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ERRAKINA: PASTORAL FIRE USE AND LANDSCAPE MEMORY IN THE BASQUE REGION OF THE FRENCH WESTERN PYRENEES

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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.

Key words: *fire use, fire management, historical ecology, landscape memory, French Western Pyrenees*

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.

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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

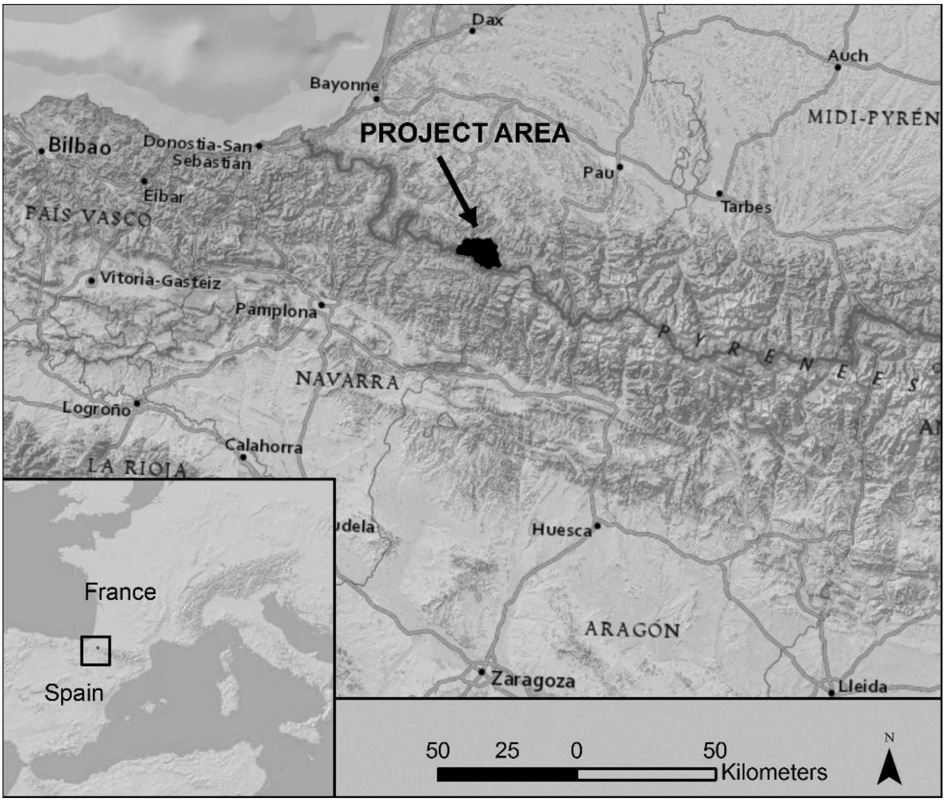

Figure 1. Map of project area. Cartography, Michael R. Coughlan. Image courtesy of ESRI, Inc. under creative commons licenses CC By-NC-SA 3.0.

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 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.

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: $\mathbf{P(D \mid B) = P(B \mid D)\ P(D)\ /\ P(B)}$, where $\mathbf{P(D)}$ is the probability that **D**, which represents a known sample, occurs in a sample space given no other evidence. $\mathbf{P(B)}$ is the probability that **B** occurs in the same space, and $\mathbf{P(B \mid D)}$ 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 km²) into a grid of 30 m² 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 m² 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 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

Figure 2. Fires burn dry pastures along the slope, but do not penetrate woodland or hay meadows. Photograph by Michael R. Coughlan.

employees of the valley 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). 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. 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 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 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). 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 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) suggest strong associations between pasture persistence and fire use (Figure 4). 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.

