Forgetting Fire:
Traditional Fire Knowledge in Two Chestnut Forest Ecosystems of the Iberian
Peninsula and its Implications for European Fire Management Policy

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HIGHLIGHTS

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- We compare the impact of state fire exclusion policies in two chestnut forest ecosystems.
- Our analysis integrates biophysical and human system methodologies and evidence.
- Differences between forests are useful for considering Traditional Fire Knowledge.
- Our findings are contrasted with those of the E.U. sponsored FIRE PARADOX project.

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Abstract

Human beings have used fire as an ecosystem management tool for thousands of years. In the context of the scientific and policy debate surrounding potential climate change adaptation and mitigation strategies, the importance of the impact of relatively recent state fire exclusion policies on fire regimes has been debated. To provide empirical evidence to this ongoing debate we examine the impacts of state fire exclusion policies in the chestnut forest ecosystems of two geographically neighbouring municipalities in central Spain, Casillas and Rozas de Puerto Real. **Extending the concept of ‘Traditional Ecological Knowledge’ to include the use of fire as a management tool as ‘Traditional Fire Knowledge’ (TFK), we take a mixed-methods and interdisciplinary approach to** argue that currently observed differences between the municipalities are useful for **considering the characteristics of “pre-industrial anthropogenic fire regimes” and their** impact on chestnut forest ecosystems. We do this by examining how responses from interviews and questionnaire surveys of local inhabitants about TFK in the past and present correspond to the current biophysical landscape state and recent fire activity (based on data from dendrochronological analysis, aerial photography and official fire statistics). We then discuss the broader implications of TFK decline for future fire management policies across Europe particularly in light of the published results of the EU sponsored FIRE PARADOX research project. In locations where TFK-based **“pre-industrial anthropogenic fire regimes” still exist, ecosystem management strategies** for adaptation and mitigation to climate change could be conceivably implemented at a minimal economic and political cost to the state by local communities that have both the TFK and the adequate social, economic and cultural incentives to use it.

Key words: Fire exclusion policies; traditional ecological knowledge; traditional fire knowledge; Chestnut forest ecosystems; FIRE PARADOX

“This universe, which is the same for all, has not been made by any god or man, but it always has been, is, and will be an ever-living fire, kindling itself by regular measures and going out by regular measures”.

Heraclitus

1. INTRODUCTION

Contemporary ecology understands that many ecosystems **can be considered “fire adapted”**, **their** structure and function being partly determined by the fire regimes with which they have co-evolved (Gill, 2002; Pausas and Keeley, 2009). Humans have often played a long-standing role in such fire-adapted ecosystems. Anthropogenic landscape burning is believed to have had a significant ecological impact on the Earth system for thousands of years and in many flammable ecosystems worldwide it has become a key ecological process conditioning present biodiversity and climate (Stewart 1957; Ruddiman 2003; Bowman et al. 2009). However, biomass burning has also been recently determined to be an important contributor to the global greenhouse gas emissions causing climate change, though the impact of anthropogenic fires on net emission outputs is highly uncertain and remains widely debated within the scientific community (Hurteau and Koch, 2008; Fule et al., 2008; Fernandez-Muñoz, 2012; Moritz et al., 2013; IPCC AR5, 2014; Gill et al., 2014).

In the context of the scientific and policy debate surrounding potential climate change adaptation and mitigation strategies, researchers continue to discuss the importance of the impact of state fire exclusion policies on fire regimes. Fire exclusion policies have been defined as the attempt to exclude all types of landscape fires from a specified area (Scott, 2015). One of the first contemporary large-scale attempts at implementing a state-wide fire exclusion policy was carried out by the United States throughout the 20th century prompting other countries receiving its technical advice and forestry aid funds, such as Spain, to follow suit (Donovan and Brown, 2007; Seijo and Gray, 2012). At the end of the 20th century it has become apparent that the effects of fire exclusion policies **on fire regimes may be provoking what some researchers have termed a “firefighting trap”** (Collins et al., 2014). **By altering historical fire regimes and landscape fuel structures, state fire exclusion policies may well be contributing to contemporary “megafires” that seem to positively feedback with anthropogenic climate change** as well as spiralling fire suppression costs in many countries (Millar et al, 2007; Seijo and

Gray, 2012; Pezzatti et al., 2013; Stephens et al., 2014; Fernandes et al., 2014). In this **volatile and uncertain scenario, theoretical concepts such as “applied historical ecology” and “pre-industrial anthropogenic fire regimes” have been advanced in an attempt to** come to terms with the role that historical fire patterns (in general) and traditional anthropogenic fire practices (in particular) should or should not play as a baseline for informing future fire management decisions (Swetnam et al., 1999; Keane et al., 2009; Seijo and Gray, 2012; Pezzatti et al., 2013; Gill et al., 2014; Petty et al., 2015).

Traditional ecosystem management practices are reliant on ‘traditional ecological knowledge’ (TEK), defined as, **“the cumulative body of knowledge, practice, and belief,** evolving by adaptive processes and handed down in generations by cultural transmission, about relationships of living beings [including humans] with one another **and with their environment”** (Berkes, 2000:8). A variant of TEK but with particular regard to the use of fire as a management tool, traditional fire knowledge (TFK) has more recently been defined as, **“fire-related knowledge, beliefs, and practices that have been developed and applied on specific landscapes for specific purposes by long time inhabitants”** (Huffman, 2013:1).

Decline of the use of TEK and TFK can lead to significant changes in ecosystems. Some of the first descriptions of these **impacts appear in Omer C. Stewart’s collection of essays “Forgotten Fires” (Stewart 1957), which has inspired this article’s title.** In his 1950s pioneering work, Stewart identified diverse TFK-based fire uses by native Americans for ecosystem management and described some of the ecological **consequences that emerged when these practices were “forgotten”.** Today, the gradual abandonment of traditional land use – resulting in a loss of both TEK and TFK – has been recognized as one of the main structural factors leading to the emergence of so-called **“Large Wildland Fires”** across Mediterranean Type Ecosystems in Europe (Seijo and Gray, 2012; Galiana et al., 2013; Pezzatti et al., 2013; Montiel, 2013; Stephens et al., 2014; Fernandes et al., 2014). Much of the literature now acknowledges that socio-economic and political drivers are at the core of this change (Seijo, 2005; Seijo and Gray, 2012; Pezzatti et al., 2013; Fernandes et al., 2014). However, little attention has been paid to the exact mechanisms by which state fire exclusion policies – which have been shown to be ecologically, economically and politically undesirable (Seijo and Gray, 2012; Montiel, 2013) – and rural development policies have impacted TEK and

TFK. For example, in the Iberian peninsula these policies often set the stage to the enclosure of large tracts of land for new industrial era uses (eg. afforestations, conservation areas, recreational hunting estates, etc.) and the prohibition of traditional land use practices such as extensive animal husbandry and swidden agriculture (Fernandes et al., 2014). These changes shifted rural economies away from approaches that required the use of TFK-based practices and therefore contributed to rural abandonment (Seijo and Gray, 2012; Stephens et al., 2014). It is important, therefore, to re-evaluate the fire management potential of TFK-based practices, particularly since continent-wide European Union funded research projects such as FIRE PARADOX are calling for a reform of present fire suppression based management strategies and advocating for the promulgation of new European legislation on the matter in the form of a **“Fire Framework Directive”** (Montiel, 2013).

