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Research Article

Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurrence

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Abstract

In this paper we test the hypothesis that landscape changes in a region of Northern Portugal (Minho) in the last 40 years could be predicted from socioeconomic and political history. The major predicted changes were related to agricultural abandonment and afforestation. We further predicted that these changes contributed to increased fire risk. Analysis of aerial photography for the years 1958, 1968, 1983 and 1995 in a study area of 3700 ha revealed a significant decline in agricultural areas and low shrublands and an increase in tall shrublands and forests. This represented a 20–40% increase in fuel accumulation at a landscape level, suggesting that the abandonment of farming activities is a major driving force of increasing fire occurrence in the region. With one exception, all the predictions were partly or totally confirmed. This study confirms that socioeconomic factors might explain a significant part of the variation in landscape composition across time, in the Mediterranean region.

Introduction

Farina (1998) defined a cultural landscape as a region in which human disturbance has occurred for thousands of years, creating a unique assemblage of patterns, species and processes. Cultural landscapes thus reflect the long-term interactions between people and their natural environment. Temporal changes in landscape patterns can be attributed to a combination of natural and human derived disturbances (Forman 1997; Dunn et al. 1991). In these human-dominated landscapes, change is mostly determined by socioeconomic factors (Etienne et al. 1998; Farina 1998) which are often ignored in studies of landscape change (Gardner and Turner 1991). In fact, relevant landscape changing processes such as agricultural intensification or abandonment, deforestation, fire suppression, livestock grazing or development (Farina 1998) are mostly determined by socioeconomic and political issues. Good examples of the importance of combining socioeconomic factors with the physical environment to fully understand patterns of change in human-dominated landscapes can be found in Parks (1991), Kienast (1993) and Simpson et al. (1994).

As in many cultural landscapes, the Minho region of northwestern Portugal is a fine-grained mosaic in which physiotopes (spatial units characterized by relatively homogeneous abiotic state factors; see Farina 1998) are traditionally well defined and utilized in different ways for agriculture, forestry and pastoralism. The size of this area is ca 2200 km^2, of which the predominant land cover types are forests and shrublands (65% of total area) and agricultural land (32%) (CCRN 1995). Population density is 113 inhabitants/km^2 (CCRN 1995). This region has the particularity of having the highest fire frequency in Europe, although the average size of the burned areas is small (European Commission 1996; Moreno et al. 1998). Analysis of the number and size of fires occurring in the region during the period 1988–

1995 (Direcção Geral das Florestas, unpublished data) showed that fire frequency was well over 25 fires/10 000 ha/year and that for most years median size was less than 3 ha (Moreira et al. unpublished data). Most fires are human-caused. Although there are no long-term data specific for this region, it is known that fire frequency in Portugal has increased mainly since the mid 20th century, along with rural exodus and decreasing intensity of agricultural use (Rego 1992).

In this paper we test the hypotheses that:

(i) *Landscape changes occurring across 40 years in a 3697 ha Minho landscape could have been predicted from socioeconomic and political events.* We started by making an overview of the major socioeconomic and political changes in the region during the last half century. As there were no rigorous data specific for the study area, we restricted our analysis to milestones occurring at the national or regional scale, which were certainly reflected in the study area. Secondly, we predicted how these changes might have been expressed at the landscape level. Finally, we characterized landscape changes in the area during the period 1958–1993 using aerial photographs and compared the measured changes with the initial predictions.

(ii) *The observed landscape changes contributed to an increased fire frequency in the region.* This hypothesis was tested using three different approaches. The first was the analysis of wildfire data (number of fires and total area burned) available for the study area. The second was based on theoretical models of fuel accumulation in the landscape, by attributing to each land use category an estimated fuel load. Multiplying the area of each land use by its fuel score yielded an index of fuel accumulation for the whole landscape. The latter approach was based on the present pattern of fire occurrence in the area. We characterized how 13 wildfires occurring in the period 1983–1995 used the landscape and with these data created and index of proneness to fire for each of the land use categories and subsequently for the whole landscape.

