historical and social contexts of fire use, the methods presented in this paper hold promise for reconstructing historical processes responsible for fire use patterns.

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References

Agterberg, F.P. and Q. Cheng
2002 Conditional independence test for weights-of-evidence modeling. *Natural Resources Research* 11(4):249-255.

Agterberg, Frederik P.
1992 Combining indicator patterns in weights of evidence modeling for resource evaluation. *Natural Resources Research* 1(1):39-50.

Arrizabalaga, Marie-Pierre
1997 The Stem Family in the French Basque Country: Sare in the Nineteenth Century. *Journal of Family History* 22(1):50-69.

Bal, Marie-Claude, Albert Pelachs, Ramon Perez-Obiol, Ramon Julia and Raquel Cunill
2011 Fire history and human activities during the last 3300 cal yr BP in Spain's Central Pyrenees: The case of the Estany de Burg. *Palaeogeography, Palaeoclimatology, Palaeoecology* 300:179-190.

Barlett, Peggy F.
1976 Labor Efficiency and the Mechanism of Agricultural Evolution. *Journal of Anthropological Research* 32(2):124-140.

Barlett, Peggy F.
1980 Adaptive Strategies in Peasant Agricultural Production. *Annual Review of Anthropology* 9(1):545-573.

Bonham-Carter, G.F.
1994 *Geographic Information Systems for Geoscientists: Modelling with GIS*. Computer Methods in the Geosciences. Pergamon, Tarrytown, New York.

Bonham-Carter, G.F., F.P. Agterberg and D.F. Wright
1989 Weights of evidence modelling: a new approach to mapping mineral potential. In *Statistical Applications in the Earth Sciences*, edited by F. P. Agterber and G. F. Bonham-Carter. Geological Survey of Canada, Ottawa, Canada.

Bortoli, Dolores De and Pascal Palu
2009 Le système maison comme déterminant de la pérennité organisationnelle. *Revue française de gestion* 192:141-150.

Cavailles, Henri
1931 La transhumance pyrénéenne et la circulation des troupeaux dans les plaines de Gascogne. Armand Colin.

Cole, John W.
1969 Economic Alternatives in the Upper Nonsberg. *Anthropological Quarterly* 42(3):186-213.

Cole, John W.
1973 Social Process in the Italian Alps. *American Anthropologist* 75(3):765-786.

Colombaroli, Daniele, Paul D. Henne, Petra Kaltenrieder, Erika Gobet and Willy Tinner
2010 Species responses to fire, climate and human impact at tree line in the Alps as evidenced by palaeo-environmental records and a dynamic simulation model. *Journal of Ecology* 98(6):1346-1357.

Crumley, C. L.
1994 *Historical Ecology: Cultural Knowledge and Changing Landscapes*. School of American Research Press; Distributed by the University of Washington Press.

Cursente, Benoît
1998 *Des maisons et des hommes : la Gascogne médiévale (XIe-XVe siècle).* Tempus. Presses universitaires du Mirail, Toulouse.

Delcourt, P. A., H. R. Delcourt, C. R. Ison, W. E. Sharp and K. J. Gremillion
1998 Prehistoric human use of fire, the eastern agricultural complex, and appalachian oak-chestnut forests: Paleoecology of Cliff Palace pond, Kentucky. *American Antiquity* 63(2):263-278.

Dickson, Brett, John Prather, Yaguang Xu, Haydee Hampton, Ethan Aumack and Thomas Sisk
2006 Mapping the probability of large fire occurrence in northern Arizona, USA. *Landscape Ecology* 21(5):747-761.

Dilts, Thomas E., Jason S. Sibold and Franco Biondi
2009 A Weights-of-Evidence Model for Mapping the Probability of Fire Occurrence in Lincoln County, Nevada. *Annals of the Association of American Geographers* 99(4):712-727.

Durrenberger, E. Paul
1980 Chayanov's Economic Analysis in Anthropology. *Journal of Anthropological Research* 36(2):133-148.

Flatley, William T., Charles W. Lafon and Henri D. Grissino-Mayer
2011 Climatic and topographic controls on patterns of fire in the southern and central Appalachian Mountains, USA. *Landscape Ecology* 26(2):195-209.

Foster, D. R., S. Clayden, D. A. Orwig and B. Hall
2002 Oak, chestnut and fire: climatic and cultural controls of long-term forest dynamics in New England, USA. *Journal of Biogeography* 29(10-11):1359-1379.

García-González, Ricardo, Rafael Hidalgo and Catalina Montserrrat
1990 Patterns of Livestock Use in Time and Space in the Summer Ranges of the Western Pyrenees: A Case Study in the Aragon Valley. *Mountain Research and Development* 10(3):241-255.

Gómez-Ibáñez, Daniel Alexander
1975 *The Western Pyrenees : differential evolution of the French and Spanish borderland*. Oxford research studies in geography. Clarendon Press, Oxford [Eng.].

Gragson, Ted L.
2005 Time in Service to Historical Ecology. *Ecological and Environmental Anthropology* 1(1):2-9.

Guyette, R. P., R.M. Muzika and D.C. Dey
2002 Dynamics of an Anthropogenic Fire Regime. *Ecosystems* 5(5):472-486.

Guyette, R. P., M. A. Spetich and M. C. Stambaugh
2006 Historic fire regime dynamics and forcing factors in the Boston Mountains, Arkansas, USA. *Forest Ecology and Management* 234(1-3):293-304.

Heyerdahl, Emily K., Linda B. Brubaker and James K. Agee
2001 Spatial Controls of Historical Fire Regimes: A Multiscale Example from the Interior West, USA. *Ecology* 82(3):660-678.

Jenks, George F
1967 The data model concept in statistical mapping. *International yearbook of cartography* 7:186-190.

Kerby, Jay, Samuel Fuhlendorf and David Engle
2007 Landscape heterogeneity and fire behavior: scale-dependent feedback between fire and grazing processes. *Landscape Ecology* 22(4):507-516.

Kuhnholtz-Lordat, L
1939 *La terre incendiée: essai d'agronomie comparée*. Bruguier, Nimes, France.

Lefèbvre, Theodore
1928 La transhumance dans les Basses-Pyrénées. *Annales de Géographie*:35-60.

Lefèbvre, Theodore
1933 *Les Modes de Vie dans les Pyrénées Atlantiques Orientales*. Armand Colin, Paris.

Mensing, Scott A., Robert G. Elston, Gary L. Raines, Robin J. Tausch and Cheryl L. Nowak
2000 A GIS model to predict the location of fossil packrat (Neotoma) middens in central Nevada. *Western North American Naturalist* 60(2):111-120.

Métailié, Jean-Paul
1981 *Le feu pastoral dans les Pyrénées centrales : Barousse, Oueil, Larboust*. Editions du C.N.R.S., Paris.

Métailié, Jean-Paul
2006 Mountain Landscape, Pastoral Management and Traditional Practices in the Northern Pyrenees (France). In *The Conservation of Cultural Landscapes,* edited by M. Agnoletti. CAB International.

Mottet, Anne, Sylvie Ladet, Nathalie Coqué and Annick Gibon
2006 Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agriculture, Ecosystems & Environment* 114(2-4):296-310.

Mouillot, Florent, Jean-Pierre Ratte, Richard Joffre, Jose Manuel Moreno and Serge Rambal
2003 Some determinants of the spatio-temporal fire cycle in a mediterranean landscape (Corsica, France). *Landscape Ecology* 18(7):665-674.

Naveh, Z.
1975 Evolutionary Significance of Fire in Mediterranean Region. *Israel Journal of Botany* 24(1):51-52.

Netting, Robert McC
1972 Of Men and Meadows: Strategies of Alpine Land Use. *Anthropological Quarterly* 45(3):132-144.

Netting, Robert McC
1974 Agrarian Ecology. *Annual Review of Anthropology* 3:21-56.
Netting, Robert McC
1993 *Smallholders, householders : farm families and the ecology of intensive, sustainable agriculture*. Stanford University Press, Stanford, Calif.

Ninot, J. M., e. Carrillo, X. Font, J. Carreras, A. Ferre, R. M. Marsalles, I. Soriano and J. Vigo
2007 Altitude Zonation in the Pyrenees. A Geobotanic Interpretation. *Phytocoenologia* 37(3-5):371-398.

Ott, Sandra
1993 *The circle of mountains : a Basque shepherding community*. University of Nevada Press, Reno, USA.

Palu, Pascal
1992 Rapports entre organisation sociale et écosytème dans la société pastorale souletine. *Sociétés contemporaines*:239-264.

Peaucelle, Denis
1977 Analyse d'une communauté rurale basque, Larrau en Haute Soule, Département d'Etudes Rurales, Université de Paris 7, Paris.

Poli, S. and S. Sterlacchini
2007 Landslide Representation Strategies in Susceptibility Studies using Weights-of-Evidence Modeling Technique. *Natural Resources Research* 16(2):121-134.

Rhoades, Robert E. and Stephen I. Thompson
1975 Adaptive Strategies in Alpine Environments: Beyond Ecological Particularism. *American Ethnologist* 2(3):535-551.

Rica, J. P. Martinez and P. Montserrat Recoder
1990 Biogeographic Features of the Pyrenean Range. *Mountain Research and Development* 10(3):235-240.

Rius, Damien, Boris Vanniere and Didier Galop
2009 Fire Frequency and Landscape Management in the Northwestern Pyrenean Piedmont, France, Since the Early Neolithic (8000 cal BP). *The Holocene* 19(6):847-859.

Rius, Damien, Boris Vannière and Didier Galop
2012 Holocene history of fire, vegetation and land use from the central Pyrenees (France). *Quaternary Research* 77(1):54-64.

Romero-Calcerrada, Raul, C. Novillo, J. Millington and I. Gomez-Jimenez
2008 GIS analysis of spatial patterns of human-caused wildfire ignition risk in the SW of Madrid (Central Spain). *Landscape Ecology* 23(3):341-354.

Roura-Pascual, N., P. Pons, M. Etienne and B. Lambert
2005 Transformation of a rural landscape in the Eastern Pyrenees between 1953 and 2000. *Mountain Research and Development* 25(3):252-261.

Russell, Emily W. B.
1997 *People and Land Through Time: Linking Ecology and History*. Yale University Press, New Haven.

Santana, Victor M., M. Jaime Baeza and Rob H. Marrs
2012 Response of woody and herbaceous fuel to repeated fires in Mediterranean gorse shrublands. *International Journal of Wildland Fire*:-.

Sawatzky, D.L., G.L. Raines, G.F. Bonham-Carter and C.G. Looney
2009 Spatial Data Modeller (SDM): ArcMAP 9.3 geoprocessing tools for spatial data modelling using weights of evidence, logistic regression, fuzzy logic and neural networks, http://arcscripts.esri.com/details.asp?dbid=15341.

Sigaut, Francois

1975 *L'agriculture et le feu: rôle et place du feu dans les techniques de préparartion du champ de l'ancienne agriculture Européenne*. Mouton and Co., Paris.

Tinner, W., M. Conedera, B. Ammann and A. F. Lotter

2005 Fire ecology north and south of the Alps since the last ice age. *Holocene* 15(8):1214-1226.

Tinner, Willy, Priska Hubschmid, Michael Wehrli, Brigitta Ammann and Marco Conedera

1999 Long-term forest fire ecology and dynamics in southern Switzerland. *Journal of Ecology* 87(2):273-289.

Trabaud, Loius

1981 Effects of Past and Present Fire on the Vegetation of the French Mediterranean Region. Paper presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, San Diego, California.

Vanniere, B., D. Colombaroli, E. Chapron, A. Leroux, W. Tinner and M. Magny

2008 Climate versus human-driven fire regimes in Mediterranean landscapes: the Holocene record of Lago dell'Accesa (Tuscany, Italy). *Quaternary Science Reviews* 27(11-12):1181-1196.

Vicente-Serrano, S. M., T. Lasanta and A. Romo

2004 Analysis of spatial and temporal evolution of vegetation cover in the Spanish Central Pyrenees: Role of human management. *Environmental Management* 34(6):802-818.

Welch-Devine, Meridith

2010 Local Places, Global Influences: Pastoralism in Xberoa and EU Regulation. In *Social and Ecological History of the Pyrenees: State, Market, and Landscape,* edited by I. Vaccaro and O. Beltran. Left Coast Press, Walnut Creek, Ca.

White, PS and STA Pickett

1985 *Natural disturbance and patch dynamics: an introduction*. Academic Press, San Diego, California.

CHAPTER 5

HOUSEHOLD ABANDONMENT, SOCIOECONOMIC CHANGE, AND LANDSCAPE TRANSITION IN THE FRENCH WESTERN PYRENEES (*PAYS BASQUE*), 1830-1958: A PARCEL LEVEL EVENT-HISTORY ANALYSIS.[4]

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Abstract

Landscape transition poses a challenge to the sustainable conservation and management of mountain landscapes. In the Pyrenees, aerial photos from the late 1940s onward show the transition of former agropastoral landscape mosaics to homogenous shrub and woodlands with diminished cultural and ecological value. Yet knowledge concerning the interplay of individual households and land use change remains rudimentary for the period leading up to the 1940s. In order to contribute to a better understanding of the historical processes of landscape transitions, this paper examines the local processes of household abandonment and socioeconomic change that set the stage for transitions apparent over the last 60 years. We analyze the effects of socioeconomic and demographic factors contributing to changes in parcel level land use and ownership, in a Pyrenean Mountain village from 1830 to 1958. We use a parcel level event-history analysis to examine how individual households influenced both the pace and character of landscape transition through their internal composition and their mediation of market pressures. Our analysis suggests that earlier and more severe "abandonment" of the landscape was prevented by households that were able to both engage in markets and maintain higher fertility rates.

Résumé

La transition entre les paysages pose un problème à la conservation durable et la gestion de la terre des paysages de montagne. Dans les Pyrénées, des photographies aériennes de fin des années 40 en avant démontrent la transition de mosaïques précédents des paysages agropastoraux aux arbustes et aux bois homogènes avec une valeur culturale et écologique inférieur. Afin de contribuer à une meilleure *compréhension des processus historiques des transitions entre les paysages, cet article examine les processus locales de l'abandonnément des maisons et de la change socioéconomique qui a préparé le terrain pour les transitions apparentes pendant les dernières 60 années. On analyse les effets des facteurs socioéconomiques et démographiques qui contribuent aux changes de l'usage de terre au niveau de parcelle et de propriété, dans un village Pyrénéen de l'année 1830 à l'année 1958. On utilise une analyse des événements historiques au niveau de parcelle pour examiner comment les maisons individuelles ont influencé même tous les deux la vitesse et le caractère de la transition de paysage à travers leur composition interne et la médiation des influences du commerce. Notre analyse suggère que l' « abandonnément » du paysage plus tôt et plus sévère était prévenu par des maisons qui pouvait tous les deux participer du commerce et soutenir des taux de fertilité plus hauts.*

What we call land is an element of nature inextricably interwoven with man's institutions. Polanyi (1957:178).

Introduction

The second half of the 20th century witnessed the relatively rapid disintegration of traditional smallholder farming systems in a variety of mountainous landscapes in Europe (MacDonald, et al. 2000). In the Pyrenees Mountains, these changes resulted in significant shrub and forest encroachment of landscapes formerly characterized by a diverse and manicured patchwork of agropastoral land uses (Gibon, et al. 2010; Métailié 2006; Pasche, et al. 2004; Roura-Pascual, et al. 2005; Vicente-Serrano, et al. 2004). This phenomenon of landscape transition is part of a larger, global trend of systemically linked demographic, agricultural, and forest “transitions”. These transitions involve increases in population, land use intensification, and forest depletion followed by population decline, agricultural abandonment, and reforestation of marginally productive areas (Lambin and Meyfroidt 2010; Mather and Needle 2000; Rudel 1998; Rudel, et al. 2010).

In the specific case of the Pyrenees, where landscapes represent the vestiges of millennial land use systems, research suggests that the period most crucial to the current trajectory of agricultural abandonment and landscape change began in the late 1940s and accelerated in the 1960s (Métailié 2006; Mottet, et al. 2006; Puigdefabregas and Fillat 1986). Referencing the mid-20th century France “rural crisis” (Champagne 2002; Scargill 1994), conventional narratives portray demographic and socioeconomic changes as mostly insignificant for the landscape until after World War II (ca. 1945). However, with few exceptions (Agnoletti 2007; Bender, et al. 2005), landscape scale studies of land use and change in Europe have been limited to the era of aerial photo documentation (ca. late 1940s). Moreover, knowledge concerning the interplay of individual households and land use change remains rudimentary for the historic period.

The research presented here examines the socioecological dynamics of agricultural transition and landscape change for the period 1830 to 1958 in a low density farming neighborhood (*quartier, Fr.*) of an agropastoral village in the Basque portion of the French Western Pyrenees. Today farms are most numerous in the western part of the Pyrenees (Pyrénées-Atlantiques) (Métailié 2006) and the village investigated in this study retains a relatively high density of smallholder farms (25 as of 2011) in comparison to neighboring villages. Yet between 1830 and 1958, the *quartier* investigated experienced both household abandonments and changes in patterns of parcel ownership. Landscape transition may not always be a uniform, monolithic, or rapid process readily observed in the aerial photo archive. Rather, the transitions visible in aerial photos represent latent effects of socioecological processes such as changes in household land use and ownership that occurred in the past, perhaps over the course of several generations (Gellrich and Zimmermann 2007). The task of this paper is to account for the socioecological processes that set the stage for the more recent phase of landscape transition.

Analysis combined annual resolution, parcel level land use and ownership data with household level demographic information with the goal of quantifying associations between parcel level landscape transition and the long term socioeconomic strategies of individual households. With the aid of a relational database, we reconstructed parcel level land use, land ownership patterns, and demography for households for 128 years in the sample *quartier*. We used multivariate event-history analysis (Allison 1984) to examine two interlinked transformation processes: change in parcel level land use intensity (extensification) and the abandonment of stem-family households.