As an evidence-based contribution to this ongoing debate, in this study we examine the current biophysical attributes of two adjacent sweet chestnut forest ecosystems of the Iberian Peninsula **and local inhabitants’ perspectives on** pre-industrial anthropogenic burning within them. The present existence of chestnut forest ecosystems throughout Europe was only made possible by centuries of intense management by local communities (Conedera et al., 2004; Conedera and Krebs, 2008). In fact, the chestnut forest ecosystems of the study sites we consider in this paper – the municipalities of Casillas and Rozas de Puerto Real in the foothills of the mountains of Gredos, central Spain – can be theoretically described as coupled human-natural systems because of the historically verified, prolonged and intense interaction between human and natural system variables in them (Liu et al., 2007). Communities in this region have managed their chestnut forests with a sophisticated ecosystem management toolkit that exemplifies TEK and TFK. Through time these communities actively participated in the design of their chestnut forest ecosystems through terracing, grafting, pruning, careful tree specie selection and burning in what can be most aptly described as a pre-industrial effort at large-scale environmental engineering (Martin et al., 2010).

Changes in the use of TEK in coupled human-natural chestnut forest ecosystem management have been known to result in substantial transformations in both their structure and function as natural succession processes resume unaltered (e.g. Mazzoleni et al. 2004; Romero-Calcerrada and Perry 2004; Millington et al. 2007; Millington et al.

2009). Such change in forest stands formerly dominated by chestnut trees has been observed in Corsica, for example, with the encroachment of mixed and closed-canopy stands dominated by Holm oak (*Quercus ilex* L.) and Cluster pine (*Pinus pinaster* Ait.) following abandonment (San Roman, et al., 2013). In Bulgaria, in the absence of traditional management, chestnut forests have apparently become increasingly vulnerable to pest disturbances such as chestnut blight (Zlatanov et al., 2013), and in Switzerland the loss of ecologically valuable old growth **“giant” chestnut trees is feared** – as well as the emergence of significant fire regime changes – as the anthropogenic silvicultural practices of the past fade away (Krebs et al., 2012; Pezzatti et al., 2013).

In an effort to restore ecosystem structure and process in abandoned chestnut forest ecosystems a debate is thereby emerging concerning the appropriate role of traditional pre-industrial era burning in the ecological restoration of these ecosystems. Some researchers advocate for continued use of TFK-based practices or surrogate prescribed burning (Grove and Rackham, 2000; Seijo and Gray, 2012; Fernandes et al., 2013) in contrast to others who argue it should be limited to certain specific sites where the goal is the conservation of locally endangered species associated via coppiced (or abandoned) chestnut stand communities (Grund et al., 2005; Moretti et al., 2006; Moretti, 2008; Pezzatti et al., 2013).

Here, we take a mixed-methods and interdisciplinary approach to explore these issues, integrating both quantitative and qualitative methods, to capture and understand the complexities and feedbacks between coupled human and natural systems in our sites (Bryman, 2006; Liu et al., 2007). We compare contemporary fire regimes, landscape characteristics and use of TEK-based landscape burning practices in two Spanish municipalities and argue that currently observed differences are useful for considering **the characteristics of “pre-industrial anthropogenic fire regimes” and their impact on** chestnut forest ecosystems. We do this by examining how responses from interviews and questionnaire surveys of local inhabitants about TFK in the past and present correspond to the current biophysical landscape state and recent fire activity. We then discuss the broader implications of TFK decline for fire management policies across Europe.

2. METHODS

2.1 Study species and site selection

The sweet chestnut (*Castanea sativa* Mill.) is a deciduous, hardwood angiosperm tree species belonging to the Fagaceae family. It has been widely cultivated throughout the temperate world, particularly across the Mediterranean Basin in areas with abundant precipitation and its geographical range is closely associated with the activities of pre-industrial traditional agrarian societies (Conedera et al., 2004). Currently, sweet chestnut forests are mainly concentrated in southern Europe (France, Italy, Spain, Portugal and Switzerland) and Turkey where there is a long tradition of their cultivation as groves for nuts and wood production (Conedera et al., 2004). The species itself seems to be native to the Iberian Peninsula with pre-Holocene glacial refugia having been identified in primary and secondary foci located in N and W Spain and N Portugal regions (Krebs et al., 2004; Postigo-Mijarra, 2010). The chestnut forest ecosystems of our study area are located in the foothills of the mountains of Gredos (central Spain). These forests, in all likelihood, originated in the 13th and 14th centuries as a result of the **anthropogenic diffusion of sweet chestnut after the “Reconquista” (Reconquest) and the subsequent “repoblación” (re-population)** of these territories with social groups originating from Northern Spain, though further palynologic and genetic research would be needed to confirm this hypothesis.

Our data collection was conducted in the municipalities of Casillas, autonomous community of Castilla y León, and Rozas de Puerto Real (hereafter abbreviated as Rozas), autonomous community of Madrid (Figure 1) from June 1st, 2012 to May 31st 2013. These municipalities are contiguous geographically but separated by a political boundary between autonomous communities in the Spanish state (Figure 1). Site selection was informed by a **previously articulated conceptualisation of “pre-industrial anthropogenic fire regimes” in Mediterranean Type Ecosystems (MTEs)**, which hypothesizes that uneven economic and political development processes have driven, to varying degrees, the fire regime changes taking place at present in many MTEs (Seijo and Gray 2012). Casillas and Rozas have differing economic conditions (Table 1), but relatively similar mountainous MTEs. Casillas has lower family income and municipality expenditure than Rozas, with a smaller proportion of the local population employed in the service sector and a greater proportion in agriculture. By selecting these sites we have endeavoured to ensure that the biophysical variables underlying any

differences in fire regimes could be held (as far as possible in a natural non-laboratory setting) constant so as to better highlight the ecological effects of different fire management recently. This is a proven methodological approach that has yielded interesting findings on changing fire regimes in other MTEs (Minnich, 1983).

2.2 Biophysical Data

To assess the current biophysical state of the municipalities' forests and their fire regimes we used National Forest Inventory data (IFN3 2007), fire reports from autonomous communities, dendrochronological sampling and military aerial photographs from 2011. Individual fire reports for the two municipalities were received from the regional autonomous governments of Madrid and Castilla y Leon for the period 1984–2012. In this study we have only quantified the fire regime attributes that can be inferred from official Spanish government fire statistics for the selected sites. These include information on fire regime characteristics, frequency, size, season and causality. Comparable figures for both municipalities were only available for the period 1984–2009. **Aerial photographs were received from the “Centro Geografico del Ejercito” of the Spanish army.**

We used dendrochronology to estimate the age of chestnut stems apparently not affected by recent fires. We took cores at 1.3 m from dominant trees ($n = 11$ in Rozas, $n = 18$ in Casillas) randomly selected in each site and not presenting visible ‘catfaces’ (cavities at the foot of the trunk with darkened burn markings), using a Pressler increment borer. We sampled non-fire scarred trees distributed as broadly as possible across each of the two study areas. All wood samples were air dried, sanded using several papers of successively finer grains until tree-rings were clearly visible and then visually cross-dated. The sampling area was approximately from 1 to 3 ha in each study site.

We interpreted forest stand structure (i.e., primarily canopy cover) in the two selected study sites/municipalities using historical aerial photographs (see Figure 3). **Aerial photographs were obtained from the Spanish army's geographical services and included** color photographs for 2011 for both Rozas and Casillas. To analyze the data we placed a grid over the existing cartography for the two municipalities and numbered each grid cell (Nowak et al. 1996). Using a random number generator 74 grid cells (plots) were

selected for analysis (Rozas n=27 Casillas n=47). Only complete grid cells were analyzed while plots crossing municipal boundaries were discarded. Grid cells including buildings, roads, orchards and other man-made infrastructures were also discarded. Grid cells for the municipality of Casillas covered 5.2 hectares while grid cells for Rozas covered 7.3 hectares. To visually estimate foliage cover in both sites we used a standardized comparison chart in order to determine the canopy cover for each grid cell. To describe the structure of each grid cell we developed a stand structure code with the following characterizations: no canopy (a), open, mixed-canopy stand (b), closed mixed-canopy stand (c), closed and small-canopy stand (d), open and small-canopy stand (e), open and large-canopy stand (f) and closed and large-canopy stand (g) (see Figure 3).