Methods

Study area

The study area (ca 41°53′ N, 8°33′ W) is located in Minho region (North-western Portugal) (Figure 1) and covers 3697 ha. It has a hilly topography with elevation ranging from 400 to 880 m. Yearly average precipitation ranges from 2000 to 2500 mm, falling all year round except July and August which have scarce rain. Annual average temperature is ca 14.5 °C. Mean maximum temperature in July is 25 °C, and mean minimum temperature in January is ca. 4°C (Ribeiro et al. 1987). Phytogeographically the region is located within the Eurosiberian region, Galicia-Portuguese sector, with *Quercus robur, Acer pseudoplatanus, Ilex aquifolium* and *Pyrus cordata* as characteristic species (Costa et al. 1998). This area was selected because it represents the general geomorphologic features of upland Minho region and previous information on land use was available.

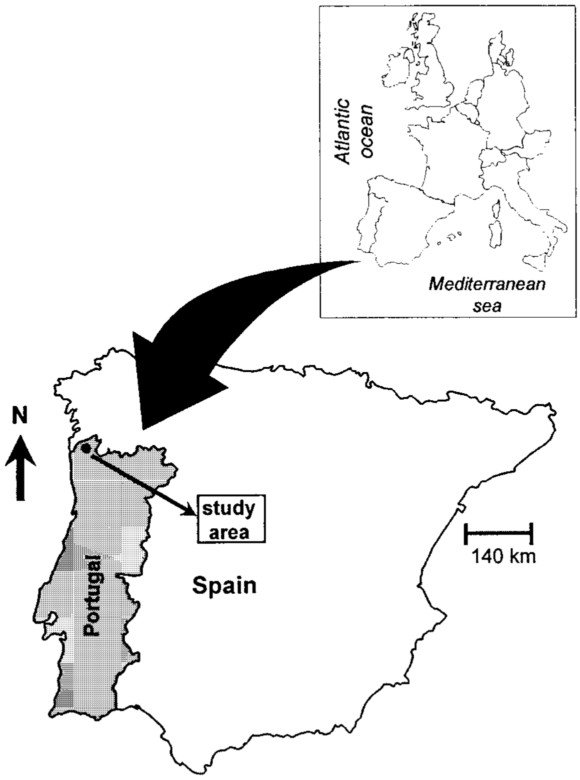

Figure 1. Map of Western Europe and the location of the study area.

Making predictions: overview of recent socioeconomic history

The landscape in the Minho region before the 1940s can be characterized as follows: the valleys and gentle slopes were used as agricultural land, with extremely small mixed farming holdings (usually less than 2 ha) where a wide range of crops was grown (pastures, corn, cereals, potatoes, etc). Around the valleys, in the slopes between the farmed land and the mountains,

Table 1. Changes in demographic and farming variables considered relevant for predicting landscape changes in the region surrounding the study area. Data were taken from Instituto Nacional de Estatística (1954, 1960, 1979, 1981, 1989, 1993).

Variable	Period	% change
Number of farms[a]	1954–1989	−33.6
Number of cattle[a]	1954–1989	−74.4
Number of sheep[a]	1954–1989	−93.7
Number of goats[a]	1954–1989	−95.3
Population size[b]	1950–1991	−31.3
Number of farmers[c]	1950–1991	−58.6

[a] 'concelhos' of Arcos de Valdevez, Paredes de Coura and Ponte de Lima.
[b] 'freguesias' in the study area.
[c] Viana do Castelo district.