Landscape Transition and the Industrialization Hypothesis

Studies taking a broad view of landscape transition suggest that transitions are primarily driven by "exogenous" forces defined broadly as "innovations that originate outside the boundaries of the local system" (Lambin and Meyfroidt 2010:116). For mountainous areas in Western Europe, scholars identify global socioeconomic processes as driving forces responsible for landscape change by causing a decline in rural populations, agricultural intensification (capitalization), and engagement with non-local labor markets (Benayas, et al. 2007; Lambin, et al. 2001; MacDonald, et al. 2000). These explanations are formally tied to the idea of forest transition as the "industrialization hypothesis" (Rudel 1998). They stem from a synthesis of Polanyi's (1957) concept of "the great transformation," demographic transition theory (Davis 1945), and concepts of land rent from central place theory (von Thünen and Hall 1966) and neoclassical economics (Ricardo 1891).

The industrialization hypothesis states that industrialization of regional urban centers simultaneously transforms labor markets, fertility patterns, and the relative economic advantage of using agricultural lands (land rents) according to distance to market and quality of land. In the final stage of the industrialization hypothesis, official agricultural policies and incentives that promote "modernization" facilitate transitions to a mechanized and capital intensive agricultural regime (Buller 1992). These factors accelerate land use changes through their "artificial" effects on both labor markets and land rents.

Farm Labor

Demand for workers by growing industries in cities provided economic incentive for rural residents to emigrate. This new market for labor decreased incentives to farm, since payoffs were greater for off-farm work (Cole 1969; Friedl 1972). Scholars propose a wide variety of hypotheses for the decline in fertility ranging from women's status and participation in the labor market to the economic burden of children as educational opportunities increase (Caldwell 1980; Schultz 1985; Shorter 1973). Regardless of the specific causes of fertility decline, most agree that the decline can be attributed to socioeconomic transitions tied to the industrialization process. In combination with off-farm employment opportunities, declining fertility constrained the availability of farm labor, forcing the abandonment of certain lands or land uses.

Land Rent

The concept of “land rent” refers to the net economic benefits derived from the use of land after deducting labor, costs of management, and the interest on capital inputs (von Thünen and Hall 1966). The concept holds labor and capital inputs (material improvements) constant for a particular land use but allows that the quality of the parcel itself varies by location as a result of its biophysical attributes. The market price for farm produce ultimately controls the amount of land rent since labor, capital, and interest on capital remains externally fixed. If capital investments are immobile (infrastructure) and the interest rate continues to allow for profits, use of the land continues when market prices drop. With falling market prices, it is possible for the land rent to become negative. However, land owners will curtail new investments as infrastructure degrades and abandonment will ensue once the parcel no longer produces profits.

Since land can be used for multiple purposes, the definition of land rent in neoclassical economics terms concerns the economic benefits derived from land put to its most optimal use (Ricardo 1891). As growing markets and infrastructure shift land rents, the most distant and marginally productive lands shift toward uses requiring less material and labor investment (extensive uses) until they are abandoned (Gellrich and Zimmermann 2007; Prishchepov, et al. 2013).

Nevertheless, in socioecological systems organized around traditional smallholder agricultural production, individual households produce the demographic conditions and make economic decisions responsible for local patterns of land use and change (Mottet, et al. 2006; Netting 1993; Perz, et al. 2006). Further, landscape transition is often influenced by spatially and historically contingent human-environment interaction (Foster 1992;

Foster, et al. 2003; Gragson and Bolstad 2006). The mediation of local institutional contexts and historical and spatial contingencies each contribute to the differential onset, intensity, and scale of landscape transition at the local level (Gragson 2008).

The Institutional Context: Households and Socioeconomic Strategies

Historical documents evidence stem-family households as the key component of Pyrenean social organization below the village level from the late medieval period onward (Bortoli and Palu 2009; Zink 1997). The stem-family institution (Le Play 1871) was historically common in southwestern France and figures prominently in the characterization of Western Pyrenean society (Bourdieu 1962; Douglass 1988; Parish and Schwartz 1972; Zink 1969). The *Etxe* or Basque household follows the stem-family pattern but as a spatially fixed, formal institution, it is conceptually independent from "family" in the Basque culture (Ott 1993). The *Etxe* could technically be abandoned while the family continued. Similarly the stem-family bloodline could "dead end" and the *Etxe* could continue, usually by attracting a niece or nephew as an heir (Arrizabalaga 1997).

Customarily, *Etxe* inheritance practices followed primogeniture and impartibility of the household estate among heirs (Arrizabalaga 2005; Bortoli and Palu 2009; Gómez-Ibáñez 1975). This inheritance custom entitled the eldest child, regardless of gender, to the entire estate and the right to form a family. The inheritor's younger siblings had the right to stay on as productive household members, but remained celibate and were ultimately beholden to the decisions of the inheritor (Arrizabalaga 1997). These rules did not simply ensure a place for younger siblings, but were integral to the sustainability of the farm unit which relied on the labor of subordinate siblings (*cadets* and *cadettes, Fr.*).

The household structured land use through its command and control over labor, access to land, and other material assets. In this sense the *Etxe* represented a cultural adaptation to the spatial patterning and seasonal rhythms of the biophysical environment (Cunchinabe, et al. 2011; Ott 1993; Palu 1992).

Although the *Etxe* provided an enduring solution to subsistence in a relatively harsh environment, households were not static. Variability in available labor and economic demand tracked the rhythms of the family life cycle. Through marriages, births, deaths, and the aging processes of individuals, each stage along the family life cycle exhibited a different generational composition and thus different capacities for work and consumption. Based on initial work of A.V. Chayanov, these variations are thought to impact the intensity of household production through variability in the ratio between consumers (children and elderly) and producers over time (C/P) (Berkner 1972; Chayanov 1986; Durrenberger 1980; Foster 1978; Perz 2001; Sahlins 1971).

Chayanov argued that nuclear family households practicing subsistence agriculture did not operate according to the rules of neoclassical economic theory (i.e. as maximizing capitalists) because they based their labor efforts on the consumptive needs of the family. Farmers worked hard enough to meet their needs at the time and no more; they were “satisficing” rather than maximizing (Simon 1959). Despite its attractiveness for explaining the seemingly irrational economic behavior of “peasant” farmers (Sahlins 1971; Wolf 1966), anthropologists have had difficulty operationalizing and empirically testing Chayanov’s theory (Hedican 2009). Recent work suggests that the effects of consumer-producer dynamics were buffered in contexts with extended household institutions and where inter-household cooperation was an important component of the traditional agricultural system (Hammel 2005). These are dominant characteristics of the traditional Basque *Etxe* agricultural system (Ott 1993). Yet, paying attention to the C/P and to other aspects of the family life cycle may shed light on household decision-making (Hammel 2005), especially under the numerous novel conditions with which farmers interacted during the "great transition."

Research Questions

The main question guiding this analysis asks how *Etxe* individually contributed to landscape transition at the parcel level. The industrialization hypothesis relies on the idea that household heads consistently make rational, profit maximizing decisions. Parcel extensification and household abandonment should therefore result from decisions to optimize production. Yet the cultural values embodied in the *Etxe* institution combined with the Chayanovian forces operating within the household suggest that the socioeconomic strategies of Basque households reflect a more complex situation.

We designed the analysis to answer three specific questions: (1) Did the demographic and socioeconomic strategies (including abandonment) of individual households influence the pace and character of landscape transition in terms of parcel-level extensification between 1830 and 1958? (2) Do factors influencing parcel-level extensification reflect market "controls" specifically with respect to presumed shifts in "land rents"? (3) Did the varying demographic composition of households contribute to the persistence and abandonment of traditional *Etxe* land use? Answering these questions may help to refine our understanding of the process of transition itself.

Study Area

The Pyrenees Mountains follow an east-west orientation forming the divide between France and Spain. The study area is located in the commune of Larrau (Figure 5.1.), a small village on the French side of the French-Spanish border (43° 1′ 10.92″ N, 0° 57′ 15.84″ W). The village territory consists of the western half of the headwaters of the Saison River, in the ancient province of Soule. Elevations range from 300 to 2000 meters above sea level (msl). The climate is cool and humid with precipitation averaging 1600 mm per year and temperatures ranging from an average of 1.4° Celsius in winter to 13.3° Celsius in summer (average 1956-2010, weather station located at 1300 msl). Oak (*Quercus* sp.) dominates forests below 800 msl, transitioning to beech (*Fagus sylvatica*) and fir (*Abies alba*) from 800 to 1300 msl. Alpine and subalpine grasslands and heaths with patches of mixed conifer dominate elevations above 1300 msl (Gómez-Ibáñez 1975; Ninot, et al. 2007).

The area is culturally Basque. Inhabitants are bilingual (Basque and French) but continue to speak the local Basque dialect, *Souletin*, as the primary language of day-to-day interaction. The population is around 200 people, down from a maximum of 1300 in 1856. For the vast majority of its history, subsistence agriculture was the dominant economic activity. However, the village had iron mines and substantial ironworks from at least 1730 to about 1865. At its peak the operation employed up to 600 workers and created a substantial market for charcoal (Peaucelle 1977). It is difficult to imagine that such a large workforce had no impact on commercial demand for produce from local farms. In 1902, the Roquefort cheese company opened a factory in nearby Tardets (approx. 17km distance) (Lefèbvre 1933). This created the first substantial commercial market for ewe's milk in the upper Soule valley.

Today the economy continues to be rural but with a growing tourism sector. Many residents commute to jobs in larger towns down valley. As of 2011, there were 25 households farming in the village. Crops are no longer planted, but haying continues and farming activity is focused on livestock. Farmers primarily raise sheep, cattle, and horses. Sheep provide lambs for meat and milk for both commercial and household cheese production. Since the mid-1970s, there is a growing emphasis on commercial veal production, a practice encouraged by government subsidies.

The landscape can be divided into a set of hierarchically organized socially and ecologically significant spatial units: valley, commune (a village and its territory), *quartier* (a neighborhood), household, and parcel. Consequently, a valley is comprised of many communes, a commune is comprised of several neighborhoods, a neighborhood consists of a number of adjacent household landholdings, and a household's landholdings consist of a set of discrete land management units called parcels. Official cadastral parcelization for taxation purposes began in 1830. Since that time, annual cadastral accounting has systematically preserved the record of usufruct relationships of specific households to specific parcels.

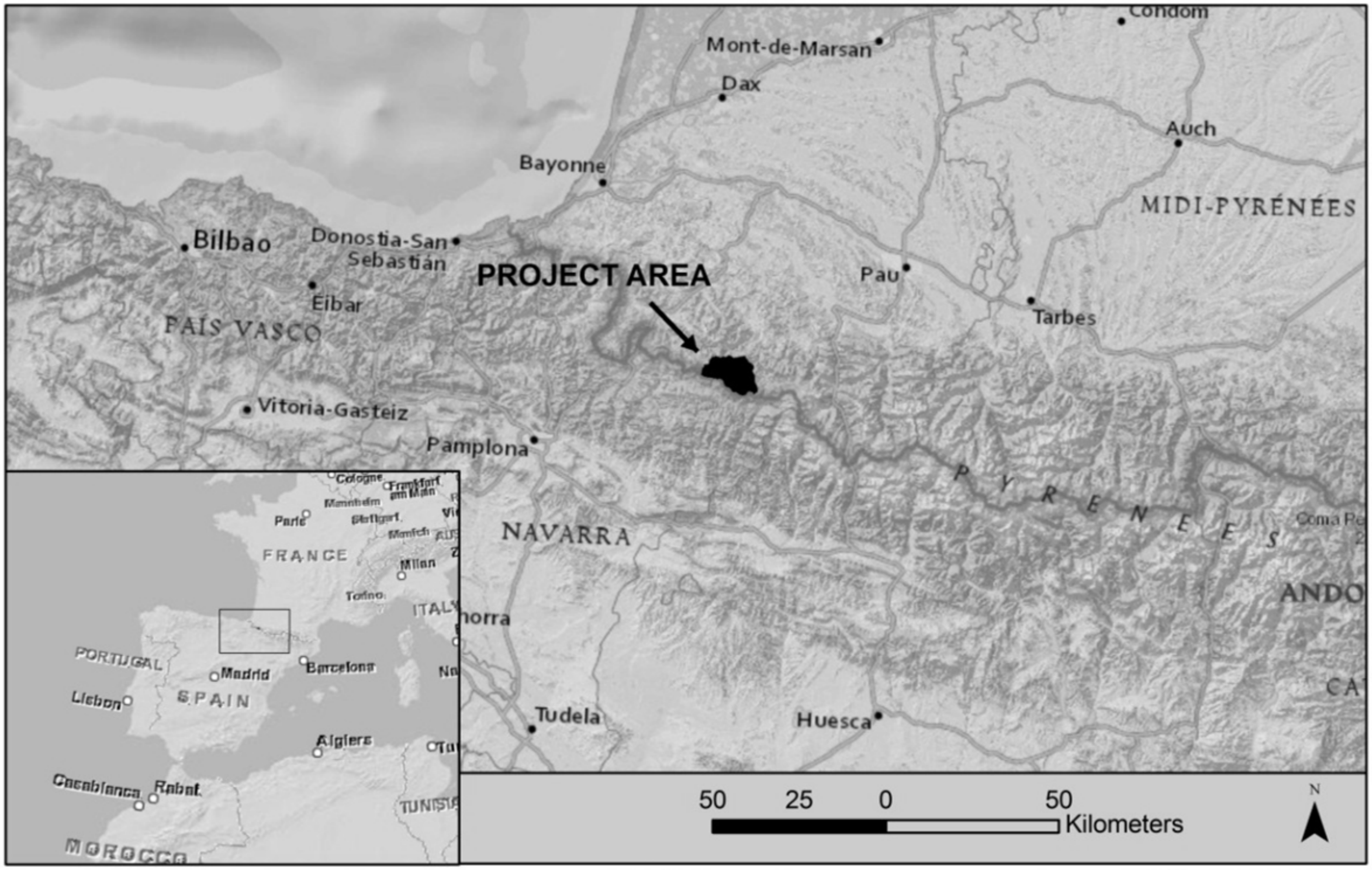

Figure 5.1. Map of project area. Cartography, Author. Imagery courtesy of ESRI, Inc. under creative commons licenses CC By-NC-SA 3.0.

Traditional Land Use

Climatic and topographic constraints played a significant role in the temporal and spatial distribution of land use and tenure for mountain agropastoralists (Burns 1961; Cole 1972; Netting 1972; Rhoades and Thompson 1975). In mountains, the quality of land is extremely variable across space and land suitable for raising crops is relatively scarce. Private households monopolized crop fields, hay meadows, and other areas of high production value. In Larrau, crop fields and hay meadows were located in less steep, well watered, low- to mid-elevation areas (300-800 msl). Availability of these areas was limited and relatively fragmented. For example, in 1830, crop fields averaged 0.34 ha while hay meadows were slightly larger averaging 0.53 ha.

Until the late 1600s, Pyrenean households grew wheat, oats, rye, and millet (Gómez-Ibáñez 1975). By the 1700s, New World maize supplanted millet and ushered in a new two course schedule that opened up infields for winter pastures (Gómez-Ibáñez 1975). Maize was used to make flat bread (*Mestura, Bsq.*) in special ovens attached to the exterior house (Ott 1993). Households also adopted potatoes, which they grew on steeper slopes, but not extensively. In 1927, for example, households in the commune cultivated a total of 10 ha of potatoes at a yield of 800 kg/ha, 2 ha of beans at 100 kg/ha (planted “in the maize”), 1 ha of barley at 300 kg/ha, 50 ha of wheat at 500 kg/ha (plus straw), and 50 ha of maize at 400 kg/ha. However, plantings and yields varied year to year. By 1937, land devoted to potatoes increased to 14 ha, beans to 10 ha, and reported yields increased: wheat to 1000 kg/ha plus 1200 kg of straw/ha and maize to 1100 kg/ha. During this same time span, the number of motorized harvesters (*Batteuses, fr.*) in the commune went from 0 in 1927 to 5 in 1937.

Hay meadows continue to form an important part of the farming system. Households harvest hay twice yearly, in early and mid- to late summer. Weather permitting, farmers graze livestock in the meadows during the fall and winter but generally rotate them from field to field to prevent overgrazing. Hay produced is fairly consistent from year to year, but droughts occasionally impact yields. Livestock consumption of hay varies due to winter temperatures and variability in length of the stalling season. In the past, if hay stocks fell short, households supplemented the hay with leaf fodder from cultivated chestnut stands, ash and beech hedge rows, and from special coppice woodlots called *taillies* (Cunchinabe, et al. 2011; Métailié 2006). Today, supplemental hay is purchased commercially.

Bracken fern (*Pteridium aquilinum)* meadow constitutes another category of private land use. Although the practice continues, it is on a much smaller scale than previous years. Farmers harvest bracken fern in the fall, cutting it like hay and stacking it on poles to dry. In late fall and winter, the meadows are used as pasture and the bracken serves as bedding in the barn. In the spring, the soiled bracken is mucked out for manure and used as fertilizer on hay meadows and formerly, on crop fields (Palu 1992).