[INSERT TABLE 1 NEAR HERE]

[INSERT FIGURE 1 NEAR HERE]

2.3 Human Activity and Perceptions Data

Between September 2012 and May 2013 we interviewed and carried out a survey among 54 randomly selected respondents in the municipalities (n=29 Casillas; n=25 Rozas). The respondents were asked to identify their individual preferences to a series of questions on a Likert scale while, simultaneously, the qualitative justifications for these responses were recorded by the interviewers. The survey itself was divided into four sections: land use, land tenure, fire use and demographic related questions. As in other similar survey-or interview-based studies this design was conditioned by the research questions (Mistry, 1998; Fernández-Giménez and Fillat, 2012). The surveys/interviews were administered and completed face-to-face with respondents by the principal investigator and other collaborators since, as has been the case in other research studies on TEK taking place in Spain, many respondents were functionally illiterate or had problems reading, understanding or answering the written questions on their own (Otero-Rozas et al., 2013). The questionnaire itself contained 83 semantic differential scale and rank order type questions, 38 multiple choice and 13 open-ended questions.

Questions examined in this paper refer to inhabitants' perspectives on fire causes, fire sizes, attitudes towards fire and fire use (see Table 2). To test for possible differences in answers between groups of respondents (e.g. between municipalities), non-parametric Mann–Whitney U tests were used to compare median values of coded responses (all results are reported at the 95% confidence level).

[INSERT TABLE 2 NEAR HERE]

3. RESULTS

3.1 Biophysical Characteristics

3.1.1 Forest cover and land use results

Based on National Forest Inventory data (IFN3, 2007), forests within the municipal territory of Rozas de Puerto Real are composed mainly of six tree species, namely: *C. sativa*, *Quercus pyrenaica* Willd., *P. pinaster*, *Pinus pinea* L., *Quercus ilex* and *Fraxinus angustifolia* Vahl. In Rozas 40.7% of rural lands are forested while 55.8% form pastures and shrubland (**including 'dehesa'**). A **'dehesa'** is an extensive area which is generally, but not always, enclosed, with low densities of old growth trees that allows multiple pasture and arable farming practices in the spaces between (e.g. see Millington et al. 2007). The most important agricultural crop in Rozas is wine which covers 3.2% (Caja España, 2012) and the most extensive tree species is *C. sativa* which is estimated to occupy 39% of Rozas forested surface (442 ha). In Casillas, IFN3 data identifies *C. sativa*, *P. pinaster*, *Q. pyrenaica*, *Pinus sylvestris* L. and, to a lesser extent, *Pinus nigra* J. F. Arn. as the main tree species. In Casillas 52.9% of rural lands are forested, while 42.1% are pasture and shrubland and 4.8% are agricultural land. The chestnut forests of Casillas occupy approximately 24% of all forested land (155 ha), though this figure may be, in fact, larger since it only accounts for chestnut trees employed for nut production. Other chestnuts are classified as timber wood and may constitute a large proportion of the remaining 483 ha of the forested surface.

Chestnut forest groves in Rozas and Casillas exhibit subtly different stand structures as can be appreciated in Figure 2. A significant proportion of chestnut forest patches in both Rozas and Casillas are composed of young saplings re-sprouting from root systems. These chestnut trees grow in closed canopy, coppiced stand formations. Results from our dendrochronological sampling indicate that tree stems in chestnut

groves are on average younger in Rozas than in Casillas, with median age 64 years and 96 years respectively. Furthermore, survey respondents claimed that the young chestnut forests of Rozas are apparently the result of salvage logging implemented after the **“large fire” event that took place in 1985. Many chestnut** stems in Rozas, therefore, seem to be of the same age cohort though there are also disperse patches with what seem like older chestnut trees and younger individual saplings seemingly planted from seed and managed for timber rather than chestnut production. In Casillas chestnut groves seem to be slightly older overall with trees growing from single stems though younger *C. sativa* and *Q. pyrenaica* saplings are increasingly encroaching into these patch types. **Many of Casillas’** older chestnut trees are regularly pruned, grafted and planted in front of old terraces to both contain erosion and favour chestnut production.

[INSERT FIGURE 2 NEAR HERE]

Aerial photo analysis (see Figure 3) reveals that current landscape structure in the municipalities is similar. The main differences that do exist are the proportion of the landscape with 'open, no canopy' patches (greater in Casillas), **and ‘open, large canopy’** patches (greater in Rozas; Table 3). In the former case this may be the result of Casillas greater elevation, slope inclination and granite outcrops which impede trees from **growing in some areas. In terms of the greater abundance of ‘open large canopy’ patch types in Rozas this is likely the consequence of the presence of large “dehesa” type *Q. ilex*** patches which sustain sizeable cattle and horse herds. In Casillas livestock is composed mainly of sheep and goats with some cattle grazing on the treeless mountainous pastures and shrublands during the summer months.

Patches of *C. sativa* are difficult, if not impossible, to discriminate purely from an aerial photo analysis since this specie can be easily confused with other deciduous species common to both municipalities (such as *Q. pyrenaica*, *F. angustifolia*) and even from evergreen pine species. Structure types in our analysis therefore include all tree species types mentioned in the IFN3 data. Though the aerial photo analysis sheds little light on the quantitative extent of differently managed chestnut forest patches in both municipalities it does help us interpret differences between burned area and fire size differences in the municipalities (see Section 3.1.2).

[INSERT TABLE 3 NEAR HERE]

[INSERT FIGURE 3 NEAR HERE]

3.1.2 Individual fire reports

Official statistics for 1984–2009 indicate that 76.9% of fires in Casillas were classified as “surface” fires, 11.5% as “crown” fires and 11.5% as “mixed-severity” fires. **In Rozas all incidents were classified as “surface” fires. The total number of recorded fire incidents during 1984–2009 in Casillas was 52 whereas in Rozas it was 31.** Fire incidence in Casillas peaked in 1989, 1995 and 2009 with 8, 4 and 10 recorded fire incidents. In Rozas fire incidence peaked in 1989, 1999 and 2005 with 3, 3 and 4 recorded fire incidents. Median burned areas are similar (Rozas 0.41 ha, Casillas 0.42 ha) but once differences in territorial size are accounted for, burnt surface per year was larger in Rozas than in Casillas by a factor of 10 ($2.12 \text{ ha km}^2 \text{ yr}^{-1}$ compared to $0.22 \text{ ha km}^2 \text{ yr}^{-1}$). **Rozas experienced a 1,257 hectare “large fire” (official statistical definition: >500 hectares)** in 1985, whereas in Casillas the largest fire during the study period burned 20.7 hectares in 1989. In both municipalities the fire season peaked in the summer months (JJA) but in Casillas fires were more evenly spread out throughout the calendar (Figure 4). In Casillas fires in spring (MAM) and autumn (SON) months accounted for a greater proportion (53%) of fire events than in summer months (47%). This is in contrast to Rozas where summer months accounted for the vast majority of events (71%) with spring and autumn months contributing far less (29%). Finally, 77% of fires in Casillas had a verified anthropogenic origin, 21% were caused by unknown factors and 2% by lightning. In Rozas 58% had an unknown origin, 39% were anthropogenic and 3% were ignited by lightning. In many cases fires classified as **“unknown” in both municipalities probably had an anthropogenic cause but if forest agents are unable to verify that this is the case they must classify it as such in the official report.**

[INSERT FIGURE 4 NEAR HERE]

3.2 Perceptions and Traditional Fire Knowledge

3.2.1 Survey on perceptions of fire

There is a statistically significant difference between municipalities regarding perspectives on causes of past fires, but not for fires in the present (Table 4). Differences seem to be driven mainly by views of inhabitants of Rozas, many of whom disagree or disagree strongly that past fires were accidental and agree or strongly agree that past fires were intentional (Figure 5a). In contrast, opinion on the importance of accidental or intentional causes of past fires in Casillas is divided. Inhabitants of both municipalities predominantly disagree that the cause of past fires was natural (inhabitants of Rozas holding views more strongly than Casillas, Figure 5a). Regarding present fires, respondents in both municipalities predominantly agree that most fires at present are intentional in origin, disagreeing that they are accidental or natural (Figure 5b), and there are no significant statistical differences between municipalities for any class of present cause (Table 4).