there was a region where privately owned shrubland areas with some scattered trees (called 'bouças') were used as a source of timber and organic matter to fertilize lowland soils. Thus, each farmer had a 'bouça' where shrubs were cut every 2 or 3 years. At higher elevation, large extensions of common land ('baldios') with heath were used as pasture for cattle, sheep and goats. These were frequently burned to increase forage production and quality. Small to medium-sized forested patches of pines and oaks (mainly *Q. robur*) also occurred in the region (Rodrigues de Queiróz 1920; Castro Caldas, 1941, 1994; Finan et al. 1993). Several changes in socioeconomic and political conditions in the second half of the century caused abandonment of farming activities and emigration flows, which were most pronounced during the 1960s (Finan et al. 1993). These changes (see Table 1) reflect a population decline and a drastic reduction in farming activities since the 1950s until the 1990s. Parallel to this decline in population and agricultural activities, several policy measures were already in action to promote afforestation (Neiva Vieira 1995). The first was the 'Plano de Povoamento Florestal' (Ministério da Agricultura, 1940), implemented in 1938 with the goal of afforestating the 'baldios', the shrubland areas in the slopes and mountains. According to an inventory made in 1935, only 1400 ha of 'baldios' were forested in the whole Minho region, and the amount foreseen to be planted with trees was ca. 78 500 ha. Other political measures included the 'Fundo de Fomento Florestal', implemented in 1965 with the aim of promoting the afforestation of private land (Neiva Vieira 1995) and the 'Projecto Florestal Português' and the 'Programa de Acção Florestal', both applied during the 1980s. All these policy instruments promoted the afforestation of land, mostly with conifers, particularly *Pinus pinaster*.

Based on the previous overview, the following landscape change trends were predicted: (i) the decrease in farming activities would have caused a decrease in both the total area of agricultural land and the mean patch size of this land use category; (ii) the decrease in farming activities plus the drastic reduction in livestock grazing would have caused shrub encroachment in both abandoned agricultural fields and shrublands used as pastures. This would be reflected in an increase in both the total area of shrubland and shrub vegetation biomass. The latter could be expressed as an increase in the ratio of tall/low shrublands (see below) and mean patch size of tall shrublands; (iii) the afforestation incentives plus land abandonment would have caused an increase in the area of forests, with a larger increase in conifers; (iv) changes mentioned in the previous points would have caused a regional increase in vegetation biomass in the landscape, resulting in fuel buildup in forests and shrublands which might have contributed to increased fire occurrence.

Characterization of the landscape mosaic

Following Dunn et al. (1991), landscape characterization was based on manual photointerpretation of black and white aerial photographs for the years 1958 (the first photographs available for the area), 1968, 1983 and 1995 (scales 1:15 000 or 1:30 000). The minimum mapping unit was approximately 0.5 ha. Interpretations were delineated on Mylar overlays using a stereoscope. These were digitized in vector format (ARC-INFO, ESRI 1992) and incorporated in a raster-based geographic information system - IDRISI (Eastman 1990) with a 0.01 ha resolution. We used a hierarchical classification system for patches (Dunn et al. 1991) so that the ca. 90 initial categories of land use were simplified to 7 broad categories to which each patch was assigned: urban areas, agriculture (mostly irrigated cropland located in the valleys, but also some pastures), low shrubland (less than 50 cm height, with *Ulex europaeus, U. minor, Chamaespartium tridentatum, Halimium alissoides* and *Erica* spp.), tall shrubland (50–250 cm, with *Cytisus striatus* and *Ulex* spp., sometimes with more or less scattered trees), deciduous forests (mainly *Q. robur, Castanea sativa* and *Betula celtiberica*), conifer forest (mostly *P. pinaster* plantations but also *Pseudotsuga menziesii* and *Chamaecyparis lawsoniana*) and mixed forests (less than 75% cover by either conifer or deciduous). The height distinction in shrublands probably had some associated photointerpretation errors but it was considered important to test some of the predictions made. Only two small burned patches (one shrubland and one conifer patch) were detected in aerial photographs, and this was probably due to both the extremely small size of burns and the high rate of vegetation recovery, which makes most burned areas undetectable within 1 to 3 years (personal observations).