Lands less amenable to intensive uses served as pasture and woodland. Larger, higher elevation pastures and woodlands were communally owned, their management subject to customary regulations. These lands nevertheless played a large role in household subsistence due to the practices of seasonal transhumance and of free ranging pigs in the forests (Palu 1992). Transhumance involves the seasonal movement of livestock between pastures in response to the seasonal availability of forage (Rinschede 1988). In the Western Pyrenees both seasonal patterns and distances traveled varied by village, but the general pattern involved the movement of animals to communal high mountain pastures in summer (May – September) and barn stabling in winter or long distance movement to pastures in the lowlands (Cavailles 1931; Gómez-Ibáñez 1977; Lefèbvre 1928). In Soule, the herds were dominated by sheep, but cows and pigs were also herded to higher pastures in summer (Ott 1993). Shepherds accompanied the animals to the distant pastures while the rest of the family remained on the farm.

By the 1920s, farmers in Larrau no longer practiced the long distance winter transhumance, except in cases of drought or severe winter, where they used pastures immediately down the valley (Lefèbvre 1928). During this period, neighboring villages, even at lower elevations, continued to practice long distance transhumance in order to feed their animals during the lean winter months. Lefèbvre (1928) hypothesizes that farmers in Larrau compensated for the lost forage through the development of haying fields, which he suggests represented a relatively recent intensification of land formerly dedicated to pasture. He also notes that herds in Larrau were not nearly as large as those of neighboring villages, enabling them to house and stall-feed the animals in winter. At the same time, winter stalling became increasingly important to farmers after the installation of the Roquefort factory, since stalling enabled the sale of ewe's milk through the winter.

Settlement Patterns

The 1830 cadastral map of Larrau reveals two general types of landholding patterns: (type 1) households "*au bourg*" (in village) that exhibit a clustered residential pattern, and (type 2) households "*section borde*" (farm neighborhoods) that exhibit a dispersed residential pattern (Figure 5.2). In both types of settlement patterns, the physical house was generally attached to a barn and in close proximity to one or more kitchen gardens, barn yards, and occasionally, small vineyards and orchards. Following the legacy of the open field system of the feudal abbey, type 1 households held strips of plow land (*labour, fr.)* adjacent to the village. For type 2 households, plow lands were distributed around the house and barnyards according to topographic suitability. In other respects, land use and tenure was very similar between the two household types with the exception that type 1 households tended to exhibit a more fragmented pattern, owning and using land in more than one *quartier* at a time.

The *borde* “section” begins outside the concentrated *bourg* and “open fields”. This section is characterized by type 2 households and dispersed, non-residential farm properties called *borde bordaar (borde)* (Cunchinabe, et al. 2011). *Borde* consisted of one or two barns, hay and bracken meadows and occasionally crop fields, all used as fall and winter pasture. *Bordes* often also included a small cabin for temporary accommodations, fallow land, coppice woodlots, and chestnut groves. Nomenclature, location, and the physical layout of type 2 households suggests that at least some of these originated as *borde* and evolved into full-fledged households as village populations expanded and land use intensified (Champagne and Le Couedic 2012).

Higher up, above approximately 900 msl, the *Olhaltia* begins (Cunchinabe, et al. 2011). This area is comprised of communal landholdings used for grazing and wood collection. The Olhaltia also contains small collectively owned “inholdings” that comprise the cabin and milking grounds of the traditional grazing cooperatives known as *Olha* institutions (Ott 1993).

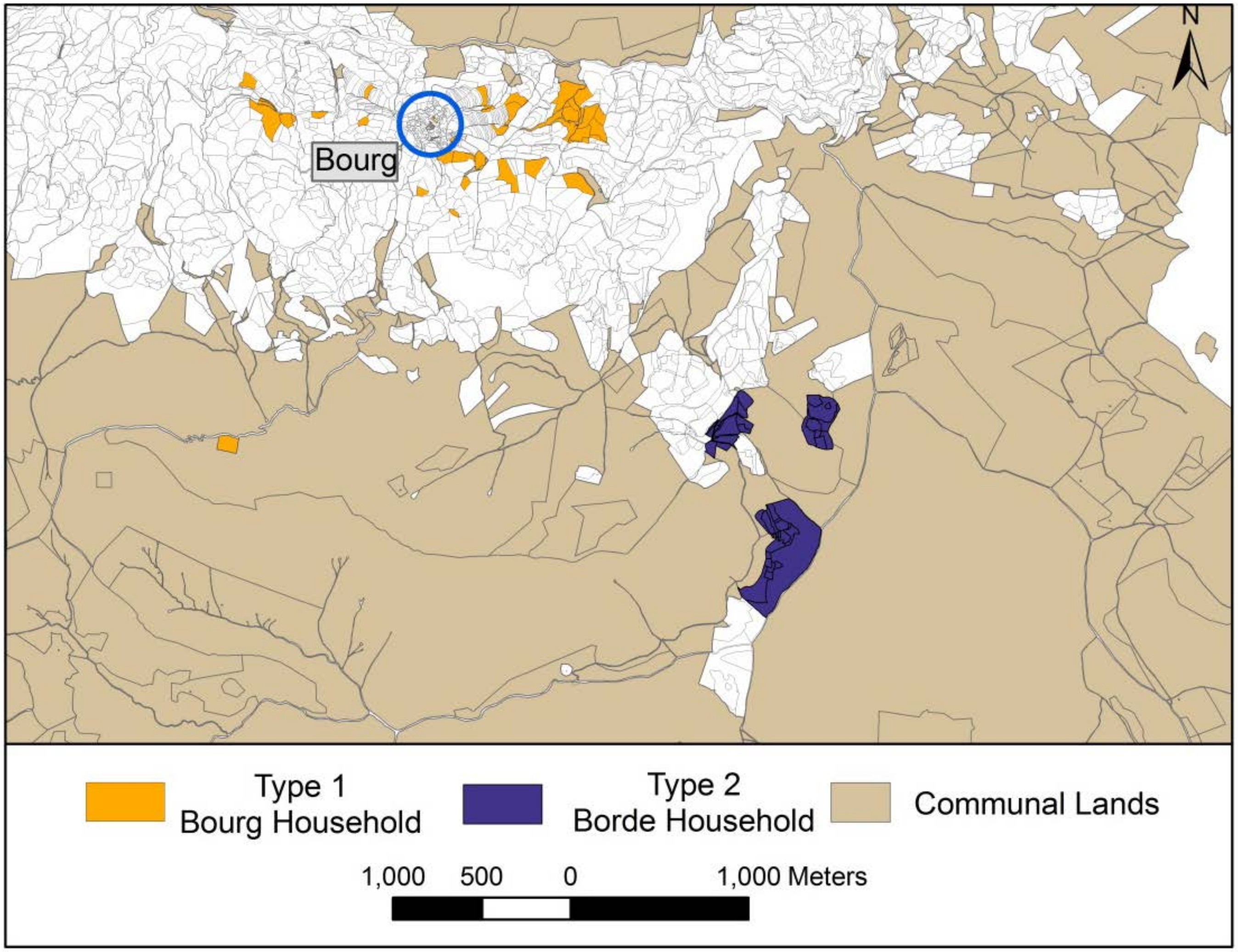

Figure 5.2. Household settlement patterns.

Methods

Data Sets

We made photographic copies of all historical documents for this analysis from communal and departmental archives in France[5]. We obtained birth abstracts from the original bound copies of the *État Civil, extract de naissance* (1793-1949), an official registry of births, deaths, and marriages. Original ledgers of cadastral records provided recorded changes in ownership and land use for all parcels in the commune for the years 1830 through 1957. As a companion to the parcel records, we obtained a shape file version of the cadastral base-map from digitally-scanned copies of the 1830 land survey map.

We maximized efficiency in the construction of our demographic variables by focusing on birth abstracts alone. We extracted information pertaining to birth name, date, and household as well as parent names, ages, and professions from the abstracts. We cross validated this information with the owners' names in the cadastral data and with voter registration records for government and chamber of agriculture elections. Birth records were entered into a relational database and tied to cadastral records through the household. This was a fairly straightforward process even where household names were lacking, since the *Etxe* institution accommodated no more than two conjugal couples at a time; one in a reproductive phase and one in a post-reproductive phase (Arrizabalaga 1997). Birth abstracts for households examined in this study show that between 1793 and 1949 at least 23 children were born either to female wage workers boarding in the

[5] *Archives Communales de Larrau* and *Archives du Département de Pyrénées Atlantiques*

household or to *cadettes*. However, these births were either isolated occurrences or led to marriage and neolocal residence of the parents and child.

Tabular data in the cadastral records were organized and indexed by land owner “portfolios” containing all of the parcels owned by an individual. Parcel attributes and attribute changes including area, taxable land use category, tax, and place name were listed in the portfolio. Sales were indicated with the date and the portfolio number indexing the following owner. Purchases were indicated as new entries along with the date of purchase and the portfolio number indexing the previous owner. Inheritors of each portfolio were listed under the original owner’s name along with the date of inheritance. Portfolios of parcels therefore provided two forms of network information: (1) between portfolio exchange networks, and (2) among portfolio inheritance networks.

Owner portfolios were roughly equivalent to household estates with a few caveats: (1) portfolios consisting of properties jointly owned between 2 or more households, and (2) some households held more than one portfolio at a time, possibly as a strategy for circumventing inheritance law requiring the equitable partitioning of the estate among heirs (Arrizabalaga 2005). For the sake of simplicity, we excluded parcels that met the first condition. We accounted for this second condition by using inferred “household” rather than individual portfolios to track parcel ownership changes.

Sampling

We selected a spatially contiguous portion of a first-order watershed representing one of 6 *quartiers* within the village territory (Figure 5.3). The sample landscape (*quartier* A) consists of approximately 725 hectares (ha) ranging from 400 to 1300 msl. Q*uartier* A comprises a west to east trending ridge and is circumscribed on its north and southeastern sides by deeply incised gorges. The western boundary is defined by first order streams and “artificially” by parcel boundaries that mark the *de facto* border between landholdings by owners residing in the neighboring *quartier*.

We followed the parcel ownership and attribute history of all households owning parcels within *quartier* A for the entire 1830 - 1958 period. This entailed the inclusion of parcels outside of the *quartier* if they were owned by households owning a parcel in the sample area. If a household divested itself of all parcels within the *quartier*, we dropped the household out of the study. We designed a recursive, relational database to facilitate data entry and reconstitution of parcel ownership and attributes for each year. This sampling process resulted in a shifting number of parcels and households within the sample itself (Figure 5.4.). Parcels shifted in and out as a result of transfer (presumably purchase and sale) between households owning and those not owning parcels within the sample landscape. This enabled us to examine parcel history within the *quartier* without losing track of the total size and diversity of households owning them. Thus if a household only owned 2 parcels within q*uartier* A, we nonetheless have the complete parcel-level profile of that household.

For the demographic data, we selected all households whose principal landholdings, including the house itself, were found within *quartier* A. This process allowed us to examine the parcel level effects of internal household dynamics on household abandonment while at the same time maintaining focus on the sample landscape. We thus maximized our understanding of household-landscape interaction. In other words, we can more confidently link a household within the demographic sample to a coherent and physically contiguous landscape.

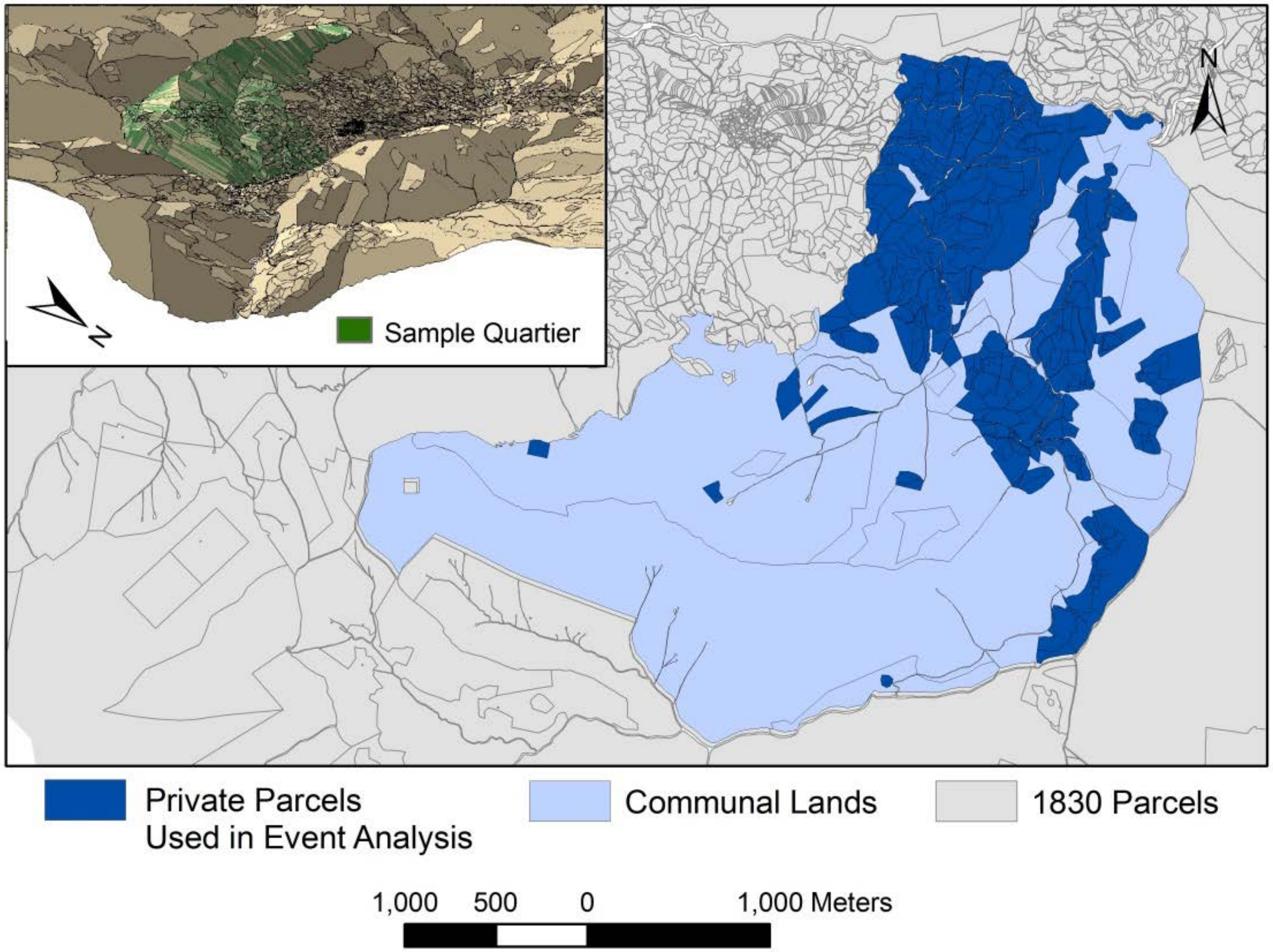

Figure 5.3. Sample *quartier* (blue shades) showing the privately owned parcels included in the event analysis. 3d view of sample *quartier* shown in upper left cutout.

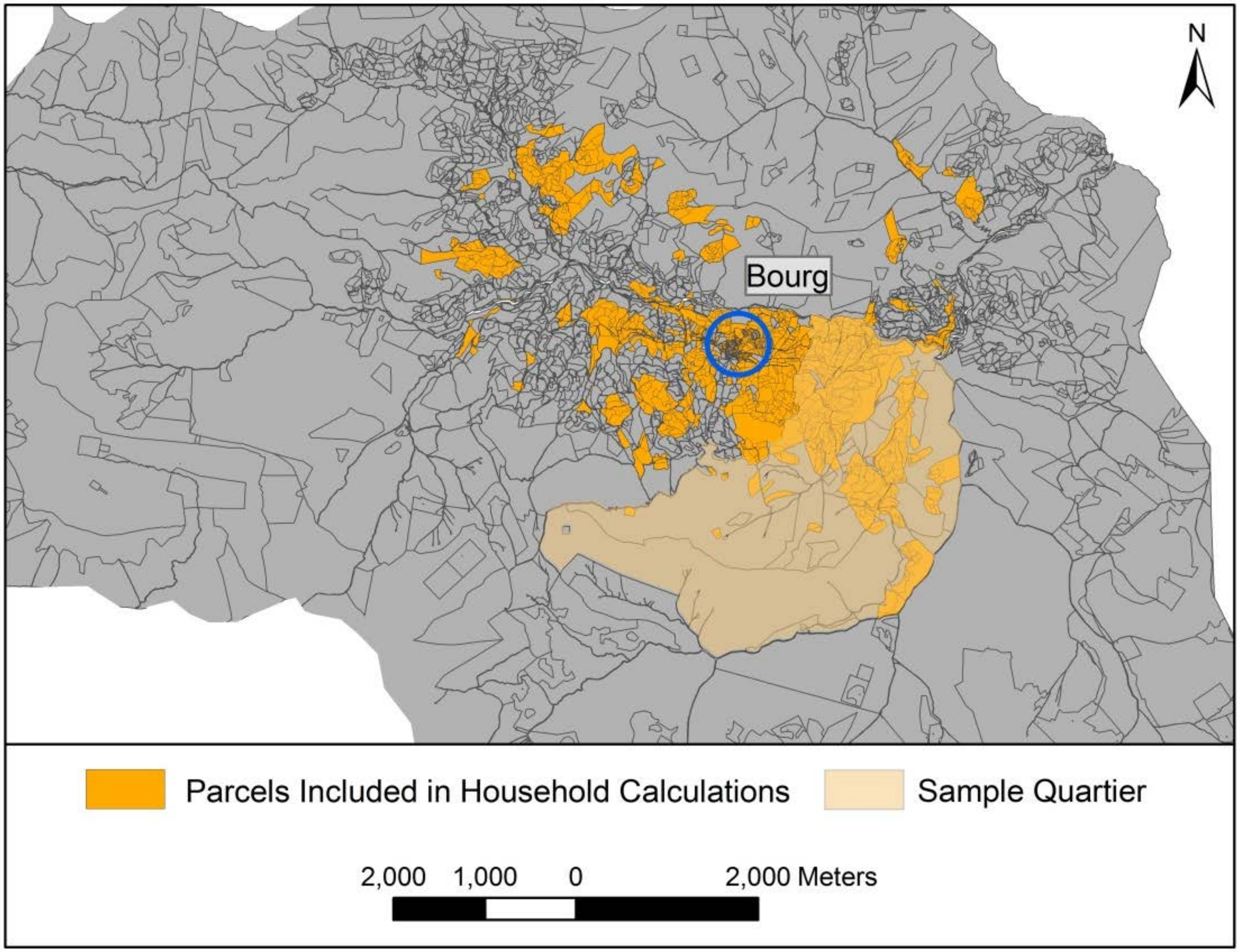

Figure 5.4. Parcels owned by households owning parcels within the sample *quartier*.