[INSERT TABLE 4 NEAR HERE]

[INSERT FIGURE 5 NEAR HERE]

Perspectives on fire size in the past and present vary to differing degrees between municipalities. We detected a statistical difference in the perspectives of inhabitants between the two municipalities with regards fires *at present* (Table 5). Inhabitants of Casillas generally perceive fires at present to be larger than inhabitants of Rozas (Figure 6). There is no statistically significant difference between municipalities in their perspectives on past fires (Table 5), although the median response for Casillas is smaller than for Rozas (Figure 6; 2.0 vs 7.0 respectively). There is a statistically significant difference in perspectives on sizes of present vs past fires for inhabitants of Casillas (Table 5), with inhabitants perceiving fires to be larger now than in the past (Figure 6). There is no statistical difference between perspectives on present vs past fire sizes in Rozas (Table 5), although median response is smaller for fires at present compared to the past (Figure 4; 1.5 vs 7.0 respectively).

[INSERT TABLE 5 NEAR HERE]

[INSERT FIGURE 6 NEAR HERE]

There are no statistical differences between the municipalities in terms of median responses to questions about their attitudes towards fire (whether bad, good, destructive, necessary, useful; Figure 7). Furthermore, inhabitants of both municipalities clearly **perceive fires as ‘bad’ and ‘destructive’ (most respondents replied strongly agree) and not ‘good’ (most respondents replied strongly disagree).**

[INSERT FIGURE 7 NEAR HERE]

3.2.2 TFK survey and interviews

As can be seen in Figure 8, fire is perceived as a useful ecosystem management tool by a large proportion of the survey respondents in both municipalities. The most important perceived utility ascribed to anthropogenic burning is as a tool for understory burning under woodland, in general, and useful trees (i.e. chestnuts), in particular. In both municipalities more than 60% of the respondents believed this to be the case. A second important fire use identified by respondents is both to improve fertility and clear shrubs or trees from arable land. Again, in both municipalities around 60% of the interviewed locals responded favourably to the use of fire for improving arable land fertility with about 50% in Casillas and approximately 40% in Rozas believing fire to be a useful tool for clearing land from shrubs and trees for agricultural cultivation. In terms of using fire to improve or clear land for pasture about 40% of respondents in both municipalities believed this to be the case with a slightly higher percentage of positive responses in Rozas. Finally, about a fifth to a quarter of respondents in Casillas and Rozas, respectively, identified fire as being a useful tool for improving habitat for hunting species.

[INSERT FIGURE 8 NEAR HERE]

By asking the respondents to elaborate on their rationale for these responses we developed a more detailed content analysis of the body of TEK–TFK (Table 6). At least 14 different reasons for using fire as an ecosystem management tool were identified, many of them connected to the adequate care of chestnut forest ecosystems.

[INSERT TABLE 6 NEAR HERE]

In the course of conducting the survey/interviews, respondents commented on important qualitative aspects of human system developments affecting the natural environment in their municipalities. These comments could not be quantified but provide the necessary background to the discussion in Section 4.

Of 25 interviewees in Rozas, 9 highlighted the importance of “**Los Reginos**”, an entrepreneurial family based in the neighbouring town of Sotillo de la Adrada, as the driver of the significant land tenure changes taking place in the municipality throughout the 20th century (1920s–1980s). Interviewees claimed that by using both their political and economic pre-eminence as the main employers in the area, “**Los Reginos**” registered many “montes comunales” (communal lands) with no written property titles under their name or forced their employees, many of whom were small landowners, to sell their land in exchange for employment and/or political protection. For example, as one interviewee noted;

“Los montes eran todos del pueblo. Los Reginos se hicieron con todo a base de emborrachar a la gente y haciendoles firmar con malas artes. Lo compraron todo a traves de unos encargados que tenían.”

(“The “montes” belonged to the village. The Reginos took them over by getting people drunk or forcing them to sign with devious methods. They bought everything through some representatives they had”).

During the first years of the new democratic period “**Los Reginos**” further consolidated these larger estates by buying off small landowners through other means. As another interviewee explained;

“Yo vendi a los ‘Reginos’ obligado prácticamente porque no limpiaban sus fincas y así yo no tenía acceso a las mías. Para eso mejor venderlas.”

(“I was practically forced to sell to the Reginos because they didn’t clean their land plots and so I couldn’t reach mine. So before they disappeared I chose to sell to them”).

In the 1980s “**Los Reginos**” sold their lands, in turn, to wealthy families from Madrid for use as recreational hunting estates. This decades-long process of land grabbing may

have generated some conflict within the municipality, according to some survey respondents, and may constitute the social setting leading to the large fires in the municipality. As an interviewee put it;

“Pueblo pequeño, infierno grande. Hay mucha rivalidad y enemistad entre los que tienen fincas grandes y pequeñas. En Rozas los fuegos han sido todos por venganza”

(“Small town, large hell. There is a lot of enmity between those who have large and small estates. In Rozas all the fires are motivated by revenge”).

Regarding the Comunidad de Madrid’s forest and rural development policies, many interviewees from Rozas complained about a certain disdain or even hostility on the part of the authorities towards traditional ecosystem management practices associated with stockbreeding or agriculture. As an interviewee in Rozas observed;

“Antiguamente la Comunidad pagaba para limpiar el monte ahora ya nada. Hace poco dieron algo para hacer unas rutas de senderismo pero ahora estan abandonadas”

(“Some time ago the regional government would pay for us to keep the forests clean but now nothing... Lately, they spent some money in creating some hiking paths but those have also been abandoned”).

This same interviewee also expressed his dismay about having to apply for burning permits and paying a tax for them;

“Ahora hay que pagar para quemar €1 o €1.5 por metro. En seguida vienen los helicópteros cuando quemas algo ahí estan encima”.

(“Now you have to pay to burn about €1 or €1.50 per square meter and as soon as you burn they send the helicopter to control you”).

Finally, another interviewee openly accused the authorities of mismanaging the few forestry projects that are actually funded **in the municipality’s communal lands**;

“El monte publico esta sin arboles. Hace 8 años se repoblo con castaños y se gastaron unos €118.000 pero no se cuidó y desaparecieron”

(“The comunal lands have no trees. About 8 years ago they reforested with chestnuts and they spent about €118,000 but they didn’t take care of them and they disappeared”).

Even the management of hunting estates, which seems to be the main land use priority for the Comunidad de Madrid’s regional government in the municipality,

does not escape the scrutiny of Rozas inhabitants. As an interviewee from Rozas told us;

“Antes habia cebada, trigo, centeno, algarroba y claro las perdices eran como gallinas. Ahora como esta todo a monte no hay mas que jabalíes y estos no las dejan criar”.

(“In the old times the fields were planted with barley, wheat, rye and carob kernel and the partridges were like chickens. Now everything is abandoned and there’s only wild boar because the boar eats the partridges’ eggs”).

In Casillas interviewees also manifested their discontent with the Castilla y Leon community authorities thought to a lesser extent than in Rozas. When asked to compare the management of chestnuts in both municipalities an interviewee in Casillas succinctly told us;

“El castaño en Rozas es de propiedad comunal y aquí en Casillas es todo privado y por eso esta bien”

(“The chestnut groves in Rozas are communal whereas here in Casillas its all private that’s why here it’s well kept”).