Landscape composition data from IDRISI were analyzed using FRAGSTATS software (McGarrigal and Marks 1995). The following statistics were estimated for each of the 4 years, for each of the seven land use categories and for the whole landscape area: (i) total area, (ii) mean patch size, and (iii) total number of patches. Additionally, (iv) the total number of patches in the landscape, (v) mean patch size in the landscape and (vi) Shannon's evenness index were estimated (McGarrigal and Marks 1995). To examine pixel-to-pixel changes in land use categories we cross-tabulated (Eastman 1990) each pair of consecutive images in order to obtain a transition matrix (e.g., Luque et al. 1994; Muller and Middleton 1994). From these data, for each land use category we estimated the retention frequencies (defined as the proportion of pixels belonging to a land use category in a given photograph that belonged to the same category in the previous photograph) plus the proportion of pixels of a land use category in a given year that originated from other land uses in the preceding photograph.

Fire occurrence

Data on fire occurrence in the region ('freguesias' including the study area) for the period 1980–1996 were available from Direcção Geral das Florestas. For each of these years, the number of fires and the total burned area were registered. Correlation and regression analyses (Sokal and Rohlf 1981) were used to test the existence of significant trends in the total number of fires and burned area across time, for the 1980–1996 period.

Theoretical models of fuel accumulation

The relationship between landscape composition and fire proneness was first estimated by assuming that a fuel accumulation score (defined as a function of estimated fuel load) could be attributed to each land use category. In the absence of data on biomass accumulation and moisture content of the several vegetation types specific for the region, we defined five possible models of fuel accumulation ranging from refined (model 1) to coarse (model 5). The basic principle behind these models is that there is a monotonic relationship between fuel accumulation and vertical vegetation structure (e.g., Rego 1992; Forman 1997; Vasconcelos et al. 1998). Model 1 considered six fuel accumulation levels with scores ranging from 1 to 6 for the sequence: agricultural and urban areas, low shrublands, tall shrublands, deciduous forests, mixed forests and conifer forests. Model 2 was similar to Model 1 but assumed a similar maximum score (5) for conifer and mixed patches. Model 3 considered four fuel accumulation levels: score 1 to agriculture and urban, score 2 to low shrublands, score 3 to tall shrublands and score 4 to the remaining forest patches. Model 4 had only three scores (1 for agricultural and urban areas, 2 for shrublands and 3 for forests). Model 5 was the simplest, assuming a dichotomy between combustible and non combustible patches (score 0 for agriculture and urban areas and score 1 for the remaining land uses). For each of these models, multiplying the area of each land use by its fuel score and summing across land uses yielded an index of fuel accumulation in the landscape, for each year. The index for the different years was standardized by dividing by the 1958 index so that this year took the value 1.

Resource selection functions

The last approach used to relate landscape composition and fire proneness was based on real patterns of fire occurrence in the study area. At the landscape level, the effects of fire are heterogeneous, depending on fire regime (particularly fire size, interval and intensity) and landscape structure (mainly physical or vegetation features) (Fox and Barry 1987; Malanson 1987; Turner and Dale 1990; Forman 1997; Farina 1998). Like other disturbances, fire may spread from a local epicentre to cover large areas, with propagation rate enhanced or retarded by landscape heterogeneity (Turner and Dale 1990), mostly in what concerns fuel load composition. Thus, different combinations of fire regime and landscape structure will cause differential patterns of fire occurrence. The final configuration of fire perimeters and burned patches provides useful information on the differential use of the land use types previously available. If the several land use categories of a given landscape are equally fire-prone, then we would expect fires to occur randomly in the landscape, with an equal proportion of burned and available (before the burning season) categories. The fact that a large fire occurs e.g., in a conifer forest does not provide information on the selective fire-proneness of the different patches of the landscape, as it would occur by chance alone in a landscape dominated by conifer patches. In reality, certain patch types in a landscape are more susceptible to fire (e.g. shrublands or conifer plantations) then others (e.g. wetlands, agricultural areas or recently burned patches) (Forman 1997).