Event Analysis

As a type of survival analysis, event analysis examines the “hazard” of an event occurring as a function of the duration of time leading up to that event. For this analysis, we chose Cox proportional hazards models (Cox models) (Cox 1972). The goal was to explore positive and negative associations between selected covariates and the rate of (1) parcel “extensification” and (2) household “abandonment” events. The Cox models are well suited to this analysis as they have been successfully applied to related studies of residential land use change (Bell and Irwin 2002; Irwin and Bockstael 2002) and landscape settlement abandonment (Jones and Wood 2012). Cox models can account for subjects that do not experience the event, such as households that were not abandoned. These “survivors” constitute “right censored” data (Fisher and Lin 1999). The models also accommodate continuous, time varying covariates (TVC) (Allison 1984; Fisher and Lin 1999). TVC, such as the size of demographic cohorts within individual households, are paramount for assessing the effects of the internal dynamics of households on failure events.

For fixed time covariates the Cox proportional model is expressed:

$$\text{Log } h_i\ (t) = a\ (t) + \beta_1 x_{i1} + \ldots + B_k x_{ik}$$

Where a (t) is survival time in years, β_1 through β_k are coefficients, for x_1 through x_k covariates. And for TVC, the Cox extended model is expressed where one or more covariates interact with (t):

$$\text{Log } h_i\ (t) = a\ (t) + \beta_1 x_{i1} + \ldots + B_2 x_{i2}(t)$$

Parcel Extensification and Household Abandonment Criteria

Landscape abandonment in smallholder socioecological systems comprises two processes: (1) extensification or abandonment of land use at the parcel level and (2) failure of discrete units of socioecological organization, i.e. household abandonment. Extensification concerns a decrease in extractive pressures and material or labor inputs to land. In the context investigated here, extensification represents a diffusion of management activities and extractive pressures across the landscape. This diffusion was caused by an increase in individual households' landholdings without concomitant and proportional increases in the number of people or livestock per household.

The expansion of landholdings entailed extensification of land use under both market- and subsistence-based strategies. For households practicing the subsistence strategy, we assume that after crossing a certain threshold in size, traditionally structured households lacked the work capacity or provisioning demands necessary to maintain labor intensive land uses in newly acquired parcels. If expanding households allowed for the increase of livestock, they were still likely to convert intensive lands to more extensive uses. For example, newly obtained crop lands would be converted to hay or bracken meadow, which require less labor investment, but enable the expansion of livestock.

If households augment work capacity by hiring laborers, they are no longer practicing "subsistence" agriculture and must be obtaining capital or trading produce at an advantage in order to pay for the labor. Hiring of labor indicates a shift in the orientation of household production away from family provisioning toward markets and profit maximizing behavior. Under market strategies, household land use is subject to both market control of labor price and land rent. According to central place theory, mountainous areas are peripheral to markets and therefore optimally lend themselves more to "extensive" uses (von Thünen and Hall 1966).

Parcel level extensification is systemically linked with household abandonment, but it is not operationally the same phenomenon. As households "fail," extant households gain access to the parcels of the failed households. Household failure thus causes a net increase in land available for use by remaining households. However, abandonment is not a prerequisite for households to sell one or more parcels to a household already exceeding the normal range of variability for a farm size. Further, some households failed after "extensifying," according to the definition used here. Therefore we treat extensification and abandonment in two separate analyses.

We used three criteria to classify parcel use as "extensive": (1) sale of the parcel to a household whose landholdings exceeded the "normal" range of variability for a stem family farm in 1830 (> 20.615 ha), (2) the parcel belonged to a farm at the time that it exceeded 20.615 ha, and (3) the abandonment of the house and land by household heirs. For the first criteria, we totaled the landholdings of all households where the household head reported their principle occupation as farmer ("*cultivateur*") on the 1830 cadaster. We excluded two households that owned tenant farms since their landholdings represent land used by more than one household. Farms averaged approximately 12.5 ha, but with a standard deviation of 7.3 ha. We standardized household landholdings and excluded households that fell below z-score of -1. These households were abnormally small (less than 4 ha each) and likely represented households that either rented land or were already undergoing the process of disintegration. We then re-standardized the values and placed the cutoff for “extensive” households at a z-score of 1 or 20.615 ha. We applied the criteria to every year to identify parcels belonging to expanding households as they exceeded 20.615 ha. Using this method, we identified the extensification event (“failure”) to the last year a parcel belonged to a household less than 20.615 ha.

While the first and second criteria for parcel extensification were straightforward calculations executed through database queries, the third criteria took triangulation of several types of historical records including birth and death records, voter registration records, and tax record classification of the physical house as ‘*démoli*e’ (demolished) or ‘*batiment rural’* (non-taxable agricultural building). For example, some households abandoned farming but did not divest themselves of their parcels. It was necessary to consult birth abstracts and voter registration records to confirm the absence of land owning, farming occupants.

Abandoned households were sometimes rented to tenant farmers (*metayer*, Fr.) who continued to farm and have children in the house. We classified parcels belonging to these household as “failed” because the *metayer* families were not technically in control of the long term economic strategy of the farm. They therefore did not meet the criteria of a traditional *Etxe* institution with regards to autonomy of land use. *Metayer* were also invariably temporary occupants. One *metayer* household did exhibit multi-generational usage, but this farm was owned by another actively farming household. Parcels belonging to both the tenant farm and the owner farm were already in the “extensive” category.

For the separate event analysis of household abandonment, the “failure” event was defined as the year households divested all parcels or were determined to be abandoned based on the third criteria used in the parcel extensification analysis. We "right censored" all parcels belonging to households that did not fail by 1958.

Covariates and Stratification Criteria for the Parcel Extensification Model

We identified three basic household economic strategies to serve as covariates: (1) persistent : not persistent, (2) investor : divestor, and (3) extensive : not extensive. We defined "persistent" as all parcels belonging to households (a) actively farming in 1958, (b) with a minimum of 4500 ha, and (c) with resident family members of age 45 years old or less in 1958 (i.e. potentially reproductive). We considered all other parcels as "not persistent." "Investors" were households that in their last year before failure (or 1958) showed a total land area greater than their 1830 land area and greater than their average land area. "Divestors" were households with total land areas less than their 1830 value and less than their average at the time of failure (or 1958). These two scenarios accounted for all parcels in the sample. "Extensive" identified households that invested in land and exceeded the 20.615 ha threshold in total surface area at some point over the time period regardless of persistence. "Not extensive" indicated households that did not exceed 20.615 ha in total surface area.

The analysis of parcel extensificaiton makes use of "fixed" covariates only. These are covariates that do not vary as a function of time. We omitted the "extensive" covariate from this analysis because it simply identified households whose parcels all met the criteria for failure. Instead, we stratified the analysis by "extensive" (extensive = 1, not extensive = 0), thus keeping the hazard rate of parcel extensification events separate depending on whether parcels "failed" because households extensified or because households divested. We retained "investor" and "persistent" since we wanted to know if these household strategies were statistically associated with extensification processes.

We derived two parcel attributes as covariates from the 1830 cadastral data: median land use tax and land use optimality. Cadastral data is predominantly a documentation of tax assessment that was designed to extract taxes from pre- or non-market production. Cadastral taxes were assessed based on the parcel area, its fiscal land use classification, and its "quality" (Clout and Sutton 1969). Median 1830 tax values by land use reflect logical assumptions of per ha outputs with gardens and crop fields ranking highest and pastures and "wastelands" ranking lowest. This means that that tax assessors were holding labor and material inputs constant according to land use. Since taxes were designed to capture a proportion of the assessed potential output, we can infer that variability of the tax value within the land use categories represents the assignment of land "quality" to the parcel beyond the labor and materials necessary for the land use. Given this inference, we divided the tax per ha of each parcel by the median per ha tax value for the land use class to derive a measure for the "suitability" of that parcel to its land use. The lower the quality of land, the smaller the ratio of tax value to median land use tax value. Since we were interested in testing the potential influence of shifts in "land rent" on household decision-making at the parcel level, we used land use suitability as a proxy for pre- or nonmarket "land rent". In other words, we took land use suitability to represent the "optimality" of its use within the context of the 1830 subsistence regime. If households were less integrated with external markets, the suitability of a parcel to its land use should buffer against extensification.

As another measure of the physical attributes of the parcel itself, we derived topographic covariates from a 50 m^2 resolution digital elevation model (DEM). We used ArcGIS Spatial Analyst to construct aspect and slope layers from the DEM. We then used the zonal statistics tool to obtain elevation, slope, roughness (standard deviation of elevation), and aspect ("eastness") for each parcel in the study area. Lastly we used ArcView Spatial Analyst tool to calculate the distance of a parcel from houses and from the local commercial center, the *bourg*.

Covariates for the Household Abandonment Model

To examine household abandonment events, we required covariates that tracked the internal dynamics of the household as well as changing characteristics of farm property as an aggregated whole. We included the fixed time variables "investor" and "extensive" variables used in the parcel extensification analysis, whereas the rest are TVC. We stratified by "extensive" in order to remain consistent with the parcel extensification analysis.

We used the cadastral tax data to develop 4 covariates indicative of aggregate farm characteristics: the mean per ha optimality of crop fields, hay meadows, woodlands, and pastures. We calculated farm land use optimality by using the "suitability" index developed from the parcel extensification analysis. We simply averaged the optimality value for each household's crop fields, hay meadows, woodlands, and pastures respectively. We took these values as proxies for the relative suitability of a household toward provisioning of the various products of each land use.

We modeled the consumer-producer (C/P) cycles using reconstructed household demographic arrangements from birth abstracts. We estimated age specific survival probabilities for each birth based on 19th and 20th century life tables for France from the "Human Life-Table Database" (http://www.lifetable.de). We estimated the size of age cohorts within households by summing the contemporaneous probability values for individual births by year up to age 26. Given the structure of the traditional *Etxe*, we assumed that each viable household had a minimum of 3 members over age 26, 2 representing the conjugal couple and 1 representing either a subordinate sibling or an elder member. Holding these constant rendered a conservative estimate of the number of producers per household. We constructed C/P for each household by multiplying age cohort values by the non-competitive (male only) consumer and producer age weights based on the scale developed by Hammel (2005). Although we included females in the calculation, we did not differentiate consumption or production weights by gender.

In order to examine the possibility for intra-household "conflict," we considered two variables representing generational and gender balance. As a proxy for competition between potential heirs of the household estate, we used a moving estimate of the size of the age cohort 25 – 45 based on birth records and age specific survival probabilities. Competition between heirs might have an effect on household failure since resolution would require cash payments, the breakup of the household estate, or the liquidation of land assets. Customarily, cash payments were made to non-inheriting siblings of both genders and these served as a dowry for marrying into another household (Arrizabalaga 2005; Ott 1993). In order to look at the relationship between the gender balance of descendants and household persistence, we used the annual ratio between females and males 15-26. We constructed this ratio by adding 1 to the survival probabilities for the

15-26 age cohort for each gender. This had the effect of holding the gender ratio for age 26 and over at a constant 1:1.

Survival Rates and Fertility Decline

Lastly, we examined rate of change between extensification, household abandonment, and fertility on the landscape level. We calculated the Kaplan–Meier "survival" rates for both parcels and households. The survival rate represents the inverse of the "hazard" rate of event occurrence: e.g. extensification for parcels and abandonment for households. Whereas hazard rates increase with time, survival rates decrease. We plotted the stratified survival rates for visual inspections and generated the unstratified survival rate for use in ordinary least squares regression with the demography for the *quartier*.

For the demographic variable, we used a total cohort fertility statistic which uses birth records to calculate the sum of a cohort's age-specific fertility (Frejka and Calot 2001; Ryder 1986). We summed the total number of births for seven - four year interval cohorts beginning with the youngest mother's age at birth: 16-20, 21-25, 26-30, 31-35, 36-40, 41-45, over 45. We followed each cohort sequentially through its seven stages. The final statistic gives the total number of children birthed by women in the cohort who turned 16 in a given year. So, for example, if the total cohort fertility for 1800 is 6, we calculated this by summing the two births for women ages 21 to 25 in the years 1804 to 1807, two births for women 26 to 30 in the years 1808 to 1811, and the two births for women ages 31 to 35 in the years 1812 to 1815 where there were no births for women 16 to 20 and women older than 35. For linear regression with survival rates, we used the natural logarithm of the total cohort fertility.

Results

Parcel Extensification

The results of the parcel extensification model (Table 5.1.) showed a mixed significance between covariates. Significance was determined based on a *p* value < 0.1 and 95% confidence intervals that do not contain 1 (Jones and Wood 2012). To interpret the proportional effects, represented as the hazard ratio, a value of 1.02 should be understood as having a 2% increase in the rate of extensification whereas a value of 0.55 would have a 45% increase (1-0.55). Negative values decrease the rate of extensification. All significant covariates for the parcel extensification model displayed negative effects.

Table 5.1. Cox proportional hazards analysis of parcel extensification stratified by variable "extensive". *N*=358 parcels, 280 failures. Global *P* and *P* value for Ph test of proportional hazards assumption, < 0.001. Significant covariates highlighted.

Covariate	Haz Ratio	Std. Err.	z	P>z	95% Conf.	Interval]
Elevation	-0.999674	0.000525	-0.62	0.534	0.998645	1.000704
Roughness	-0.997363	0.008664	-0.3	0.761	0.980525	1.01449
Aspect	-0.997157	0.00068	-4.17	0	0.995825	0.998491
Slope	-0.99218	0.010262	-0.76	0.448	0.972269	1.012498
Dist_house	-1	2.43E-07	-1.92	0.055	0.999999	1
Dist_village	1	3.49E-08	4.58	0	1	1
Investor	-0.557272	0.101449	-3.21	0.001	0.39004	0.796205
Persistent	-0.485412	0.091982	-3.81	0	0.334822	0.703732
Optimality	-0.646935	0.139156	-2.02	0.043	0.424392	0.986175
Median tax	-0.993784	0.013108	-0.47	0.636	0.968422	1.019809

As the only significant topographic covariate, aspect ("eastness") buffered against extensification. Distances to house and *bourg* were not significant. Household economic strategies were significant with both investment in parcels ("investor") and persistence ("persistent") showing fairly strong negative associations. So, most parcels belonging to households that were not extensive were nevertheless part of households that did invest and grow over time. Parcels belonging to persistent households were more likely to avoid extensification. Suitability of the parcel to its land use also showed a strong negative association. Thus, the quality of parcels relative to the 1830 subsistence system buffered against extensification. At the same time the specific use intensity of parcels, as represented in the median tax value, had weak and statistically insignificant effects. Although optimality of a parcel to its 1830 land use may have buffered against their sale, the results also show that parcel quality was not influencing parcel purchase by extensive households.

The stratified survival estimates (Figure 5.5) show that persistent, non-extensive households (n = 87) held on to over 75% of their parcels during the time period. Parcels belonging to persistent, extensive households (n = 68) showed the most rapid transition with over 50% of the change occurring by 1865. The majority of parcels from failed, extensive households (n = 102) extensified later (1910) than the persistant, extensive households. Most parcels belonging to failed households that were not extensive (n = 213) took longer to be absorbed by extensive households, but nearly half had transitioned by 1930. The general pattern across strata shows a flattening of hazard rate between about 1865 and 1902.

The transfer of parcels from farms within the normal size range for 1830 to farms greater than 20.615 ha in size resulted from household decisions involving investment and divestment in land. But the unstratified survival rate shows that households predominantly divested parcels at the point of abandonment rather than through a process of attrition. Linear regression of the unstratified survival rate with the total cohort fertility rate (1871 to 1941) showed a significant ($P<0.001$) R^2 of 0.81 from 1886 to 1958 with cohort fertility lagged by 16 years (one generation).

Household Abandonment

The results of the household abandonment analysis were nearly all significant, but of more mixed effect (Table 5.2). Investment in parcels showed a strong negative effect on abandonment. The potential for competition between heirs (age cohort 25 to 45) showed a weak positive effect on household abandonment but was not significant. The ratio of female to male descendants also showed a weak positive effect. Surprisingly, the C/P also showed a strong, negative association.

The optimality of the households' landholdings had varying effects on abandonment according to land use. Pasture and crop fields had positive associations while hay meadows and woodlands had negative associations. This supports the assumption that crops became less important while hay meadows became more important to households as ties to markets became stronger. Woodlands were also important to households, since access to communal woodland was increasingly restricted under the *Régime Forestier* (French Forest Service) (Métailié 2006). The positive effects of the optimality of pastures are puzzling. However, place names suggest that the dominant function of privately owned "pastures" was for bracken fern meadow. Given that bracken can be grown in poor soils, bracken meadow may represent a suboptimal use of higher quality land.