However, the same interviewee noted increased interventionism on the part of the regional authorities on privately owned chestnut forest groves and traditional management practices in them;

“Estos bosques los han plantado nuestros padres y abuelos y ahora tienes que pedir permiso hasta para hacer una poda, no hay derecho.”

(“These trees were planted by our grandparents and parents and now you have to ask for a permit even to prune them. It’s unfair”).

Since, in the 1950s and 1960s, the regional government of Castilla y Leon was perceived as being more supportive in its policies of pine tree plantations than chestnut forests, criticism of the regional government’s forest policies appear in a subtler manner such as in this quote from another Casillas interviewee;

“Estoy de acuerdo en que planten mas castaños. Pinos no. La castaña se puede vender a la cooperativa y sacar una renta pero la madera de pino ahora no la quiere nadie, ni la resina tampoco”

(“I think that more chestnut trees should be planted not pines. We can sell the chestnuts to the cooperative but no one wants the pine wood now or the resin”).

4. DISCUSSION

4.1 Contrasting anthropogenic fire regimes

According to Guyette et al. (2002: 473), “an anthropogenic fire regime can be defined as patterns of wildland fire shaped by the dynamic interactions of vegetation [fuels] and **human populations [ignitions] whether voluntary or involuntary**”. Following this definition it is clear that present fire regimes in both Casillas and Rozas are anthropogenic in character since less than 4% of forest fires are ignited by lightning in both municipalities according to official governmental statistics. The contrast between present anthropogenic fire regimes in both municipalities is, however, quite remarkable. In Casillas most ignitions seem to fit within the rationale of what we argue constitutes a **“pre-industrial anthropogenic fire regime” based on TFK burning practices (Seijo and Gray, 2012)**. This is rendered most evident by the fire season and frequency data obtained from the official municipal individual fire reports (see section 3.1.2). Most fire incidents in Casillas still take place in the traditional fire season (i.e. autumn and spring months, Figure 4) and seem to be linked to the management devoted to the production of chestnuts, firewood and, occasionally, timber or other uses compatible with and related to TFK management goals (see Table 6).

In Rozas, on the other hand, the vast majority (71%) of fires occur in summer months, seemingly corresponding to the **markedly different rationale of an “industrial or post-industrial anthropogenic fire regime” with fire regime attributes in all likelihood linked** to different land use (greater abandoned shrubland in Rozas), land tenure (larger land holdings used as hunting estates) and the abandonment of traditional fire use (Seijo and Gray, 2012; Huffman, 2013; Fernandes et al., 2014). This is not to say that absolutely all fire incidents in both municipalities respond to the aforementioned theoretical characterizations. Some fire incidents in Rozas may indeed respond to the logic of the **“pre-industrial anthropogenic fire regime” (fires linked to pastoral or chestnut understory burning which then burned out of control to unintended areas) and vice versa** for Casillas.

Fires in Rozas are less frequent than in Casillas but have a much larger mean size (see section 3.1.2). While official fire statistics in Casillas actually registered far more fire incidents than in Rozas (by a factor of almost 2:1) annual burnt surface in Casillas was inferior to Rozas by a factor of 1:24. In other words, more frequent, traditional seasonal burning in Casillas produces less burnt annual forest surface overall than in Rozas. This difference may be an indirect consequence of both the fuel structure of chestnut grove forest stands resulting from frequent TFK-based burning (open with larger, older trees; Figure 2) and the fire season preferred by TFK practitioners (unintended fire escapes are likely to be less common if burning takes place during the less dry and hot Spring, Autumn and Winter months; Figure 9, Table 6). In addition, Casillas, in spite of having a smaller fire return interval than Rozas, has not experienced any large fires during the 1984–2009 period while in Rozas a “large fire” event took place in 1985. These results seem to replicate **Minnich’s (1983) findings on the contrast between fire regimes in Baja California (Mexico) – where during the time of his study state fire suppression policies had never been implemented – and California (USA) where active state fire suppression policies had been a part of the landscape since the beginning of the 20th century.** These findings have been confirmed and further refined in posterior comparative studies of fire regimes in both countries (Stephens et al., 2008).

[INSERT FIGURE 9 NEAR HERE]

4.2 Perceptions of past and present fire regimes

There seem to be some significant differences in the perception of fire between the **populations of both municipalities. In both, respondents believed that both “past” and “present” fires were anthropogenic in origin. Regarding “past” fires it seems that most of the respondents of Casillas perceive that most were “accidental” in nature while in Rozas most respondents believe those fires to have been “intentional”. Is it possible that these differing perceptions of causes of past fire demonstrate a greater empathy towards TFK based burning in Casillas than in Rozas in the present? If this were the case this could help explain, in part, the continued persistence of TFK based burning in Casillas today and its almost total disappearance in Rozas. However, in terms of “present” fires the survey evidence seems to be more contradictory, since most respondents in both municipalities perceive “current” fires to be mostly “intentional”. This perception in Casillas may be related to a succession of “atypical” arson fire events that took place**

during 2009 which resulted in the arrest and imprisonment of the arsonist. These arson fires were frequently mentioned in the course of the in-depth interviews in Casillas where respondents were eager to differentiate between the positive ecological effects and rationale of traditional fire use **and the “destructive” character of these arson fires.** **The perception on the “intentionality” of “past” and “current” fires in Rozas may be** related, on the other hand, to conflicts over land tenure and land use which many respondents, during the in-depth interviews, believed to have been the driving force of most fire incidents in the municipality in the recent past (see Section 3.2.2).

Other perceptions that are worth noting concern the size of fires and their “useful” or “destructive” character in both municipalities. A majority of respondents in Casillas believe that fires in the past were smaller than at present. Could this perception reflect, **again, the general impression left by the “atypical” arson fire events that took place in 2009** or could it possibly be related to a general sense that TFK based burning may be withering away as a result of young people not participating as much in these traditional practices? Perhaps this could also simply reflect differences in the property structure of both municipalities since individual plots are much larger in Rozas than Casillas, hence fires would always have been larger in Rozas than in Casillas both in the past and in the present (see Table 7). Finally, there is a perception in both municipalities that fires are **generally “bad” although, contradictorily, most respondents also believe that they are often “necessary” and “useful”.** **This generalized “negative” perception of fire may be expressing a “framing effect” resulting from fire exclusion policies implemented by the** regional forest agencies of Castilla y León and Madrid in both municipalities where all fires, including those related to TFK based burning, are depicted in governmental public information campaigns as destructive ecological catastrophes or crimes (Seijo, 2009; Paveglio et al., 2011; Altangerel and Kull, 2013). Such public opinion formation processes associated with the implementation of fire exclusion policies among local community practitioners have been observed elsewhere around the world (for example, in Mexico; Matthews, 2003).

[INSERT TABLE 7 NEAR HERE]

A final perception on TFK based fire use appeared during the interviewing process but cannot be quantified through the survey responses. These observations relate to the

adequate use of “a manta” (broadcast) vs “pile” burning techniques (Table 6). Some respondents argued that the most frequent burning technique in the past was **that of “a manta” broadcast rather than “pile” burning.**

4.3 Factors conditioning present TFK-based fire use in Casillas and Rozas

Why do we currently see more TFK-based landscape burning in Casillas but not in Rozas? This is an important question for fire management, particularly if future research verifies that TFK-based fire practices favour chestnut ecosystem resilience to disturbances and carbon sequestration. If this were to be the case, managers in these **ecosystems may deem it necessary to “retain or attain” (perhaps through prescribed burning surrogate techniques where traditional burning has disappeared) the “pre-industrial anthropogenic fire regime” either through rural development policies implementing “payment for ecosystem services” schemes or just simply by providing the adequate incentives for fire practitioners to continue doing what they are already doing** (Gill et al., 2014; Redford and Adams, 2009; Galiana et al., 2013). Although it is difficult to quantify the exact mechanisms whereby human system dynamics may be influencing this outcome we suggest that the answer to this question may lie in a series of interrelated social, political, cultural and economic transformations related to the **uneven impacts of the protracted “industrialization” and “post-industrialization” process** taking place throughout the second half of the 20th and the beginning of the 21st century in both municipalities, in particular, and more generally throughout Spain as has been suggested in other studies (Seijo and Gray, 2012).