The resource selection function is a function such that its value for a resource unit is proportional to the probability of that unit being used. This function is determined from a very simple index of selection, the selection ratio. The selection ratio (w_i) for a given resource i (e.g., land use type) is estimated as

$$w_i = o_i/\pi_i \quad \text{(Manly et al. 1993)},$$

where o_i is the proportion of used resources belonging to category i (estimated from the area consumed by fire for several land use types) and π_i is the proportion of available resources in category i (e.g., estimated from the area of the several land use types occurring in the studied landscape). If resources are used in proportion to their availability, then $w = 1$. If $w > 1$ resources are used more than expected by chance (preferred). If $w < 1$ then resources are used less than expected by chance (avoided).

Data on fire location and perimeters in the study area, also incorporated in the GIS, were collected from three sources: (i) aerial photointerpretation (but provided data for only two burned areas); (ii) satellite imagery used yearly by Direcção Geral das Florestas to map fires larger than 15 ha; (iii) field work, which provided most of the data on fire perimeters for recent fires. This yielded data on 13 wildfires (1 fire in 1983 plus 12 fires in the period 1995–1999) ranging from 0.9–409.3 ha (mean=70.2 ha; median=27 ha).

Resources available for each of the fires was estimated as follows. For 1983 and 1995 we used the land use map derived from aerial photography. As we had no data on the yearly variations in landscape composition since 1995, we assumed that the main landscape changes during this period were caused by fire (field work in the area since 1996 suggests this was true). So, starting from the 1995 land use map, a recalculation of the land uses available each year was made excluding the areas burned in the preceding year. Thus, the resulting resource selection function provided an image of fire occurrence in non- burned areas. Urban areas were not included in the analysis, as they were not used in our sample of wildfires.

The values of the selection ratios for each land use category were averaged accross the 13 wildfires, and the resulting value used as a score of fire-proneness. Similarly to the theoretical models, multiplying the area of each land use by its score (urban areas were given a nil score) and summing across land uses yielded an index of landscape proneness to fire, for each year. The index for the different years was standardized by dividing by the 1958 index.

Results

Landscape change

Across the considered time period, the landscape was dominated by agricultural land (32–45% of the total area), followed by low shrublands (16–31%), tall shrublands (8–20%) and conifer forests (7–17%). The results of landscape change for the period 1958–1995 are described in Table 2 and Figure 2.

The area of agricultural land registered a 29% decline across the 40 years, more pronounced since 1968 (Figure 2a). This loss seemed to have occurred initially (1958–1968) through attrition (Forman 1997), the disappearance of patches and the increase in mean patch size of the remaining ones. After 1968, loss occurred mainly through fragmentation (*sensu* Forman 1997) of large patches, as the decrease was explained by a substantial reduction in mean patch size but an increased number of patches. Urban areas (Figure 2b) registered a 27.5% decrease in area, mainly caused by the loss of dispersed farmsteads (decline in the number of patches) which was not compensated by the growth of the remaining areas (increase in mean patch size). Low shrublands (Figure 2c) declined by 48% in area through fragmentation (patch number increased but patch size decreased). Nevertheless the small variation in the number of patches suggests perforation (Forman 1997) could also have been an important process. Tall shrublands (Figure 2d) increased substantially in area (+96%), with a larger increase in the 1958–1983 period followed by a moderate decline during 1983–1995. During the former period this was accomplished through an increase in both the number of patches and mean patch size. The latter decline was due to fragmentation. Mixed forests (Figure 2e) increased 84.5% in area, although there was a small decline during 1983–1995. There was a substantial increase in the