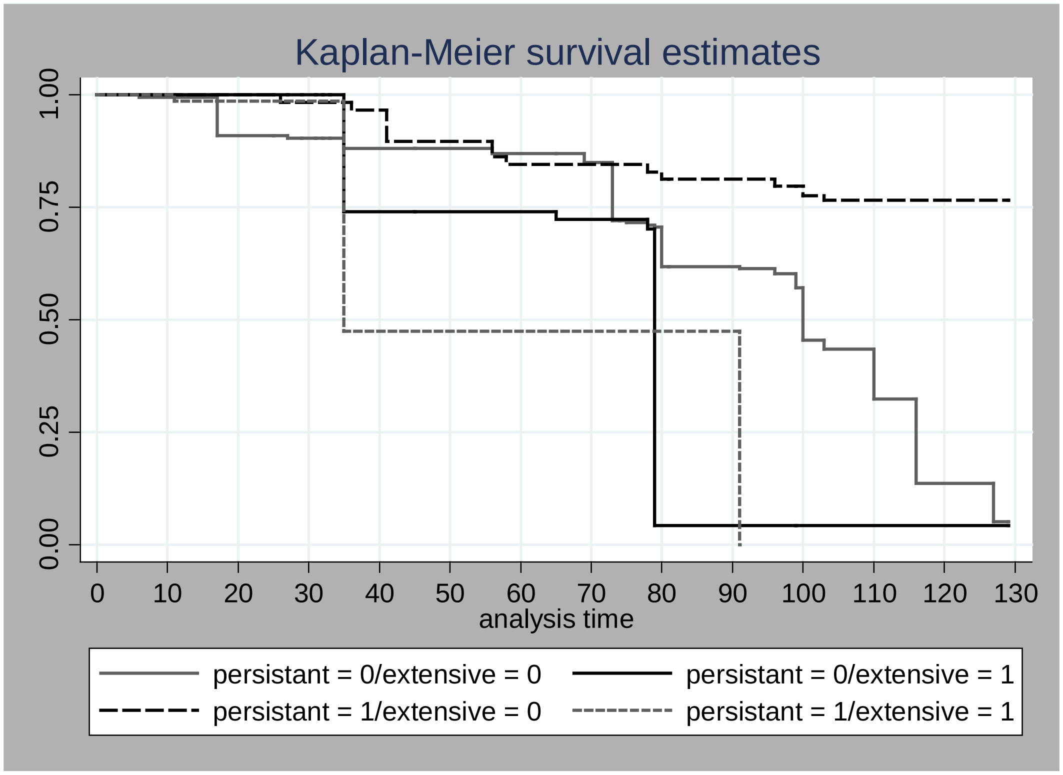

Figure 5.5. Survival estimates for the parcel extensification analysis stratified by parcels in “extensive” and “persistent” households. “Extensive = 0” are parcels belonging to households that did not exceed 20.615 ha and “Extensive = 1” are parcels belonging to households that exceeded 20.615 ha. “Persistent = 0” are parcels belonging to households that did not survive to 1958 and “Persistent = 1” are parcels belonging to households that survived to 1958. Analysis time: 0= 1830, 10 = 1840, …, 130 = 1960.

Survival estimates for households (Figure 5.6) show that households that extensified (parcel *n* = 312) avoided abandonment longer than those that did not (parcel *n* = 219). They also show that failure was fairly gradual until after about 1900, crossing the 50% threshold by 1940. Linear regression between the survival rate of all households (by parcel) and total cohort fertility showed a significant ($P<0.001$) R^2 of 0.74 for the period from 1868 through 1938.

Cautionary Note

Because our data was limited to 1830 onward, failure rates do not represent the true hazard rates for parcel or household survival. Rather, the models show the hazard rate from 1830 forward for household failure and for parcel extensification they show the hazard from 1830 forward or, if after 1830, from the date of purchase by the household. The hazard rates shown on the survival plots (Figures 5.5 and 5.6) and used for the interpretation of time periods therefore correspond to time to fail since 1830 and not the *t* used in the cox regression.

An additional problem concerns the TVC which interacted with the variable "*t*", time to event. This interaction presumes that the importance of the TVC increases with time as it approaches the event. However TVC may interact differently with time in ways not captured by the model (Fisher and Lin 1999). For example C/P ratios operate cyclically so linear interactions may not capture complete effects. The linear interaction may also mute the effects of covariates if they were more important in the early part of the study period.

Table 5.2. Cox extended hazards analysis of parcel-level household abandonment stratified by variable “extensive”. N= 475 parcels, 233 failures. Global $P < 0.001$.

Covariates	Haz Ratio	Std. Err.	z	P>z	95% Conf.	Interval
Fixed						
Investor	-0.002019	0.002205	-5.68	0	0.000237	0.017175
TVC						
F/M	1.02519	0.0026966	9.46	0	1.019919	1.030489
age25-45	-0.9975224	0.0020442	-1.21	0.226	0.9935239	1.001537
c/p	-0.5829853	0.0426099	-7.38	0	0.5051776	0.672777
Hay optimality	-0.8120568	0.0297281	-5.69	0	0.7558321	0.872464
Crop optimality	1.273194	0.0590923	5.2	0	1.162487	1.394444
Wood optimality	-0.9034304	0.0172773	-5.31	0	0.8701942	0.9379359
Pasture optimality	1.216688	0.053769	4.44	0	1.115738	1.326772

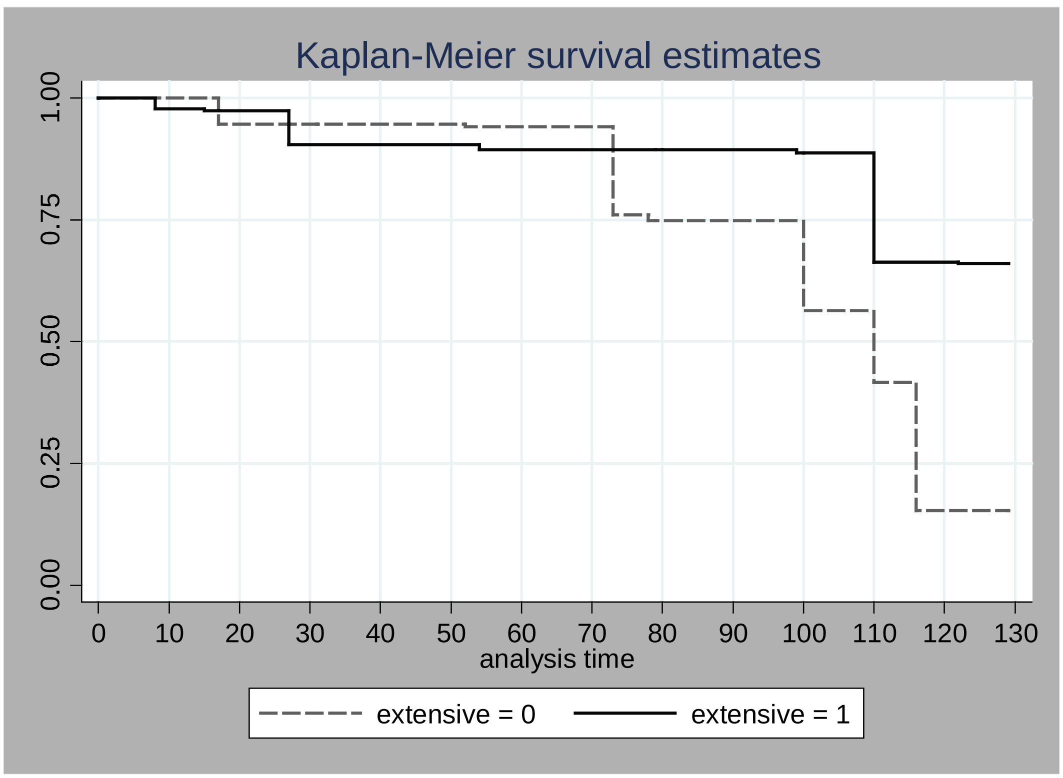

Figure 5.6. Survival estimates (y-axis) for the analysis of household abandonment, stratified by “extensive”. “Extensive = 0” are parcels belonging to households that did not exceed 20.615 ha and “Extensive = 1” are parcels belonging to households that did exceed 20.615 ha. Analysis time: 0= 1830, 10 = 1840, … 130 = 1960.

Discussion

Household Economic Strategies

Analysis results suggest that the divergent socioeconomic strategies and trajectories of households themselves played important roles in the process of land use extensification and abandonment between 1830 and 1958. Households followed one of three strategies: (1) abandon and divest all landholdings, (2) abandon farming and lease landholdings to tenant farmers, or (3) increase landholdings. Each of these options eventually led to extensification of land use, but the character and intensity of land use change varied considerably over the time period.

For example, from 1830 through 1870, there were four household abandonments, but two new households sprang up, thus delaying extensification for some of those parcels. Tenant farmers (*metayer*) also utilized some of the "abandoned" farms into the first decade of the 20th century. These factors produced a lag in the extensification of parcels from non-persistent households. On the other hand, extensification came early for parcels owned by households that increased their landholdings beyond the 20.615 ha threshold. Relative stability from 1865 to about 1902 followed an initial period of abandonments and expansions. Larger households converted many of their crop fields and bracken meadow to hay meadows during this stable period. Interestingly, the period of stability is bracketed by the closure of the mine and metal works in 1865 and the opening of the cheese factory in 1902. These periods of landscape change roughly match cyclical patterns in the total cohort fertility statistic (Figure 5.7). Despite the expansion of farms from 1830 to the "stable period" (1865-1902), the statistical relationship between the landscape and demographic transition is only apparent from about 1886 when the effects of steady fertility decline (from 1871 onward) began to show. At the same time, if we consider land use and human fertility as a reciprocal relationship, the relatively stable land use strategies that lent themselves toward demographic transition were in place shortly after 1865 with the closure of the mine and metal works.

Both household abandonments and the absorption of parcels by the larger households accelerated again after WWI (1919) and peaked in degree during the Great Depression (ca. 1930). Overall, households that maintained higher fertility rates and invested in land had a better chance of survival.

Market Controls on Land Rent

Our analysis did not capture the forces that actively encouraged extensification at the parcel level. With the exception of aspect, divestment and investment decisions were not tied to topographic factors or distance from the house or village center. Aspect offered some protective value against extensification, perhaps due to the value of "eastness" for productivity through increased exposure to solar radiation. But more likely this weak effect reflects the spatial arrangements of the sample itself rather than the effects of "von Thunen" land rents.

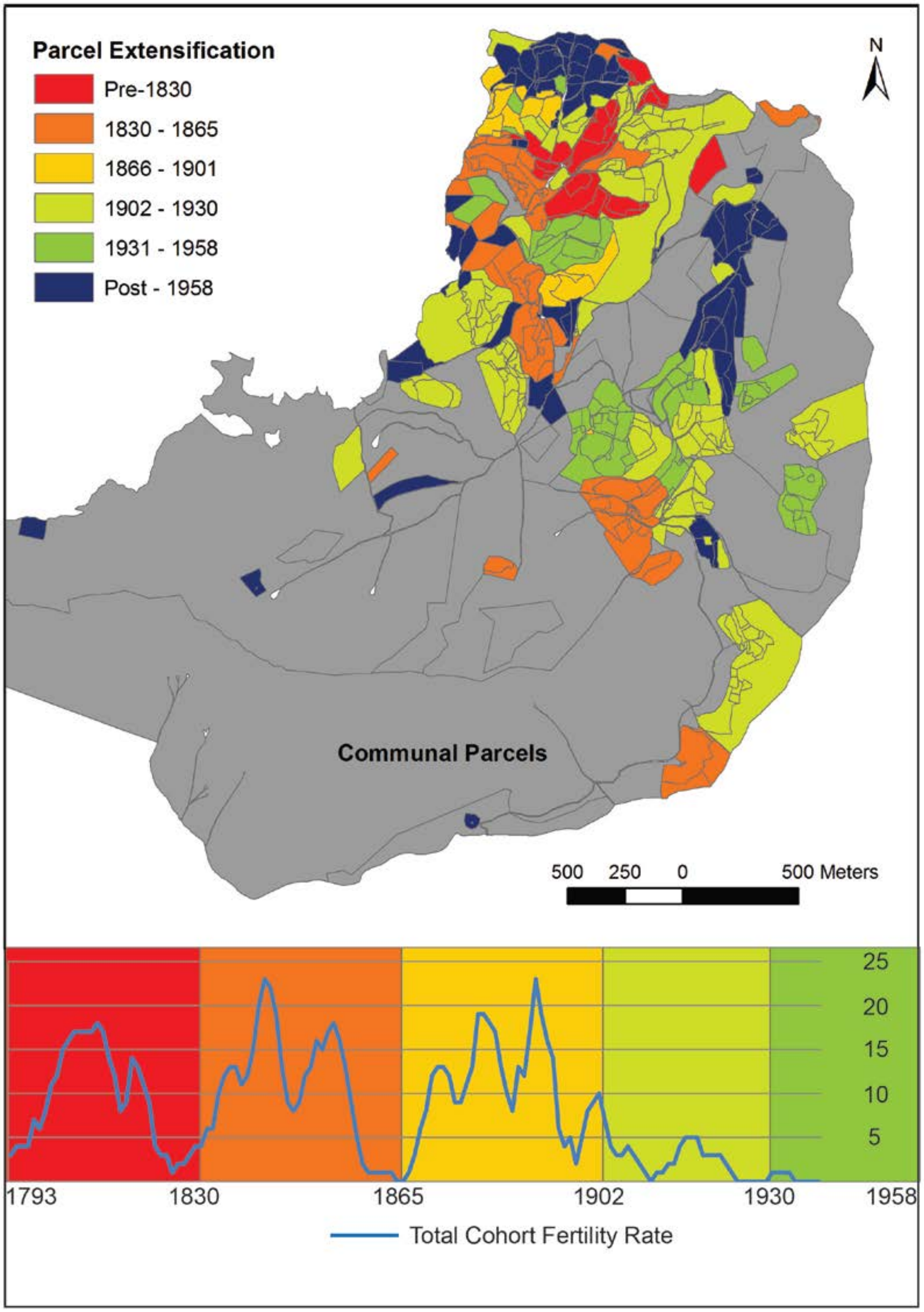

Figure 5.7. Map of parcel survival by periods showing the survival rate for the last 80 years in comparison with the total cohort fertility rate.

The results suggest that at the parcel level, landscape transition during the study period appears heavily constrained by the local institutional context. Extensive households did not show preferences for particular parcel qualities but instead appear to have opportunistically expanded their operations following the collapse of neighboring households. As a consequence, the biophysical attributes of parcels belonging to investors were largely influenced by the pre-1830 composition of the farm itself as well as the households they subsumed. The value of a parcel for non-extensive households was determined by its 1830 land use, indicating that smaller farms remained tied to non-market subsistence strategies.

At the household level, traditional subsistence strategies were increasingly less sustainable. The contribution of “crop field optimality” to household failure, and conversely, the contribution of “hay meadow quality” to survival, suggest that household survival meant a transition toward market dependence on staple carbohydrates in exchange for meat and dairy products. This transition entailed “market rational” land use through optimizing land rents. These associations may represent the impact of the market for ewe’s milk introduced by the nearby Roquefort facility in 1902. They more likely show combined effects of both labor and agricultural market opportunities and an increasing commercial availability of food staples. So while markets did not directly control parcel level extensification, forces associated with market- determined land rent appear to have had an effect on the land use strategies of surviving households.

Household Demographic Composition

The contribution of demographic factors to household persistence and abandonment leave considerable room for interpretation. Households that birthed more males were slightly more successful over the long run. This could reflect changing preferences of female heirs given the growing social effects of female emancipation (Shorter 1973). It could also reflect growing decision-making powers afforded to non-inheriting male spouses by off-farm labor opportunities. In this scenario, the husband, who has no sanguine allegiance to his wife's natal household, opts out of farm work in favor of wage labor possibilities elsewhere. Historical records suggest this scenario for at least three of the households in the *quartier*.

The effect of the C/P is equally ambiguous. Malthusian theory (Malthus 1798) suggests that high numbers of consumers in relation to producers dilutes the available resources of the household. These results could reflect our underestimation of producers for each household. Given the significant relationship between total cohort fertility and the survival rates from both parcel extensification and household abandonment, another possibility concerns the precipitous decline in the actual numbers of consumers (children) during the latter half of the study period. As the hazard of extensification and abandonment increased, the C/P ratio also declined with each family cycle after ca. 1900. This hypothesis is more in line with Chayanov (1986) and Boserup (1966) who suggest that households compensate for high C/P ratios by increasing the intensity of production. Another possibility is that households mostly failed during the post-reproductive period of the family cycle. Thus, as an artifact of the data structure, the number of consumers relative to producers insulated against abandonment.

Conclusion

Mountain landscapes represent an important ecological resource that contributes to regional level socioecological sustainability and wellbeing (Messerli, et al. 2004).

Consequently, landscape transitions pose a challenge to the sustainable conservation and management of mountain landscapes. Understanding the drivers, legacies, and historical range of variability of past socioecological interaction is important for planning land use and management (Foster, et al. 2003; Gragson and Bolstad 2006; Keane, et al. 2009; Landres, et al. 1999; Swetnam, et al. 1999; Thompson, et al. 2009).

External drivers of landscape transitions cannot alone provide explanations for why the onset, intensity, and scale of landscape transition differ between regions. In Larrau, the local institutional context provided both historical and spatial contingencies that mediated the influence of “exogenous” forces and guided the direction of change. Landscape transitions are not simple, uniform processes. Our analysis demonstrates that the pace and character of socioecological change can vary through time and across space. Although successional processes of land cover change visibly accelerated in the post-WWII period, the socioecological conditions driving that change were already well under way. Shifts toward the more extensive land uses typical of late 20th and early 21st century farms predate aerial photos by at least 100 years. At the same time, some smaller “traditional size” farms did survive with their estates intact beyond the reach of our study period. These farms, though protected by higher quality lands, nevertheless expanded in size. This meant that early abandonment of the landscape was prevented by households that were able to both engage in markets and maintain higher fertility rates.