An important factor that may play a role in the relative absence of TFK in Rozas is the different intensity with which fire exclusion and suppression policies have been implemented by the fire agency of the autonomous community of Madrid compared to that of Castilla y León. State fire exclusion policies seem to have, indeed, played an important role in determining the evolution of anthropogenic fire regimes not only in Spain but also throughout the world (Minnich, 1983; Kull, 2002; Seijo, 2005; Laris and Wardell, 2006; Stephens, 2008; Montiel, 2013; Fernandes et al., 2014). Political scientists have hypothesized, for instance, that the same international governance rural development or environmental policies may have contrasting impacts depending on the **relative “strength” or “weakness” of the implementing national state organizations** (Migdal, 1988; Scott, 1999; Guha, 2000; Goldman, 2005; Seijo and Gray, 2012). This

could very well be the case in Rozas and Casillas. As can be seen in Table 1 expenditure in fire exclusion policies in Rozas is higher than in Casillas by a factor of five. This could likely translate into a greater pressure on fire practitioners in Rozas to discontinue traditional burning. For example, in-depth interview respondents in Rozas noted that, frequently, when they lit a bonfire or conducted a pile burn in their fields, a forest agency helicopter would fly over them or a police (Guardia Civil) vehicle would appear in the scene (see Section 3.2.2). This is facilitated by the fact that the firefighting station for the Madrid forest agency is located only a few kilometres away in San Martín de Valdeiglesias. In Casillas, however, which is under the jurisdiction of the autonomous community of Castilla y León, forest agency pressure is much lower though, according to the survey respondents, it is also increasing.

Two other factors that may be playing a role in the different TFK-based practices in Rozas and Casillas concern developments in land tenure and land use since the 1950s. Today, property is concentrated in the hands of fewer owners in Rozas than in Casillas (Table 7). Correspondingly, the total number of ownership plots is greater in Casillas and mean plot area is an order of magnitude smaller than in Rozas. This was not always the case. The transformation in both land tenure and use in Rozas were driven by the entrepreneurial family known locally as "Los Reginos" (see Section 3.2.2). "Los Reginos" owned much of the local resin pine industry, and were thus the main employers in the region, and also dominated local politics during the dictatorships of generals Miguel Primo de Rivera (1923–1930) and Francisco Franco (1939–1975). After the large fires of the 1980s, significant land use changes took place in the larger properties **once owned by “Los Reginos”**. **Under the new owners these properties were** either transformed into recreational hunting estates or chestnut tree plantations for timber. Traditional chestnut recollection and its associated management practices were subsequently abandoned.

These transformations in land use and tenure may have eliminated much of the rationale for TFK-based burning in Rozas. The enclosure of the large hunting estates also blocked or made access to individual plots embedded within them difficult resulting in the abandonment of traditional management practices (see Section 3.2.2). The communal chestnut forests that still remain in Rozas may have also suffered a similar fate though for different reasons. EU and regional community forest agency rural

development projects have actively subsidized a “wildland” management approach for these forests since it is believed that urban “ecotourists” prefer a less disturbed “wild” natural environment for their recreational activities rather than a more kept “humanized” landscape (Mayor of Rozas, *pers. comm.* and Section 3.2.2). When compounded all of these factors create a very inauspicious environment for traditional fire practitioners in Rozas.

In Casillas, on the other hand, the industrialization process unfolded quite differently which may have led to a social environment more conducive to the continuity of traditional TFK based burning. In the 1970s the *P. pinaster* resin tapping industry in the area declined sharply because of increasing labour costs and the availability of synthetic substitutes for resin. In addition, resin tapping only provided seasonal employment for the inhabitants of Casillas in the first place. Both factors in all probability, halted the expansion of cluster pine plantations and their encroachment into chestnut forest groves, while simultaneously creating an economic incentive for the maintenance of the pre-industrial era chestnut groves as a complementary source of income to seasonal work in resin-tapping, industry or construction. In addition, the people of Casillas set up a cooperative to facilitate the commercialization of chestnuts which has led to an easy access to cash in exchange for chestnuts for its inhabitants (see Section 3.2.2). The combination then of a more divided property structure, stability in land use practices and economic incentives to maintain chestnut production has likely contributed to the continuity of traditional fire practices in the municipality.

4.4 Broader implications of TFK decline for fire management policies

The implications of these findings for the ongoing scholarly debates outlined in Section 1 of this article are important. The specific mechanisms by which TFK-based burning practices maintain ecosystem structure and function in traditionally managed chestnut forests (outlined in Table 6) has rarely been described in the literature, though it may be indispensable. Further research would therefore be needed to investigate longer time scales in order to fully verify these observations using, if possible, dendrochronology to rebuild the fire histories of these landscapes (Swetnam et al. 1999). Comparative research would also be necessary in other European regions (in the Mediterranean Basin and beyond), where chestnut forests are still managed traditionally but also in other sites

where traditional practices have been abandoned, so as to build a complete typology of the ecological rationale for TFK practices in these ecosystems.

The emphasis placed by Pezzatti et al.'s (2013) model for FIRE PARADOX on fire frequency and burnt area as quantitative indicators of changing fire regimes in chestnut forest ecosystems is particularly relevant from a policy point of view because, when other fire regime attributes are taken into consideration, it may be telling only a part of the story. Pezzatti et al.'s model does not account for crucial fire regime attributes in chestnut ecosystems such as fire season. As we have seen in Casillas, where TFK-based burning practices are more prevalent, the “pre-industrial anthropogenic fire regime” may well be characterized by a spring/autumn fire season as opposed to that in Rozas where the vast majority of fire events take place during the summer months (Figure 4; Section 4.1). Seasonality, then, is an important quantifiable indicator that, in view of our study's findings, should also be taken into account when identifying fire regime change points in chestnut forests as Pezzatti et al. (2013) do in their study.

Another aspect of Pezzatti et al.'s (2013) model for FIRE PARADOX that seems to require further refinement is related to the land use human system indicator chosen for quantification. Stockbreeding, though undoubtedly an important indicator of pre-industrial traditional land use practices associated with chestnut forest ecosystems, is not the only human system variable that may impact on their structure, process and disturbance regimes. Chestnut collection in both of our study sites seems to have been, in fact, the crucial socio-economic driver of traditional fire practices and forest stand structure and, should, therefore be taken into account as a valid human system indicator worthy of quantification.

Finally, Pezzatti et al.'s concluding “policy lesson”, as derived from their model's findings, regarding the proven effectiveness of “absolute fire bans” on reducing fire frequency and burnt area during certain historical periods seems to require further clarification, given our findings that large fires and burnt surface per year are greater in Rozas, where fire suppression policies are more strictly enforced. This is especially important when considering that the final objective of FIRE PARADOX is to provide an impetus for a new fire management paradigm in Europe that moves away from the

“ecologically undesirable” and “economically unfeasible” fire exclusion policies of the past (Pezzatti et al., 2013:17; Montiel et al., 2013:1).