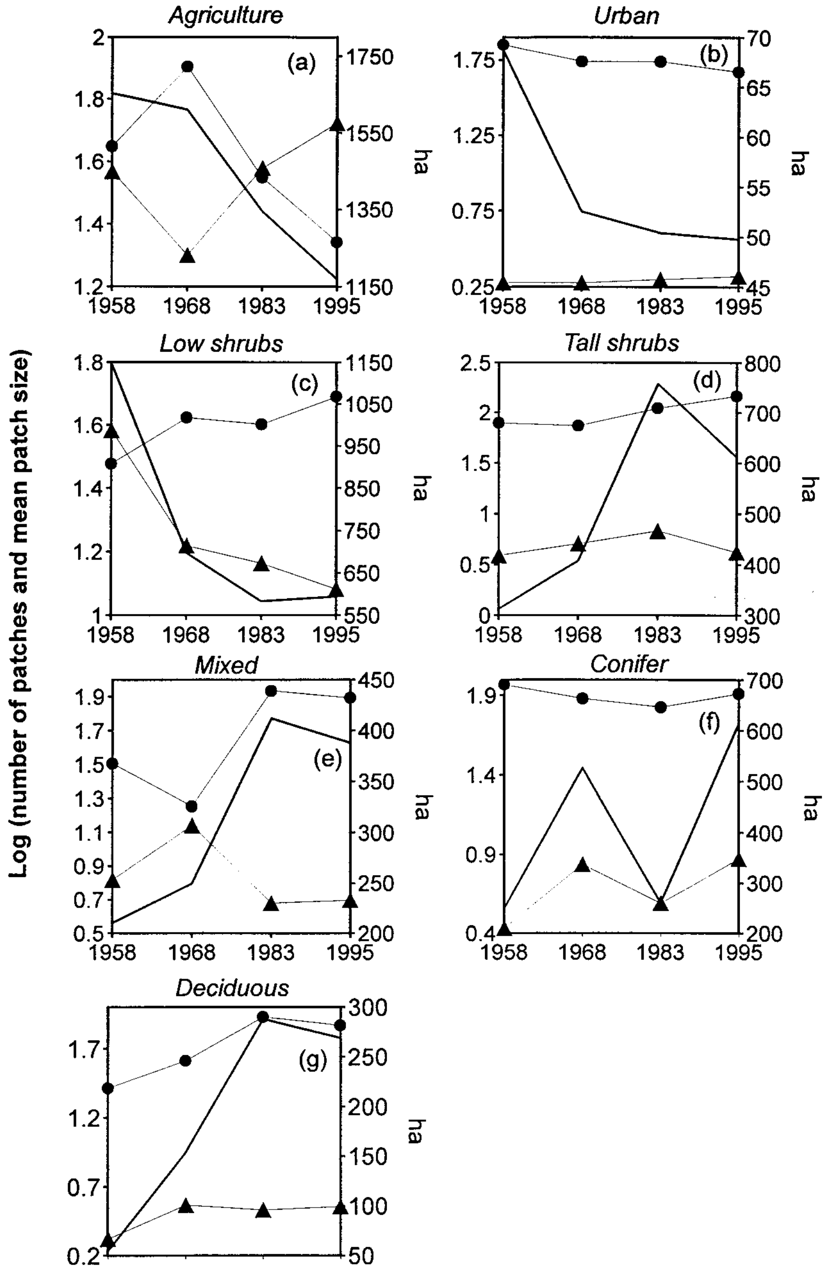

Figure 2. Number of patches (dots) and mean patch size (in ha) (triangles) (both variables in the y_1-axis) and total area (in the y_2-axis) for each of seven land use types during the period 1958–1995, in the study area. The $\log_{10}$ transformation was applied to the y_1-axis to reduce the difference of magnitude between the variables, allowing their visualization in the same axis.

Table 2. Evolution of selected landscape variables in the study area (3697 ha) from 1958 to 1995. See also Figure 2.

Year	1958		1968		1983		1995	
Total area	ha	%	ha	%	ha	%	ha	%
Agriculture	1652.4	44.7	1609.9	43.5	1345.2	36.4	1169.1	31.6
Urban	68.7	1.9	52.5	1.4	50.4	1.4	49.8	1.3
Deciduous forests	54.6	1.5	153.8	4.2	288.1	7.8	268.9	7.3
Conifer forests	249.5	6.7	526.5	14.2	260.8	7.1	615.3	16.6
Mixed forests	210.2	5.7	249.5	6.7	411.8	11.1	387.7	10.5
Tall shrublands	312.8	8.5	407.4	11.0	757.5	20.5	612.2	16.6
Low shrublands	1149.0	31.1	697.7	18.9	583.4	15.8	594.3	16.1
Total		100.0		100.0		100.0		100.0
Total number patches		367		325		481		529
Mean patch size (ha)		10.0		11.4		7.7		7.0
Evenness		0.73		0.81		0.86		0.89