The law of entropy, the vicissitudes of season and climate, ecological succession, the rhythms land use, the cycles of households each ensure that landscapes are in perpetual transition of some degree and scale. The specific socioeconomic strategies of human institutions can either accelerate or slow the pace of landscape transition. For this analysis we chose an arbitrary date (1830) to represent the traditional form of the *Etxe*. The event history of the "failure" of the 1830 *Etxe* is not intended to describe the end of some ideal traditional peasant household form. Rather, this event history shows how particular *Etxe* strategies accelerated change given the changing socioeconomic conditions of the systems within which those households were embed. These same strategies helped the newer, "extensive" *Etxe* farm system preserve and elaborate on selected legacies from the past, thus slowing the pace of afforestation processes.

If household survival is the main key to the sustainable conservation and management of agropastoral landscapes, the socioeconomic strategies of surviving households offer clues to successful policy planning. In this study, socioecological relationships were clearly transformed by "external" pressures through the mediation of local institutions, but that transformation contributed to the delay of landscape abandonment by giving rise to new institutional forms. This study suggests that it is important to understand how particular social and ecological factors variously contributed to failure events and to the legacies left by failed forms of interaction.

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References

Agnoletti, M.
2007 The degradation of traditional landscape in a mountain area of Tuscany during the 19th and 20th centuries: Implications for biodiversity and sustainable management. *Forest Ecology and Management* 249(1-2):5-17.

Allison, Paul D
1984 *Event history analysis: Regression for longitudinal event data*. Sage Publications, Incorporated.

Arrizabalaga, Marie-Pierre
1997 The Stem Family in the French Basque Country: Sare in the Nineteenth Century. *Journal of Family History* 22(1):50-69.

Arrizabalaga, Marie-Pierre
2005 Succession strategies in the Pyrenees in the 19th century: The Basque case. *The History of the Family* 10(3):271-292.

Bell, Kathleen P. and Elena G. Irwin
2002 Spatially explicit micro-level modelling of land use change at the rural–urban interface. *Agricultural Economics* 27(3):217-232.

Benayas, Jose M. Rey, Ana Martines, Jose M. Nicolau and Jennifer J. Schulz
2007 Abandonment of agricultural land: an overview of drivers and consquences. *CAB Reviews: Perspectives in Agriculture, Verterinary Science, Nutrition and Natural Resources* 2(57):1-14.

Bender, O., H. J. Boehmer, D. Jens and K. P. Schumacher
2005 Analysis of land-use change in a sector of Upper Franconia (Bavaria, Germany) since 1850 using land register records. *Landscape Ecology* 20(2):149-163.

Berkner, Lutz K.
1972 The Stem Family and the Developmental Cycle of the Peasant Household: An Eighteenth-Century Austrian Example. *The American Historical Review* 77(2):398-418.

Bortoli, Dolores de and Pascal Palu
2009 Le système maison comme déterminant de la pérennité organisationnelle. *Revue française de gestion* 192:141-150.

Boserup, Ester
1966 *The conditions of agricultural growth; the economics of agrarian change under population pressure*. Aldine Pub. Co., Chicago,.

Bourdieu, Pierre
1962 Célibat et condition paysanne. *Études rurales* 5-6.

Buller, Henry John
1992 Agricultural change and the environment in Western Europe. In *Agricultural change, environment and economy: essays in honour of WB Morgan*, edited by K. Hoggart, pp. 68-88. Mansell Publishing Limited, New York, NY.

Burns, Robert K., Jr.
1961 The Ecological Basis of French Alpine Peasant Communities in the Dauphine. *Anthropological Quarterly* 34(1):19-35.

Caldwell, John C.
1980 Mass Education as a Determinant of the Timing of Fertility Decline. *Population and Development Review* 6(2):225-255.

Cavailles, Henri
1931 La transhumance pyrénéenne et la circulation des troupeaux dans les plaines de Gascogne. Armand Colin.

Champagne, Alain and Mélanie Le Couedic
2012 *Rapport final de prospection diachronique, Larrau (Pyrénées Atlantiques), SRA Aquitaine*. Université de Pau et des Pays de l'Adour, ITEM. Copies available from 2012-100.

Champagne, Patrick
2002 *L'héritage refusé: la crise de la reproduction sociale de la paysannerie française, 1950-2000* 478. Seuil.

Chayanov, A. V.
1986 The Theory of Peasant Economy. In *A.V. Chayanov on The Theory of Peasant Economy*, edited by D. Thorner, B. Kerblay and R. E. F. Smith. The University of Wisconsin Press, Madison.

Clout, Hugh D. and Keith Sutton
1969 The "Cadastre" as a Source for French Rural Studies. *Agricultural History* 43(2):215-224.

Cole, John W.
1969 Economic Alternatives in the Upper Nonsberg. *Anthropological Quarterly* 42(3):186-213.

Cole, John W.
1972 Cultural Adaptation in the Eastern Alps. *Anthropological Quarterly* 45(3):158-176.

Cox, D. R.
1972 Regression Models and Life-Tables. *Journal of the Royal Statistical Society. Series B (Methodological)* 34(2):187-220.

Cunchinabe, Dominique, Pascal Palu, Dolores De Bortoli and Marie-Paule Lavergne
2011 *Histoire de l'écosystème cultivé et de la biodiversité à Larrau: Analyse de l'impact agropastoral dans la gestion du milieu.*

Davis, Kingsley
1945 The World Demographic Transition. *Annals of the American Academy of Political and Social Science* 237(ArticleType: research-article / Issue Title: World Population in Transition / Full publication date: Jan., 1945 / Copyright © 1945 American Academy of Political and Social Science):1-11.

Douglass, William A.
1988 The Basque Stem Family Household: Myth or Reality? *Journal of Family History* 13(1):75-89.

Durrenberger, E. Paul
1980 Chayanov's Economic Analysis in Anthropology. *Journal of Anthropological Research* 36(2):133-148.

Fisher, Lloyd D and DY Lin
1999 Time-dependent covariates in the Cox proportional-hazards regression model. *Annual review of public health* 20(1):145-157.

Foster, Brian L.
1978 Domestic Development Cycles as a Link between Population Processes and Other Social Processes. *Journal of Anthropological Research* 34(3):415-441.

Foster, David R.
1992 Land-Use History (1730-1990) and Vegetation Dynamics in Central New England, USA. *Journal of Ecology* 80(4):753-771.

Foster, David, Frederick Swanson, John Aber, Ingrid Burke, Nicholas Brokaw, David Tilman and Alan Knapp
2003 The Importance of Land-Use Legacies to Ecology and Conservation. *BioScience* 53(1):77-.

Frejka, Tomas and Gerard Calot
2001 Cohort Reproductive Patterns in Low-Fertility Countries. *Population and Development Review* 27(1):103-132.

Friedl, John
1972 Changing Economic Emphasis in an Alpine Village. *Anthropological Quarterly* 45(3):145-157.

Gellrich, Mario and Niklaus E. Zimmermann
2007 Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning* 79(1):65-76.

Gibon, Annick, David Sheeren, Claude Monteil, Sylvie Ladet and Gérard Balent
2010 Modelling and simulating change in reforesting mountain landscapes using a social-ecological framework. *Landscape Ecology* 25(2):267-285.

Gómez-Ibáñez, Daniel Alexander
1975 *The Western Pyrenees : differential evolution of the French and Spanish borderland*. Oxford research studies in geography. Clarendon Press, Oxford [Eng.].

Gómez-Ibáñez, Daniel Alexander
1977 Energy, Economics, and the Decline of Transhumance. *Geographical Review* 67(3):284-298.

Gragson, Ted L
2008 Conclusion. In *Agrarian landscapes in transition: comparisons of long-term ecological and cultural change* edited by C. L. Redman and D. R. Foster, pp. 272-278. Oxford University Press, New York, New York, USA.

Gragson, Ted L. and Paul V. Bolstad
2006 Land Use Legacies and the Future of Southern Appalachia. *Society & Natural Resources* 19:175-190.

Hammel, E. A.
2005 Chayanov Revisited: A Model for the Economics of Complex Kin Units. *Proceedings of the National Academy of Sciences of the United States of America* 102(19):7043-7046.

Hedican, Edward J
2009 Ways of Knowing in Anthropology: Alexandre Chayanov and the Perils of "Dutiful Empiricism". *History and Anthropology* 20(4):419-433.

Irwin, Elena G. and Nancy E. Bockstael
2002 Interacting agents, spatial externalities and the evolution of residential land use patterns. *Journal of Economic Geography* 2(1):31-54.

Jones, Eric E. and James W. Wood
2012 Using event-history analysis to examine the causes of semi-sedentism among shifting cultivators: a case study of the Haudenosaunee, AD 1500–1700. *Journal of Archaeological Science* 39(8):2593-2603.

Keane, R. E., P. F. Hessburg, P. B. Landres and F. J. Swanson
2009 The use of historical range and variability (HRV) in landscape management. *Forest Ecology and Management* 258(7):1025-1037.

Lambin, Eric F. and Patrick Meyfroidt
2010 Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy* 27(2):108-118.

Lambin, Eric F., B. L. Turner, Helmut J. Geist, Samuel B. Agbola, Arild Angelsen, John W. Bruce, Oliver T. Coomes, Rodolfo Dirzo, Günther Fischer, Carl Folke, P. S. George, Katherine Homewood, Jacques Imbernon, Rik Leemans, Xiubin Li, Emilio F. Moran, Michael Mortimore, P. S. Ramakrishnan, John F. Richards, Helle Skånes, Will Steffen, Glenn D. Stone, Uno Svedin, Tom A. Veldkamp, Coleen Vogel and Jianchu Xu
2001 The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11(4):261-269.

Landres, P. B., P. Morgan and F. J. Swanson
1999 Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9(4):1179-1188.

Le Play, Frédéric
1871 *L'organisation de la famille selon le vrai modèle signalé par l'histoire de toutes les races et de tous les temps. Avec trois appendices*. Téqui, Bibliothécaire de l'oeuvre Saint-Michel,, Paris.

Lefèbvre, Theodore
1928 La transhumance dans les Basses-Pyrénées. *Annales de Géographie*:35-60.

Lefèbvre, Theodore
1933 *Les Modes de Vie dans les Pyrénées Atlantiques Orientales*. Armand Colin, Paris.

MacDonald, D., J. R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. Gutierrez Lazpita and A. Gibon

2000 Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *Journal of Environmental Management* 59(1):47-69.

Malthus, T.

1798 *An Essay on the Principle of Population, as it Affects the Future Improvement of Society with Remarks on the Speculations of Mr. Goodwin, M. Condorcet, and Other Writers.* J. Johnson, London.

Mather, A. S. and C. L. Needle

2000 The Relationships of Population and Forest Trends. *The Geographical Journal* 166(1):2-13.

Messerli, Bruno, Daniel Viviroli and Rolf Weingartner

2004 Mountains of the World: Vulnerable Water Towers for the 21st Century. *Ambio*:29-34.

Métailié, Jean-Paul

2006 Mountain Landscape, Pastoral Management and Traditional Practices in the Northern Pyrenees (France). In *The Conservation of Cultural Landscapes,* edited by M. Agnoletti. CAB International.

Mottet, Anne, Sylvie Ladet, Nathalie Coqué and Annick Gibon

2006 Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. *Agriculture, Ecosystems & Environment* 114(2-4):296-310.

Netting, Robert McC

1972 Of Men and Meadows: Strategies of Alpine Land Use. *Anthropological Quarterly* 45(3):132-144.

Netting, Robert McC

1993 *Smallholders, householders : farm families and the ecology of intensive, sustainable agriculture*. Stanford University Press, Stanford, California.

Ninot, J. M., e. Carrillo, X. Font, J. Carreras, A. Ferre, R. M. Marsalles, I. Soriano and J. Vigo

2007 Altitude Zonation in the Pyrenees. A Geobotanic Interpretation. *Phytocoenologia* 37(3-5):371-398.

Ott, Sandra

1993 *The circle of mountains : a Basque shepherding community*. University of Nevada Press, Reno, USA.

Palu, Pascal
1992 Rapports entre organisation sociale et écosytème dans la société pastorale souletine. *Sociétés contemporaines*:239-264.

Parish, William L., Jr. and Moshe Schwartz
1972 Household Complexity in Nineteenth Century France. *American Sociological Review* 37(2):154-173.

Pasche, F., M. Armand, P. Gouaux, T. Lamaze and A. Pornon
2004 Are meadows with high ecological and patrimonial value endangered by heathland invasion in the French central Pyrenees? *Biological Conservation* 118(1):101-108.

Peaucelle, Denis
1977 Analyse d'une communauté rurale basque, Larrau en Haute Soule, Département d'Etudes Rurales, Université de Paris 7, Paris.

Perz, Stephen G.
2001 Household Demographic Factors as Life Cycle Determinants of Land Use in the Amazon. *Population Research and Policy Review* 20(3):159-186.

Perz, Stephen G., Robert T. Walker and Marcellus M. Caldas
2006 Beyond Population and Environment: Household Demographic Life Cycles and Land Use Allocation among Small Farms in the Amazon. *Human Ecology* 34(6):829-849.

Polanyi, Karl
1957 *The great transformation*. [1st Beacon paperback ed. Beacon paperback,. Beacon Press, Boston,.

Polanyi, Karl and Robert M MacIver
1957 *The great transformation* 2. Beacon Press Boston.

Prishchepov, Alexander V., Daniel Müller, Maxim Dubinin, Matthias Baumann and Volker C. Radeloff
2013 Determinants of agricultural land abandonment in post-Soviet European Russia. *Land Use Policy* 30(1):873-884.

Puigdefabregas, Juan and Federico Fillat
1986 Ecological Adaptation of Traditional Land Uses in the Spanish Pyrenees. *Mountain Research and Development* 6(1):63-72.

Rhoades, Robert E. and Stephen I. Thompson
1975 Adaptive Strategies in Alpine Environments: Beyond Ecological Particularism. *American Ethnologist* 2(3):535-551.

Ricardo, David
1891 *Principles of political economy and taxation*. G. Bell and sons, London, UK.

Rinschede, Gisbert
1988 Transhumance in European and American Mountains. In *Human impact on mountains*, edited by N. J. R. Allan, G. W. Knapp and C. Stadel, pp. xii, 308 p. Roman & Littlefield, Totowa, N.J.

Roura-Pascual, N., P. Pons, M. Etienne and B. Lambert
2005 Transformation of a rural landscape in the Eastern Pyrenees between 1953 and 2000. *Mountain Research and Development* 25(3):252-261.

Rudel, Thomas K.
1998 Is There a Forest Transition? Deforestation, Reforestation, and Development. *Rural Sociology* 63(4):533-552.

Rudel, Thomas K., Laura Schneider and Maria Uriarte
2010 Forest transitions: An introduction. *Land Use Policy* 27(2):95-97.

Ryder, Norman B.
1986 Observations on the History of Cohort Fertility in the United States. *Population and Development Review* 12(4):617-643.

Sahlins, Marshall
1971 The intensity of domestic production in primitive societies: Social inflections of the Chayanov slope. *Dalton, Studies in Economic Anthropology*:30-51.

Scargill, Ian
1994 Crisis in rural France. *Geography* 79(2):168-171.

Schultz, T. Paul
1985 Changing World Prices, Women's Wages, and the Fertility Transition: Sweden, 1860-1910. *Journal of Political Economy* 93(6):1126-1154.

Shorter, Edward
1973 Female Emancipation, Birth Control, and Fertility in European History. *The American Historical Review* 78(3):605-640.

Simon, Herbert A.
1959 Theories of Decision-Making in Economics and Behavioral Science. *The American Economic Review* 49(3):253-283.

Swetnam, Thomas W., Craig D. Allen and Julio L. Betancourt
1999 Applied Historical Ecology: Using the Past to Manage for the Future. *Ecological Applications* 9(4):1189-1206.

Thompson, J. R., S. L. Duncan and K. N. Johnson
2009 Is There Potential for the Historical Range of Variability to Guide Conservation Given the Social Range of Variability? *Ecology and Society* 14(1).

Vicente-Serrano, S. M., T. Lasanta and A. Romo
2004 Analysis of spatial and temporal evolution of vegetation cover in the Spanish Central Pyrenees: Role of human management. *Environmental Management* 34(6):802-818.

von Thünen, Johann Heinrich and Peter Hall
1966 *Von Thunen's isolated state: an English edition of Der isolierte Staat*. Pergamon, Oxford, UK.

Wolf, Eric R.
1966 *Peasants*. Foundations of modern anthropology series. Prentice-Hall, Englewood Cliffs, N.J.,.

Zink, Anne
1969 *Azereix, la vie d'une communauté rurale à la fin du XVIIIe siècle*. Démographie et sociétés, 11. S. E. V. P. E. N., Paris,.

Zink, Anne
1997 *Clochers et troupeaux : les communautés rurales des Landes et du Sud-Ouest avant la Révolution*. Presses universitaires de Bordeaux, Talence.

CHAPTER 6

CONCLUSION

This chapter provides a summary and synthesis of the findings from the research presented in this dissertation. I first discuss the findings and methods from Chapters 3-5 in terms of their potential to contribute research problems in historical ecology. I then provide a synthesis of the conclusions of each of the chapters and discuss the broader theoretical implications of these findings. Lastly, I discuss the implications of this research within the context of landscape management and conservation for the Pyrenees and for similar socioecological systems with millennial land management regimes.