If TFK-based fire practices are at the root of the “pre-industrial anthropogenic fire regime” we have characterized in this study, and to which chestnut forest ecosystems have become adapted through the centuries, **what can, or should be, done to “retain or attain” (Gill et al., 2014) them so as to maintain the ecologically desirable fire cycle that** has made possible the existence of these landscapes for centuries? A first necessary step would entail the scientific validation of the fire management strategies and uses articulated by TFK practitioners in Table 6. Second, the human system dynamics that favour the preservation of these TFK-based practices need to be identified and preferably quantified so as to better inform policymaking in similar ecosystems elsewhere. A third line for future research would imply studying the effects on biodiversity of maintaining the traditional pre-industrial chestnut forest ecosystem structure (Figure 2a) or abandoning it to change driven by succession and competition (Figure 2b). Anecdotal evidence obtained from the survey respondents indicates that in the absence of TFK practices and traditional land use, a range of animal species (rabbits, partridge, etc.) are substituted by others more adapted to abandoned chestnut forest landscapes (wild boar, roe deer, etc.). In these and other ecosystems in which TFK practices are declining, scientists and landscape managers will need to clarify and reconcile impacts with desired biodiversity and conservation goals (see Section 3.2.2).

What our findings seem to suggest – from a policy perspective – is that rural development policies that overlap and converge with the socio-economic effects of state fire exclusion policies can have a significant impact on fire regime change. This contrasts sharply with some of the conclusions of FIRE PARADOX (Galiana et al., 2013; Montiel, 2013). Galiana et al. (2013) affirm, for instance, **that, “It should be** recognized that large territories cannot be managed by means of agricultural or stockbreeding activities any longer; the abandonment of traditional forest management **is not to be reversed... The likelihood** of success is beyond the reach of the policies (ie. forest-related rural development EU initiatives) under analysis” (Galiana et al., 2013: 44). As our study sites show, however, rural development and fire exclusion policies (or **rather their “weak” or “strong” implementation) seem to have a significant impact on** changing fire regimes. Indeed, the emphasis placed by FIRE PARADOX on top-down

solutions to the issue of changing fire regimes in Europe through measures such as “Fire Framework Directives” or “Ecotourism” rural development initiatives will probably not accomplish much in motivating local communities to continue managing their landscapes with fire in the traditional manner. Evidence from Rozas suggests that “ecotourism” initiatives – by fostering a “wildland” approach to the management of chestnut forests – may in fact produce the opposite effect.

In sum, references to local community stakeholders’ preferences, attitudes and rationale regarding ecosystem management, state rural development policies and state fire exclusion policies are notoriously absent **or have been “forgotten”** – similarly to **observations on native American fire use practices in Omer C. Stewart’s time (Stewart 1957)** – in the published results of FIRE PARADOX and methods leading to their obtainment have not been contemplated with the exception of some questionnaires distributed among representatives of the Ministries of Agriculture and Rural Development, Environment and Civil Protection of various EU member countries (Galiana et al., 2013). This is unfortunate because some of the most promising leads in contemporary fire management seem to be emerging from non-state, local community initiatives as well as from state forest and forest-related policies that integrate local knowledge and practices (Agrawal et al., 2008; Raymond et al., 2010).

The clock, of course, cannot be turned back and it would be both impossible and undesirable to recreate the pre-industrial economic, cultural and social human systems that favoured the **expansion of Europe’s chestnut forests 2,000 years ago (Conedera, 2008)**. However, there exists a wide range of policy options available to managers who would find it desirable to maintain TFK-based practices in these (and similar) ecosystems, both as a means of conserving them but also possibly strengthening their resilience to likely future disturbance regime transformations linked to climate change in Mediterranean type ecosystems (Millar et al., 2007; CLIVAR, 2010; Fernandes et al., 2013). In chestnut forest ecosystems the simplest strategy would probably be to facilitate the profitable commercialization of chestnuts either by supporting cooperatives of producers, such as those existing already in Casillas, or through other locally tailored or Europe-wide marketing initiatives. Other options could include payment for ecosystem services (Redford and Adams, 2009) or even surrogate prescribed burning carried out by professionals that would complement or replicate the

small patch-burning mosaic pattern produced by TFK-based burning practices (Abott and Burrows, 2003; Bilbao et al., 2010; Fernandes et al., 2013).

5. CONCLUSION

Practices based on Traditional Fire Knowledge (TFK) in the chestnut forest ecosystems of the mountains of Gredos exhibit a level of sophistication that deserves further attention from scientific researchers, foresters and environmental managers. By **(attempting to) exclude fire from ecosystems that can be considered to be “fire adapted”, contemporary fire management policies may be ignoring** some promising leads as to how to manage and conserve such ecosystems in the future. This is particularly important in light of disturbance regime transformations likely to be induced by anthropogenic climate change in forest ecosystems. In locations where TFK-based **“pre-industrial anthropogenic fire regimes” still exist**, ecosystem management strategies for adaptation and mitigation to climate change could be conceivably implemented at a minimal economic and political cost to the state by local communities that have both the TFK and the adequate social, economic and cultural incentives to use it.

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TABLE 1. DEVELOPMENT LEVEL INDICATORS FOR CASILLAS AND ROZAS.
Income levels, employment sectors and other indicators were compiled to determine the uneven stages of development present in both study sites.

<i>Indicator</i>	<i>Casillas</i>	<i>Rozas</i>	<i>Year</i>	<i>Source</i>
Territory (km ²)	11.96	30.15	2011	Caja España
Population (no. of inhabitants)	841	466	2011	Caja España
GDP per capita (% of EU 27 average)*	98.80	135.80	2012	Eurostat
Family income (€ per capita)	16,290	23,929	2013	AIS
Municipality expenditure (€ per capita)	1,245	3,442	2011	Caja España
Municipal property tax (€ per capita)	181	237	2011	Caja España
Occupational sectors (% of population)			2011	Caja España
Agriculture	6.2	2.1		
Industry	0	1		
Construction	65.2	19.6		
Services	28.6	77.3		
Unemployed	24	16.2		
Regional government fire suppression costs (€ per hectare of territorial jurisdiction)	14	75	2006	ASEMFO

* Data are for the respective autonomous communities

TABLE 2. SEMANTIC DIFFERENTIAL SCALE QUESTIONS. Questions were grouped by topic and responses coded for analysis as shown.

<i>Topic</i>	<i>Question</i>	<i>Coding</i>
Fire Cause	On a scale from ‘None’ to ‘All’, how many fires were started in this municipality by the following causes? [accidental/intentional/natural] in the [past/present]	None = 0 All = 10
Fire Size	On a scale from ‘Small’ to ‘Large’ how large in area were the biggest fires in this municipality in the [past/present]?	Small = 0 Large = 10
Attitudes to Fire	On a scale from ‘Strongly Disagree’ to ‘Strongly Agree’, how do you agree with each of these statements about fire? [Fires are ... bad/good/destructive/necessary/useful]	Strongly Agree = 10 Strongly Disagree = 0
Fire Use	On a scale from ‘Not Useful’ to the ‘Best method’, how useful is fire for the following purposes? [Clearing land for cultivation/ Clearing land for livestock pasture/ Improving soil for cultivation/ Improving livestock pastures/ Eliminating shrubs and weeds underneath or near useful trees/ Eliminating shrubs and weeds in understory of forests/ Improving habitat for wildlife (e.g. rabbit, birds)]	Not Useful = 0 Best Method = 10

TABLE 3. LANDSCAPE COVER TYPES IN CASILLAS AND ROZAS. Percentages of different landscape cover types derived from aerial photo analysis (e.g. Figure 3) for 2011 are similar between municipalities except ‘Open, No Canopy’ and to a lesser extent ‘Closed, Small Canopy’.