number of patches in the last two sampled years, compared to the 1958–1968 period. The large increase in area during the 1968–1983 period was due to the appearance of new patches. Conifer forests (Figure 2f) showed a large fluctuation in area, although with a general increasing trend. The 1968 peak was explained by the increased patch size in the period 1958–1968, in spite of patch loss. The 1995 peak coincided with an increase in both the number of patches and mean patch size in the 1983–1995 period. Deciduous forest area (Figure 2g) has increased 390%, with an increase in both the number of patches and mean patch size. The small decline observed during 1983–1995 was due to attrition.

The changes in each of the land use types were reflected at the landscape level by an increase in the total number of patches and a decrease in the mean patch size. This fragmentation led to an increased evenness of the several land uses.

The main trends of change across land use categories are described in Table 3. The transition matrix for the period 1958–1968 showed two main trends: (i) transformation of former agricultural land to shrublands and forest (mainly deciduous), and (ii) replacement of low shrublands by tall shrublands and forest. Transitions for the 1968-1983 period were characterized by further increase in tall shrublands at the expense of agricultural areas, and also a change of conifer to mixed patches. During 1983–1995 two main trends were observed: the replacement of tall shrublands by low shrublands, and the transition of low shrublands to conifer patches. During all periods, important changes occurred from agricultural land to urban areas.

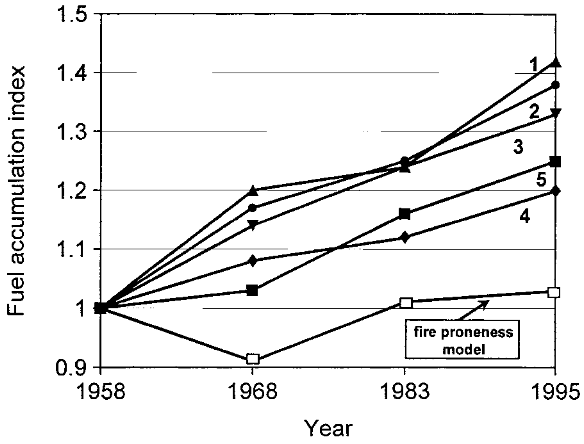

Figure 3. Variation in the index of landscape fuel accumulation as expressed by the results of the five models of fuel accumulation. Models are numbered 1 to 5 (see Methods). The index of fire proneness derived from selection ratios is also indicated. All values were rescaled by dividing by the 1958 estimate.

Landscape fuel accumulation and fire occurrence

The average number of fires per year in the 'freguesias' including the study area, for the period 1980–1996, was 14.1 (median = 11, range = 0-41, $n = 17$) and the total burned area had a mean value of 100 ha (median = 44.7 ha, range = 0–432.4 ha, $n = 17$). There was a significant trend for the number of fires to increase with time ($r = 0.51$, $p < 0.05$), with a threefold increase in the number of occurrences during the study period. Nevertheless, there was no relationship

Table 3. Matrices showing the origin of land uses in the study area, for three time periods. Each row indicates the proportion (%) of the pixels with a given land use category at the end of the time period that belonged to each of the categories, at the start of the period. Diagonal elements are the retention frequencies. Proportions higher than 25% are in bold. Codes for land use categories are: agriculture (agr), urban (urb), deciduous forests (dec), conifer forests (con), mixed forests (mix), tall shrublands (tall shr), low shrublands (low shr).