Fire Use and Landscape Memory

I used a combination of ethnographic and spatiotemporal analyses to investigate the specific ways fire is used and controlled by farmers. Ethnographic evidence provided crucial parameters for the design and interpretation of the spatiotemporal analysis. The Bayesian weights of evidence (WoE) method was useful for backcasting the presence and absence of fire use, but gained accuracy only after accounting for ethnographically derived fire return intervals in the sampling strategy. Ethnographic information proved essential to the sampling process because the objectives of fire management differ between locations: at lower elevations, the principal objective is the renewal of grass forage which requires annual to biannual ignitions. At higher elevations (above 1400 msl), the principal objective is to counter shrub encroachment and senescense which entails less frequent and regular ignitions. Thus the actual probability of fire use in a given year above 1400 msl is proportionally lower than areas below 1400 msl. In combination with the 1830 land use map, the method demonstrates the importance of topography to pasture placement and fire maintenance. Comparisons between the fire use probabilities, land use maps, and 2011 burned area show that the legacy of pasture persistence is strongly linked to the topographically derived probability of fire use.

This combination of ethnographic evidence and spatial analysis appears well suited to understanding the historical ecology of landscapes dependent on disturbance-based management in general. The application of disturbance-based land management to landscapes formerly dominated by grazing and pastoral fire use could benefit from more accurate assessments of precisely where and how fire use has been a persistent historical determinant of landscape pattern.

Conclusions from this analysis suggest that Basque pastoral fire use practices represent a self-organized management regime that emerges from the socioeconomic strategies of individual households. Institutional governance of fire use was historically unnecessary due the use of social and ecological memories entrained in the landscape over centuries of fire management. Cultural notions of the reciprocal dynamic between pasture and fire use are reflected in the Souletin term *Errakina*, which refers to both the patterns and the processes of pastoral fire. The current context of landscape change threatens the effectiveness of landscape memory as a mechanism for fire management. New forms of social cooperation and coordination that reach beyond household level economic interests may be necessary to combat the degradation of landscape memory occurring in the wake of ongoing land use changes. These institutional actions would do best to focus on maintaining landscape memory rather than imposing further regulations on fire use.

Fire Use and Landscape Change

The analysis of the relationships between changes in fire management and the landscape consisted of a “stepped” version of the Bayesian WoE analyses. Step 1 established topographic fire use probabilities as in the Chapter 3 analysis, but without the ethnographic modifications to the sample fire use locations. Analysis calculated the probability of presence or absence of fire management in a given place, rather than the likelihood of fire use in a given year. Step 2 used the spatial probability of fire management to establish probability associations to different types of land use change (1830-2003). Step 3 used binary representations of ordinal categories pertaining to the intensity of land use to draw probability associations between legacies of 1830 institutional arrangements and the relationships established in Step 2.

These methods provide one possible route to exploring historical ecological relationships. In addition to the need for information pertaining to the persistence of landscape pattern and management processes, land managers have a need to understand the historical socioecological relationships that drive spatiotemporal variability in management processes. This analysis linked the specific contexts of historical land use institutions to the long-term consequences and trajectories of change and persistence in fire management. Potential drawbacks of this analysis concern the fact that it is cumbersome in its treatment of diachronic processes. For example, the analysis assumes that changes in land and fire use were linear. However, given the level of uncertainty with regards to the proxies used for historical fire use (e.g. topographic probability of fire use), the Bayesian analysis provides an attractive option for modeling this historical ecological phenomenon.

Analysis results suggest that it is possible to disentangle the differential effects of fire use and disuse on landscapes given an explicit consideration of the institutional contexts governing land use and management. Landscape change or persistence was likely associated with change or persistence of fire use in a number of contexts: (1) pasture persisted in topographic areas conducive to fire use (south-facing slopes), suggesting persistence of fire management; (2) pasture transitioned to woodlands in areas were fire use is less likely (north-facing slopes), suggesting change in fire management; (3) woodlands persisted in areas of low fire use probability, again suggesting persistence in fire exclusion.

The strength and direction of these associations were strongly dependent on the institutional contexts. Specifically, associations varied according to the institutional property regime (communal versus private household) and the intensity of the land use strategy associated with that regime. The higher the intensity of the land use strategy, the more likely changes in fire use were tied to landscape change. These results were strongest for the pasture to woodland transitions for households with high intensity land use and pasture persistence on the low intensity, communal lands. As household land use shifted to more extensive land use, they preferentially adjusted fire management according to the suitability of the parcel to both fire use and new economic demands. These findings emphasize the differential importance of fire use to landscape change at both the parcel and the institutional levels as a function of the historical institutional context.

Household Abandonment, Socioeconomic Change, and Landscape Transition

Event history analysis provided an excellent method for examining changes in land use and households at the parcel level. The Cox proportional hazards model treats the event phenomena in terms of the probability of the event occurring through time. The method is useful because it handles both binary and continuous variables, assessing the proportional effects of each on the probability of event occurrence. One drawback, however, concerns the fact that the model assumes that covariates are multiplicative with respect to time. This means that effects are assumed to be linear. Thus the approach may mask some of the effects of the rhythmic nature of household demographic cycles.

Another drawback of the analysis concerns the limitations of the data itself. For example, the 50 m resolution of the digital elevation map excluded smaller parcels from the parcel extensification analysis. Parcels not owned by households based within the sample *quartier* were similarly excluded from the household abandonment analysis. Lastly, although parcels that were split were included in the analysis, we were unable to represent these in the results since the exact boundaries of the new parcels remain unknown. This prohibited spatial analysis of the survival rates.

Results from the event history analysis suggest that the sample landscape displayed complex and dynamic relationships between household socioeconomic strategies and parcel-level land use in the century prior to aerial photos. The effects of household abandonment and land use extensification are conspicuous at the parcel level throughout the period investigated. External forces do not provide sufficient explanations for the onset, intensity, and scale of landscape transition. Although external "market" forces likely played a role in landscape transition, they did so through the mediation of local institutional contexts.

Households that expanded farming operations and maintained higher fertility rates preserved much of the agropastoral qualities of the landscape in the face of household abandonments. These farms likely participated more heavily in agricultural markets. Smaller farms maintained subsistence strategies that were probably only marginally integrated with markets. These strategies proved less and less sustainable as external economic opportunities increased.

Synthesis

Far from being an environmentally destructive and irrational pursuit, fire use is part and parcel of livelihood activities proven to be sustainable over millennia. In the Pyrenees, fire use represents a cultural form that interlaces local ecological knowledge and practice with the reproduction of strongly resilient household and inter-household socioeconomic institutions. As much as fire use is revered as an enduring tradition and an aspect of cultural heritage, it is deployed by individuals acting within an ever-changing socioecological system that organizes and schedules the labor of individuals towards the goal of provisioning households. In combination with the density of settlement, household requirements demand a diversity of land types and qualities rendering “good” land scarce even in sparsely populated mountain environments. Households rely on inter-household property institutions that organize and ensure the functional distribution of land and provisions across the system. It is not individual needs in and of themselves, but the demands of household socioeconomic strategies that drive land use and management over the long term.

Prior to transitions in the socioecological systems of the Pyrenees discussed in Chapter 5, the rules and patterns of the property regime primarily served the local system with minimal external flow of goods. Parcel-level land uses were compatible at the landscape level and the property regime contributed to the reproduction of compatibility. Chapter 3 shows how fire use practices were compatibly integrated into this system through landscape memory.

The landscape transitions discussed in Chapter 5 indicate that in the 19th century, the patterns of the property regime gradually became insufficient to meet the demands of shifting household socioeconomic strategies. Codification and expropriation of the rules and patterns of land tenure had already enabled ruling elites and later, the French State, to use them for the purposes of taxation (Kain and Baigent 1992). At the same time, national-level laws contradicted the rules surrounding traditional inheritance patterns, but local practices circumvented these laws (Arrizabalaga 2005). Thus, as land ownership patterns changed, the rules of the property regime were nonetheless retained. Notably, the retention of communal land use institutions alongside traditional inheritance practices provided both constraints and opportunities to households as they adjusted to new market opportunities and demands. These conditions gave specific form and trajectory to the transformation of the landscape under novel socioeconomic pressures.

The WoE analysis in Chapter 4 suggests that amidst the landscape transition, land uses remained compatible on a landscape level, despite the cessation or exclusion of fire use in specific areas. Extensive land uses on communal pastures were retained along with burning practices, while use of communal woodlands was restricted, and fire use was prohibited. This may have intensified private woodland use, especially on collectively owned woodlots associated with transhumant grazing cooperatives. Communal woodlands expanded onto pastures of low topographic fire use suitability while pasture expanded into collectively owned woodlands with higher fire use suitability.

In concert with the topographic suitability of fire use, landscape change from pasture to woodland was more likely for households with a high per hectare (ha) land use intensity. These conclusions are reinforced by the event analysis results (Chapter 5) that showed how crop fields and pastures with higher value in the 1830 subsistence system were positively associated with household abandonment. Households with smaller landholdings tended to exhibit higher per ha land use intensity because viable households required a minimum of crop and garden land (both with high intensity values), but could survive without pastures and woodlots since access to communal resources sufficed. Households with high land use intensity also required more laborers per unit area, so larger landholders with intensive land use (more crop lands) required larger families to maintain them. This proved problematic under the demographic transition to lower fertility rates.

Event history analyses suggested that persistent households' socioeconomic strategies shifted toward lower fertility and a focus on more extensive livestock-oriented land use in the latter half of the 19th century and the first few decades of the 20th century. Households with high land use intensity were at a disadvantage in terms of both labor availability and the suitability of their land for market-rational use. Extensification, often through household abandonment, was therefore more rapid for parcels owned by households that did not invest in land. But as the stepped WoE analysis of fire and land use change shows, actual shrub encroachment and afforestation was more likely on lands less suitable to fire use. This means that landscape level compatibility and landscape memory remained relatively intact with regards to fire use on private lands.

In areas where landscape level compatibility of parcel-level land use was effectively subordinate to the property regime, fire use became problematic. For example, in the 1920s and 30s, the majority of “illegal” fire intrusions reported by forest guards occurred in forest service plantations on south-facing slopes. In these locales, the property regime no longer functioned in its role of ensuring distribution of provisions to households residing within the community. Instead, entities outside of the commune expropriated the regime to a variety of ends (e.g. timber and tourism). As Eric Wolf suggested, exogenous forces undermine the integrity of local socioecological systems partly through the expropriation of “strategies of ownership and inheritance,” (1972: 203).

However, Wolf believed local socioecological systems degraded as exogenous forces subjected land to disposal by households and individuals through the processes of commodification. While perhaps a truism in general, in Larrau, the local system also benefited from the disposal of lands. Parcels of abandoned households were mostly absorbed by households that were extensifying as they entered into market-based production through specialization in livestock production. Impartibility of the household estate remained the rule, and when households were abandoned, lands were transferred as integral bundles of parcels (e.g. entire household or *borde* properties) to the active farms of relatives and neighbors. This respect for the integrity of land and community, even by those who opted out, maintained the system for another century. The loss of agropastoral lands to shrub encroachment and afforestation was predominantly compatible with the new market-oriented land use strategies as well as the continued use of fire as a land management tool.

Landscape transition is ongoing. As more farms are abandoned in the future, the fragmentation of land use compatibility will worsen. The degradation of landscape memory in areas of high topographic fire use suitability has the potential to change the benevolence of fire use to the system. This is already the case in the eastern part of the Pyrenees.

Theoretical Implications

Landscape Memory

Conventional notions of the relationship between landscape and land use suggest that humans modify and shape the landscape patterns through physical manipulation of vegetation, soils, and terrain. Understanding how Basque farmers “control” pastoral fires requires that we move beyond one-way conceptions of land use and management. Concepts such as “socioecological systems” or “coupled human-natural systems” provide a more complex picture of land use, suggesting that the human relationship with landscape is reciprocal or dialectic. In this dissertation, I suggest that the concept of landscape memory best explains the utility of pastoral fire, in terms of ecological and socioeconomic efficiency and efficacy. The concept of landscape memory adds a third dimension to reciprocal interaction between social and ecological systems: it adds time.

The sustainable use and occupation of landscapes requires constant human action in the maintenance of spatial and temporally contingent ecological process and pattern. Landscape memory facilitates discussion about how people entrain and harness processes of ecological disturbance over time to manage those landscapes for both short and long term productivity. Cultural values, socioeconomic demands, and the institutions upon which human action is premised form the proximal drivers of systemic persistence and change. But these forces are predicated on historically contingent socioecological conditions. Landscape memory thus provides a way to conceptualize the degree to which past processes constrain or facilitate human action through structural legacies.

Property Institutions, Land Use Intensity, and Fire

In order to fit humans into their analyses, fire researchers have often relied on antiquated notions of culture type, grossly generalized historical epochs, and coarse-grained estimations of population density (Bowman, et al. 2011; Guyette, et al. 2002). This approach ignores human agency and collapses a diversity of sociocultural parameters influencing human-fire-landscape interactions into a one dimensional metric. Such analyses reflect a common tendency in conventional ecological analyses to fit complex processes into deterministic statistical models (Clark 2005). Yet the approach fails to provide generalizable results. For example, despite persistent efforts, researchers have failed to find a consistent linear relationship between population density and fire regime (Prentice 2010).

Typological characterization of human behavior is insufficient for understanding actual socioecological interactions such as the effects of fire management on the landscape. The analysis in Chapter 4 shows that the spatiotemporal distribution of fire and fire severity may be sensitive to fine scale shifts in land use intensity that vary across historically contingent institutional gradients. Indeed, the differential distribution of land at the household level significantly affects land management strategies at the parcel level. Chapter 5 shows that feed-back cycles with lagged responses exist between demographic and institutional changes. In some contexts, these may have significant effects on fire management. Further, transitions between “types” of socioeconomic strategies such as “subsistence” and market-orient farming are not clear cut. Some households may transition earlier while others transition later. Still other households may exhibit prolonged hybrid “transitional” economic strategies. Lastly, social and ecological legacies may allow for new forms of land use without making significant changes in fire use practices.

These findings are especially important for paleoecological investigations of the extent and intensity of fire use. Sampling strategies must make full use of available historical and archaeological information in order to account for sociopolitical complexities that may have differentially affected land use and land use intensity at a fine scale.

Implications for Land Management

Agricultural Policy

Agricultural policies should encourage land uses that maintain landscape memory. Agricultural policies and subsidies should neither force farmers to compete with commercial agriculture nor to return to pre-commercial land use strategies. Markets have played a significant role in the socioecological system for over 100 years. Farmers require subsidies in the form of infrastructure that helps them develop niche markets for their products, rather than try to compete with lowland commercial agriculture.

Fire Use

The landscape changes associated with the cessation or exclusion of fire use are not inherently problematic for the future conservation and management of the landscape.

If land use change conforms to the logic of the management system, successional processes may not pose a challenge to continued fire use. The key is identifying locations where fire use is required to maintain the functional compatibility of land uses at the landscape level.

Considering these guidelines, the legacy of forest plantations in areas of high topographic fire use suitability presents a problem for sustainable management. Land managers should consider removing these to ensure more compatible land use. Given appropriate weather and climatic conditions for traditional fire use, fire spread should not be enclosed by the "artificial" limits of property boundaries. Further, while parcel owners may retain the right to exclude fire, these owners must also shoulder the responsibility of ensuring that fire does not spread to their parcels. In the absence of a sufficient number of actively farming households, commune employees should be tasked with conducting burns on both communal and private lands within the commune's territory.

Lastly, educating tourists and the general public on the risks of encountering pastoral fire in the mountains should be the task of regional and local governments and non-governmental organizations that promote tourism and recreational land use. If the scenic and ecological benefits of an agrarian landscape are to be enjoyed by the public in general, the costs of fire management cannot be borne by individual farmers alone. Pastoral fire is an ecosystem service. It is only dysfunctional under conditions where the property regime is used to justify and enforce the maintenance of incompatible land uses.

References

Arrizabalaga, Marie-Pierre
2005 Succession strategies in the Pyrenees in the 19th century: The Basque case. *The History of the Family* 10(3):271-292.

Bowman, David M. J. S., Jennifer Balch, Paulo Artaxo, William J. Bond, Mark A. Cochrane, Carla M. D'Antonio, Ruth DeFries, Fay H. Johnston, Jon E. Keeley, Meg A. Krawchuk, Christian A. Kull, Michelle Mack, Max A. Moritz, Stephen Pyne, Christopher I. Roos, Andrew C. Scott, Navjot S. Sodhi and Thomas W. Swetnam
2011 The human dimension of fire regimes on Earth. *Journal of Biogeography* 38(12):2223-2236.

Clark, James S.
2005 Why Environmental Scientists are Becoming Bayesians. *Ecology Letters* 8:2-14.

Guyette, R. P., R.M. Muzika and D.C. Dey
2002 Dynamics of an Anthropogenic Fire Regime. *Ecosystems* 5(5):472-486.

Kain, Roger JP and Elizabeth Baigent
1992 *The cadastral map in the service of the state: A history of property mapping*. University of Chicago Press.

Prentice, I. C.
2010 The Burning Issue. *Science* 330:1636-1637.

Wolf, Eric R.
1972 Ownership and Political Ecology. *Anthropology Quarterly* 45:201-205.

APPENDIX A

DATA COLLECTION AND PROCESSING PROTOCOL FOR

RECONSTRUCTION OF HISTORICAL CADASTRAL RECORDS

Cadastral Documents

Task and Purpose

Cadastral records from 1830 onward provide fiscal land use categories and ownership changes necessary for understanding human-landscape interaction at the "parcel" level. Parcels are patches of land delineated cartographically in order to assign and delimit ownership and tax value. Where parcel boundaries are not demarcated by fences, walls, or ditches, they are physical land boundaries formed by topography, soils, hydrology, and/or vegetation manipulated, organized, and managed by humans for the purpose of land use. As such they are not only cognitively meaningful from the perspective of the specific techno-economic system they serve, but are also ecologically significant in form and function. As relatively unique patches of land cover, parcels reciprocally interact with a variety of ecological disturbances many of which are directly related to human land use type and intensity. Land use intensity is a measure of the relative technological, material, and labor inputs over a given area (i.e. per hectare). In landscapes such as the French Pyrenees, where parcels represent discrete land use practices, historical cadastral records that trace the changes in land use through time present the data necessary for understanding the relationships between land use and occupation.