<i>Landscape cover type</i>	<i>Casillas</i>	<i>Rozas</i>
ONC (open, no canopy)	21	7
OLC (open, large canopy)	17	26
OSC (open, small canopy)	0	0
OMC (open, mixed canopy)	15	15
CLC (closed, large canopy)	0	0
CSC (closed, small canopy)	13	19
CMC (closed, mixed canopy)	34	33

TABLE 4. RESULTS OF MANN-WHITNEY U TESTS COMPARING PERSPECTIVES ON FIRE CAUSES AT DIFFERENT TIMES (PAST AND PRESENT) BETWEEN MUNICIPALITIES. Values in bold indicate statistically significant differences between group medians relative to corresponding probability levels (p , at the 95% confidence level).

<i>Cause</i>	<i>Past</i>		<i>Present</i>	
	<i>U</i>	<i>p</i>	<i>U</i>	<i>p</i>
Accidental	141.0	0.003	205.5	0.091
Intentional	369.5	0.031	236.0	0.597
Natural	194.5	0.060	223.5	0.180

TABLE 5. RESULTS OF MANN-WHITNEY U TESTS FOR PERSPECTIVES ON FIRE SIZES BETWEEN TIME PERIOD (PAST VS. PRESENT) AND MUNICIPALITY. Values in bold indicate statistically significant difference between group medians relative to corresponding probability levels (p , at the 95% confidence level).

<i>Municipality</i>	<i>Period</i>	<i>U</i>	<i>p</i>
Casillas-Rozas	Past	189.5	0.214
Casillas-Rozas	Present	393.5	0.017
Casillas	Past-Present	523.5	0.014
Rozas	Past-Present	225.0	0.186

TABLE 6. COMPONENTS OF TRADITIONAL FIRE KNOWLEDGE IN CASILLAS AND ROZAS. Landscape Rozas was justified by survey respondents with various rationales which are classified here as ecosystem management

Ecosystem Management Strategy	Targeted landscape patch type or feature	TEK-TRF element
Agro-silvo-pastoral	Chestnut tree groves	Burn chestnut leaves so as to visually facilitate chestnut
	Chestnut tree groves	Burn leaves and understory so as to facilitate grassland as pasture or simply because the landscape looks “clean”
	Chestnut tree groves	Use fire to sift through the chestnut harvest. Fire roads burning into the holes made by perforating insects and separation of healthy from infected chestnuts and pre harvest chestnut harvest.
	Shrublands “Piornales” (<i>Cytisus</i> spp.) and “Escobares” (<i>Retama</i> spp.)	Some respondents maintain burning is useful for regenerating shrublands by favouring more palatable new shrub growth
Traditional landscape maintenance	Human-made stonewalls, roads, terraces and other landscape infrastructure	Eliminate annual growth from the “callejas” (paved, the terraces (“bancales”)).
	Chestnut tree groves	Burn remains of small diameter understory shrubs and firewood.
	“Acequias” (human-made irrigation ditches) and natural water courses	Unclog water courses from grass and weeds.
	Chestnut tree groves	Stop or slow down tree (<i>Q. pyrenaica</i> , <i>P. pinaster</i>) on chestnut groves.
	Forest structure and biodiversity	Use fire to keep the landscape visually “clean” and to remove foxes, vipers, etc.) near the village
	Forest structure	“Pile burning” used to maintain the understory clean so as to prevent wildfires.
Fire and smoke for plant disease control	Chestnut tree groves	Use leaf pile burning to “smoke” individual old growth argued that this was “good” for the trees to prevent fire. scientific justification were provided as to why this was

	Chestnut tree groves	Burning the leaves under old chestnut trees is believed to prevent chestnut bleeding canker (“tinta”) and chestnut blight (<i>Phytophthora cinnamomi</i> and <i>Cryphonectria parasitica</i>). about what technique to use in order to accomplish this “a manta” broadcast burning.
	Chestnut tree groves	Some respondents argued that it was also convenient to burn old-growth chestnut trees by piling leaves or straw in the groves so as to prevent fungal and insect attacks.
	Cultural Tradition	Chestnut tree groves
		Fire forms a part of the cultural feast of the “Calboter” in both municipalities around November 1 st . In this feast, the chestnut groves. The feast marks the end of the summer “grove” end of the chestnut harvest (depending on weather conditions).

Table 7. Indicators of property structure of rural lands in Rozas and Casillas. Data are from Caja España (2012).

<i>Indicator</i>	<i>Casillas</i>	<i>Rozas</i>
Total rural land owners	1,005	591
Total rural land ownership plots	5,874	1,448
Rural land area (ha)	1,208	2,969
Mean plot area (ha)	0.21	2.10

FIGURE 1. STUDY AREA LOCATION. Casillas is located within Comunidad de Castilla y Leon and Rozas within Comunidad de Madrid, both in central Spain.

FIGURE 2. “TRADITIONAL” VS “ABANDONED” CHESTNUT FOREST STAND STRUCTURE. Traditionally managed chestnut forest groves in Casillas (a, photo taken 26/11/2012) Rozas (b, photo taken 31/10/2013) Note how trees in a) exhibit an open stand structure compared to younger saplings re-sprouting from root systems in b).

FIGURE 3. EXAMPLE AERIAL IMAGERY USED TO EVALUATE LANDSCAPE STRUCTURE IN THE MUNICIPALITIES. a) Open Medium Canopy b) Open Large Canopy c) Closed Small Canopy d) Closed Mixed Canopy. Summary of the proportions of different structure types in the landscapes is shown in Table 3.

FIGURE 4. COMPARISON OF FREQUENCY OF BURNING BETWEEN MUNICIPALITIES BY SEASON. The majority of fires in Casillas occur outside summer months (characteristic for TFK practices in this area) whereas in Rozas the majority of fires occur in summer months.

FIGURE 5. PERSPECTIVES OF THE IGNITION CAUSE OF a) PAST and b) PRESENT FIRES BY MUNICIPALITY. Box plots show the median values, first and third quartiles, with whiskers extending to 150% of the inter-quartile range. There are statistically significant at the 95% confidence level ($P < 0.05$) differences between municipalities regarding accidental and intentional causes of past fires (see Table 3) driven mainly by divergent perspectives of inhabitants of Rozas. There are no statistically significant differences ($P > 0.05$) between municipalities for present fires. See Table 2 for questions and response coding.

FIGURE 6. PERSPECTIVES ON FIRE SIZES, PAST AND PRESENT, BY MUNICIPALITY. There are statistically significant differences at the 95% confidence level in responses regarding fires at present between municipalities and between fires in past and present in Casillas. See Table 2 for questions and response coding.

FIGURE 7. ATTITUDES TOWARDS FIRE BY MUNICIPALITY. There are no statistically significant differences at the 95% confidence level in responses between municipalities. See Table 2 for questions and response coding.

FIGURE 8. ATTITUDES TOWARDS FIRE AS AN ECOSYSTEM MANAGEMENT TOOL. Abbreviations as follows: *clear_arable* and *clear_pasture* are perceived usefulness of fire to clear land from shrubs and trees for new arable cultivation and pasture, respectively; *imprv_arable* and *imprv_pasture* are perceived usefulness of fire to fertilize existing arable fields or pastures, respectively; *rm_woodland* and *rm_forest* are perceived usefulness of fire to burn the understory of “wild” woodland (oak, ash, etc.) or under “domesticated” trees (olive, chestnut, etc.), respectively; and *imprv_habitat* is perceived usefulness of fire to improve habitat for huntable animal species (deer, roe deer, wild boar, partridge, etc.).

FIGURE 9. TRADITIONAL FIRE KNOWLEDGE FOR AGRO-SYLVO-PASTORAL USES AND TRADITIONAL LANDSCAPE MAINTENANCE. The ‘pile-burning’ technique involves raking (a), piling (b) and igniting (c) leaves. This contrasts with ‘a manta’ broadcast burning in which leaves and ground litter are burned across larger areas (as used in the area shown in d).

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