Table 1. Initial WoE results for significantly correlated evidence classes. See Table 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

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 through a

Table 2. Final WoE results for significantly correlated evidence classes. ''Topo Combo'' layer represents the combined presence of slope, roughness, and elevation classes (Table 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

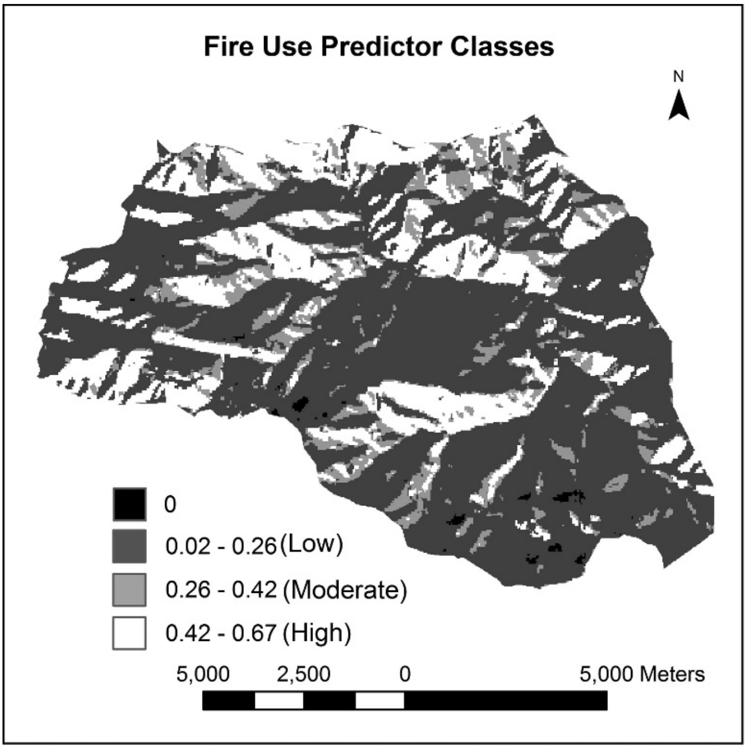

Figure 3. Fire use predictor classes derived from a prediction efficient curve of WoE posterior probability of fire use for the project area.

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

Table 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

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.

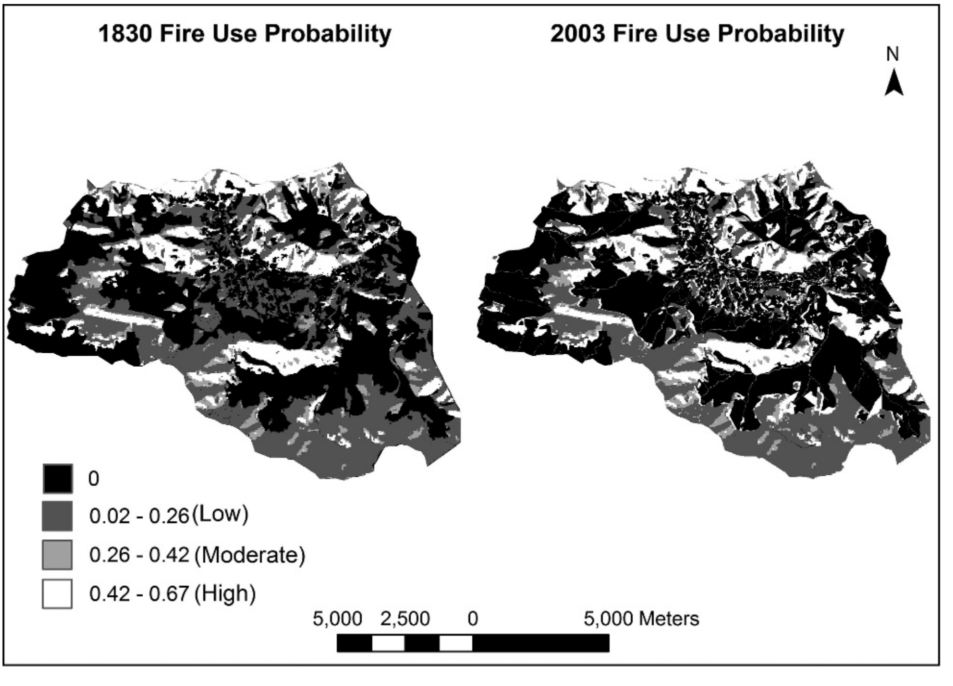

Figure 4. Fire use predictor classes for 1830 and 2003 pasture area.

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 in other 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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