In combination with an ethnographic understanding of land use, tenure, and inheritance practices, fiscal land use categories and transfers of ownership of parcels in cadastral records provide a window into past land use intensities. For example, fiscal land use types, row crop, hay meadow, pasture, and woodland receive specific kinds and/or amounts of inputs through use and maintenance. Land use potential is a function of the perceived suitability of a particular area's environmental template (soils, topography, hydrology) to a particular range land uses. Given this range, people make preferential decisions as to what to do where and in the process construct the landscape mosaic comprised of differentiation between parcels in terms of size, shape, and usage. However, land use change concerning within parcel variability is ultimately driven by the household level economic strategies that manage labor, technology, and material acquisition and use within. Because land use was taxed at different rates intended to capture the "value" of land in terms of productivity and improvements (labor and capital investments), tax values actual provide an index of land use intensity. Changes in a household's tax assessment can therefore provide an index of changes in that household's total land use intensity.

The task was to link the written cadastral records 1830 to 1957 with the GIS shapefile of the 1830 cadaster and the 1958-1997 records with the 1958 (2003) cadaster shapefile. To do this, we built a geodatabase by transcribing the data from images into tabular format for 2 quartier (neighborhoods). The database allows us to trace parcel attribute changes across years and thus understand both change and continuity in socioecological processes through time. Because households make choices to buy, sell, or retain parcels, a record of parcel ownership gives us a history of household decision-making in terms of livelihoods and wealth creation and retention. Changes in parcel nature provide clues to household production strategies, but also allow us to link ecological changes to changes in household production strategies.

Data Description and Explanation

The data set consists of 2 formats: cartographic and tabular. Two sets of analogue cadastral base maps from 1830 and 2003 were labeled with parcel key codes corresponding with associated tabular data. These maps were digitized using ArcView and tabular attribute data was entered into an excel spreadsheet.

The 1830 map sets correspond with tabular data of the same year, but contain a few unresolvable topological errors. The survey is organized into 7 sections and 4,881 individual parcel shapes. Each individual map represents a section, A through G. In each section, parcels are numbered consecutively beginning with 1. The system corresponds with the tabular attribute data through reference to both section letter and parcel number. The 2003 map corresponds with tabular data from 1997, thus introducing a small amount of topological uncertainty related to changes between 1997 and 2003. The 2003 maps use the same section-parcel system, with sections carrying over, but parcel numbers changing. The parcel count for the 2003 map is 5,358. Parcel shapes were linked to tabular attribute data in ArcView and exported to an Access Geodatabase file.

The non-cartographic tabular data consisted of 5 multi-volume ledgers with tabular cadastral records that correspond to the two maps (1830 and 2003) but contained unmapped changes. Raw data was captured with a 3.1 megapixel resolution digital camera by fitting individual leger pages into the photo frame. All pages in each leger were photographed except where a page contained no data entry. Digital photos were downloaded into a laptop computer and organized on site in folders reflecting the original order and structure of the data.

- **Document A,** *"Matrice Cadastral, le 8 Fevrier 1832,"* (Figure A1) records changes for parcels (1832 to 1911) and taxable buildings, including houses, mills, and factories (1832-1880) within the commune of Larrau. Alpha-numeric parcel numbers correspond with the 1830 Cadastral map key. Duplicate copies of the original legers were located in the communal archives at the office of the secretary of the mayor of Larrau and in the departmental archives, located in Pau. While the majority of data was collected on site in Larrau, missing information for the 1830 cadaster was obtained from the copies in Pau.

- **Document B,** *"Matrice Cadastral, 1912"* records changes for parcels following document A (1912-1957). However datasheet numbers (see below) were not carried over. Consequently, it is necessary to use the index to look up the name of last owner of the datasheet of interest from the previous cadaster.

- **Document C,** "*Matrice Cadastral, 1958"* follows changes made after document B (1958-1973), but uses an updated cartography based on a new geodetic survey. The cadaster more or less follows the same organization of data but contains new parcel numbers, datum, and topology. The organization of the ledger is roughly alphabetical, but it is not entirely consistent and is not indexed.

- **Document D**, "Matrice Cadastral des Properietes Baties 1881" follows taxable buildings from 1881-1910.

- **Document E**, ""Matrice Cadastral des Properietes Baties 1911" follows taxable buildings from 1911-1957.

For each of these legers, aggregate data summarizing changes in a variety of ways appears in the front of the ledger. The main body of the ledger is concerned with individual changes in parcels and is organized by parcel owners. The ledger assigns a numerically indexed “datasheet” to each parcel owner (corporate or individual), such that one datasheet contains all of the parcels owned by one owner.

The ledger documents three types of information on an annual basis:

(1) Changes in parcel attributes: use (*nature*), size (*contenance*), and tax revenue (*revenu*).

(2) Market exchanges of parcels between owners, expressed as the transfer of parcels between datasheets (parcel exchange network).

(3) Inheritance of parcels from person to person, expressed as the transfer of all parcels within a datasheet from owner to new owner (inheritance network).

Changes in Parcel Attributes

Ledgers document changes to parcel use (*nature*), size (*contenance*), and tax revenue (*revenu*). These changes are interrelated since revenue is a function of both use and size. Consequently changes to use or size translate to changes in revenue. Revenue changes independent of changes in use or size only occur between ledgers and not within. Changes in parcel size imply the creation of a “child” parcel. Child parcels were denoted by the addition of “p” after the parcel number. However the parent parcel retained its number. Parcel “splits” resulting multiple children were all assigned a “p” such that duplicate parcel numbers exist in the data set. Below we explain the novel parcel numbering system initiated for data entry and management of these duplicate parcel IDs.

Parcel Exchange Network

In addition to recording changes to individual parcels, the datasheets document changes in what we might think of as an individual portfolio of land ownership at any given point in time. Parcels owned collectively by two or more individuals or corporate groups are assigned to their own datasheet and therefore comprise their own portfolio. Owner name ("*noms des proprietaries et usufruitiers*") may refer to individuals, head of household, or 'head' of corporate group consisting of individuals and/or households. Portfolios range from one to hundreds of parcels. Therefore, datasheets often comprise multiple pages in the ledger.

Parcels bought or sold are exchanged between people and are thus added to or deleted from people's land ownership portfolios. Exchanges take the form of an ego-network structure where the datasheet is the ego and datasheet of origin and/or destination are directionally networked nodes. Columns exist for recording the date a parcel enters the datasheet and date it leaves.

Inheritance Network

A portfolio of land ownership is a legally distinct estate. As an estate, portfolios are inheritable. Portfolio inheritance is recorded in the left-most column of the datasheet as consecutive list of owners' names and date of inheritance. These lists constitute a linearly progressing inheritance network. In this sense, a portfolio is also an inheritance network. The inheritance network links carries a portfolio through time and across documents.

Data Entry and Transformation

Documents and document metadata were entered into a separate database table. We assigned each document an alias letter (as above) that served as a prefix for the numbered datasheets belonging to that document. So, for example for Document A, *Matrice Cadastral, le 8 Fevrier 1832,* we assigned the prefix "A," for Document B we assigned "B", and so forth, such that datasheet 45 in Document A is denoted as A45.

In order to transform the data into analyzable format, we designed a relational database organized around capturing the three main types of information: parcel attributes (tbl_parcel_Att_change), parcel exchange (tbl_Parcel_Exchange), and inheritance (tbl_person). Parcel numbers served as the common linkage between the parcel attribute table and parcel exchange. In theory, datasheets served as the common linkage between parcel exchange and inheritance. However, datasheets were document dependent and did not transfer over time. This meant that A45 did not refer to the same portfolio of land ownership as B45. Because such portfolios are inherited over time, they remain stable, albeit abstract, entities across documents while datasheets, owners, and parcels change. We therefore assigned each discrete portfolio a unique identifier (tbl_portfolio [portfolio_alias]) and linked it to its associated datasheets in a recursive table (tbl_Datasheet_Network) that uses recursive binary associations (Table A1). Thus, the parcel exchange table is linked to the inheritors through the portfolio number while both sets of information are tied to the analogue data structure through the datasheet network.

Table A1. Example of the datasheet network showing that information pertaining to changes in portfolio "12" is located in datasheet A197 and B458.

Portfolio	**Document**	**Datasheet**	**Datasheet Code**
12	A	197	A197
12	B	458	B458

We began database construction by importing the attribute data associated with the 1830 cadastral parcel map (tbl_1830Cad_raw). This data had been previously transcribed from the photocopied data sheets into a spread sheet format as attribute data for the digitized parcel map. First, we copied the 1830 data into two tables: (1) tbl_Master_Parcel_list is the baseline parcel list with the original parcel attribute information following the format of document A (see Table A1), (2) we used the 1830 data to populate tbl_Person with the selection of (unique) owners' names, address, and professions. We assigned a portfolio number to each owner and an inheritance date of 1830 (since we didn't know the actual date of inheritance). We then used the owners' names to link the parcels in the tbl_1830Cad_raw to portfolio numbers and used this list to populate the tbl_parcel_exchange. We assigned an 1830 exchange date to each "transactions," left "parcel_in" blank, populated "Parcel_out" with the parcel number, left "portfolio_in" blank, and populated "portfolio_out" with the appropriate number portfolio number (Table A2).

Table A2. Example of the parcel exchange table.

Date	Portfolio in	Portfolio out	Parcel in	Parcel out
1830		1002		E32
1835	1002	1045	E32	E32

Data entry forms were designed so that data could be entered systematically and sequentially for each datasheet following the original data organization. However, behind the façade of the forms, the queries tied to the forms were designed to parse data and feed it to the appropriate table. The data entry process involved a stepped sequence of forms that ensured all tables were updated seamlessly as datasheets were completely entered. Data entry was initiated in the first form by entering a new datasheet code (e.g. A197) and associating this code with the name of the first owner listed on the datasheet. So for example if we begin with datasheet A197 where the first proprietor is a person named “Behety Jean dit Ostal”, we use a form to query the name in tbl_Person and relate the name to datasheet code by entering “A197”. This in turn ties “Behety Jean dit Ostal” to portfolio “12” by associating portfolio with the datasheet in the “datasheet out” field of tbl_datasheet_network.

The next task is to assign the portfolio an institution type usually inferred from the initial owner’s name: household or corporate group. For the above example, the name Behety Jean dit Ostal means that Jean Behety is called by the name Ostal which signifies his household name. Therefore portfolio 12 is belongs to a household called Ostal. This information is entered on the form and fed into the table tbl_portfolio. Successive inheritors names entered on the form fed into tbl_person. Portfolio and associated institutional information from the first entry carries over automatically so that it does not need to be re-entered.

Once the Portfolio ownership and inheritance has been entered, parcel exchanges are entered. Sales and purchases are entered through separate forms because the analogue data is ego-centered while the digital organization is recursive. For parcel sales, the worker initiates the form by entering the datasheet number. As parcel sales are entered the portfolio auto fills into the “portfolio_in” field through the link made in tbl_datasheet_network. For each instance, the worker enters the date and the original parcel number in the field “parcel_in”. If the parcel is sold in its entirety, the parcel number stays the same for the field “parcel_out” and the share field is “100”. If the sale is partial, the worker enters a new parcel designation by adding the letter “a”, e.g. E56a and enters the destination datasheet. If the owner sells both portions, the worker must then repeat the entry, but create a new parcel number by adding the letter “b”. If the owner keeps a portion, the worker will enter this as recorded in the analogue datasheet which designates such transaction as a “purchase”. However, the worker must be careful to remember to assign the appropriate letter designation to the newly split parcel.

On the next form, all parcels that have entered the portfolio since 1830 are entered along with any changes that may have occurred into tbl_Matrice_Cadastral_Post1832. Parcels are queried via a drop down list box so that information could be verified and retained without risking further data entry errors. Changes in parcel attributes were not made by editing the original data, rather by entering each change into a recursive table that asks for parcel number, date, attribute type, and the new value (tbl_parcel_att_change).

These same protocol, with slight modifications, were followed for entering data from documents B and C. All data was entered in “phases” so that folios were not missed in the process of following parcels through ownership changes within each Matrice ledger. Modifications to data entry protocol were made as needed for each phase. So, for example, since Phase 1 included all owners of parcels in the sample area beginning in 1830, it was necessary to complete a “find unmatched query” between entered folios and folios listed in the “vendu” column (the destination of folio of sold or otherwise transferred parcels). Phase 2 therefore included all of the folios receiving parcels transferred from Phase 1 folios and Phase 3 included all folios receiving parcels transferred from Phase 2 folios. For Phase 4 we moved on to document B and it was necessary to modify the forms and initiate new tables in order to maintain the integrity of the original data.

Defining the subsamples for data entry

Data proved too expansive for complete entry given time and funding constraints. Consequently we systematically selected subsamples of the data. We began by defining one neighborhood (*quartier*) of interest, Arbide. We defined the boundaries of the quartier based on the 1830 Cadastral map. With the exception of one borde (barn and surrounding fields) in section D of the 1830 map, Arbide was contained completely within section E, however section E also included the *bourg*, a densely housed neighborhood that comprises the village nucleus and includes the church, mayor's office, businesses, and much of the commune's best arable land. Section E also includes a large amount of the common forest and pasture utilized by the villagers. Consequently, the southern and western boarders of the Arbide quartier subsample follows the main route to the south which conceptually defines the quartier and where this did not fit our sampling needs (i.e. included too much from the *bourg*) we used streams.

Data subsamples included all owners of parcels within the selected quartier beginning with the 1830 cadastral record. This entailed an initial entry of 32 portfolios for Arbide. All parcels were entered regardless of whether they occurred inside or outside the quartier boundary. Portfolios that received parcels from the original 32 portfolios were added in the second phase, only if those parcels were inside the Arbide quartier sample area. This phase added 38 portfolios to the subsample. Subsampling continued following the logic new portfolios were entered if they obtained parcels within the designated sample area until all parcel transfer paths had been exhausted.

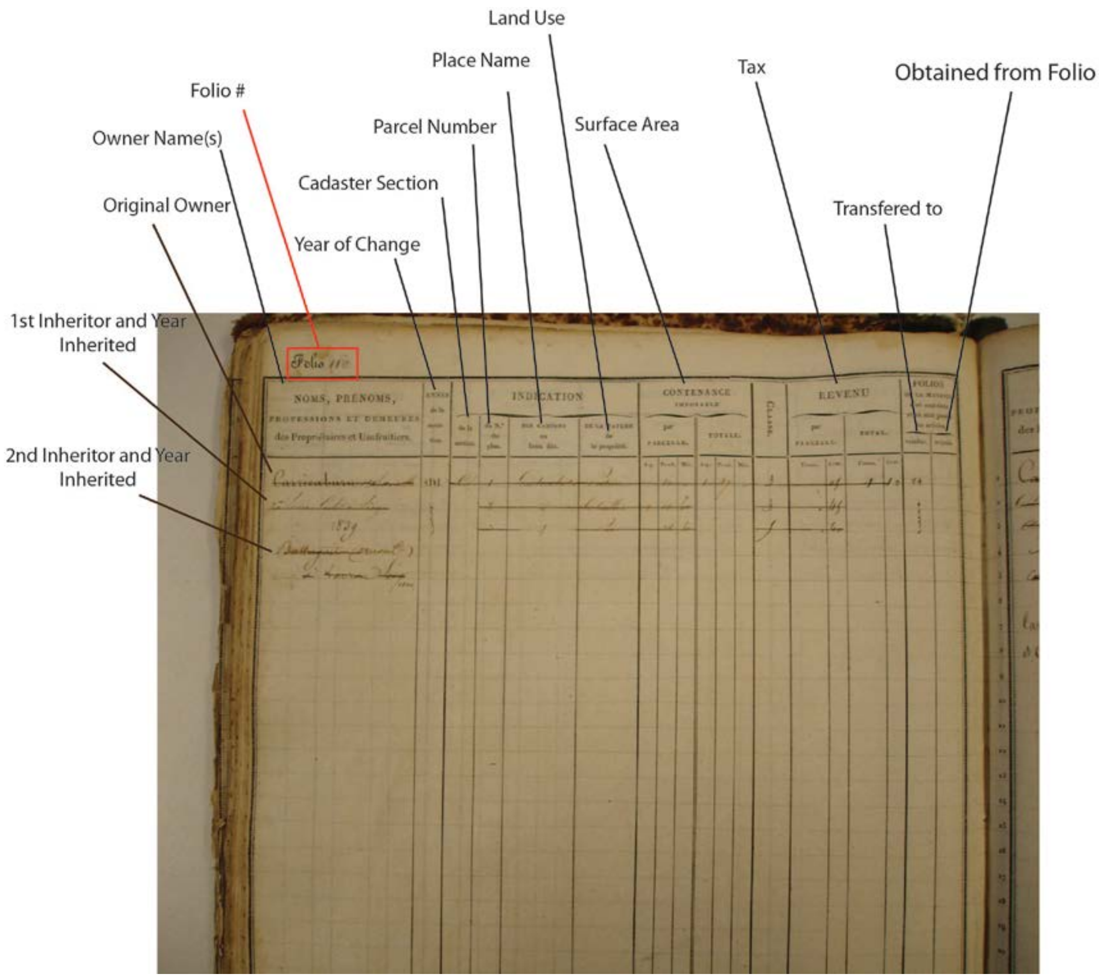

Figure A1. *Matrice Cadastral, le 8 Fevrier 1832*