	1958						
1968	agr	con	dec	mix	tall shr	low shr	urb
agr	**75.3**	4.0	1.0	4.2	5.4	7.9	2.2
con	17.0	23.3	1.5	15.1	14.5	**28.2**	0.4
dec	**28.4**	14.3	7.9	20.3	14.3	14.5	0.2
mix	19.2	5.0	3.0	7.7	2.7	**62.3**	0.2
tall shr	**29.2**	3.1	1.8	1.2	17.5	**46.8**	0.5
low shr	16.6	2.2	0.6	1.0	7.2	**72.0**	0.5
urb	**44.0**	1.7	0.0	0.9	2.7	3.3	**47.3**
	1968						
1983	agr	con	dec	mix	tall shr	low shr	urb
agr	**76.2**	4.5	1.4	2.7	3.7	9.4	2.2
con	11.6	**54.0**	0.7	3.0	7.9	22.5	0.3
dec	23.3	16.4	**33.5**	12.4	10.8	3.0	0.5
mix	20.6	**35.0**	4.3	17.4	6.1	16.4	0.2
tall shr	**40.4**	14.3	2.2	5.5	19.8	17.7	0.0
low shr	10.7	4.7	0.4	10.1	22.6	**51.3**	0.1
urb	**57.0**	1.0	0.4	0.3	1.2	2.6	**37.5**
	1983						
1995	agr	con	dec	mix	tall shr	low shr	urb
agr	**78.9**	1.4	2.2	4.1	9.2	1.8	2.3
con	13.6	21.8	2.9	15.8	18.6	**27.1**	0.0
dec	12.2	1.7	**48.4**	20.2	15.4	2.1	0.1
mix	11.7	11.7	17.1	**34.0**	19.2	6.3	0.0
tall shr	21.3	4.2	6.1	9.3	**38.2**	20.8	0.1
low shr	20.2	5.5	1.2	3.5	**30.0**	**39.6**	0.0
urb	**46.5**	0.2	0.3	2.8	1.5	5.2	**43.5**

with the total burned area ($r = 0.10$, ns). Most of the areas burned consisted of shrublands and conifer forests.

The results of the models of fuel accumulation in the landscape are shown in Figure 3. All models showed a steady increase in fuel accumulation across the 40 years, ranging from 20% in model 4 to 42% in model 1.

The selection ratios for the several land use categories are shown in Figure 4. Shrublands (both tall and low) had selection ratios significantly higher than unity, thus being used more than expected by chance alone. In contrast, agriculture, deciduous and mixed patches were significantly avoided. The confidence limits for selection ratios for conifers showed a larger variability, with preference or avoidance depending on the specific fire but a mean value very close to unity. Thus we can say that, on average, conifer patches burn in proportion to their availability. The model of landscape susceptibility to fire based on the results of selection ratios (Figure 2) suggests an increase in proneness to fire, although the trend is not as clear as the ones from the fuel accumulation models. The lowest index is obtained for 1968, instead of 1958.

Discussion

The changes occurring in the study area, a cultural landscape within the Minho region, in the period 1958–1995, consisted mainly in a large decrease in agricultural areas and low shrublands, and an increase in tall shrublands and forests. Predictions of landscape change based on socioeconomic variables were mostly confirmed by data analysis (Table 4), providing further evidence of the role of socioeconomic data to explain the dynamics of human dominated landscapes (Parks 1991; LaGro and DeGloria 1992; Simpson et al. 1994; Farina 1998).

The rate of loss of agricultural land was higher since 1968. This probably resulted from land abandonment and emigration, more pronounced since the end of the 1960s (Finan et al. 1993; Neiva Vieira 1995). The initial increase in mean patch size (contrary to the prediction) together with patch loss suggests that small isolated fields were the first to be abandoned, with farming activity being concentrated in the main agricultural valleys. This is consistent with the increase in patch size of urban areas and the decrease in the number of urban patches. Low shrublands declined at a high rate in the period 1958–1983, at the expense of an increase in tall shrublands and forests. The drastic decline in livestock numbers plus afforestation probably contributed to this decline. The small variation in low shrubland areas during 1983–1995 could have been partly explained by fire (by changing tall to low shrublands), as suggested by the amount of transitions from tall to low shrublands during that period and the increased fire frequency. This could also explain the lower value of the ratio of tall to low shrubland area (respectively 0.27, 0.58, 1.29, 1.03 for 1958, 1968, 1983, 1995) in 1995, contrary to the predictions.

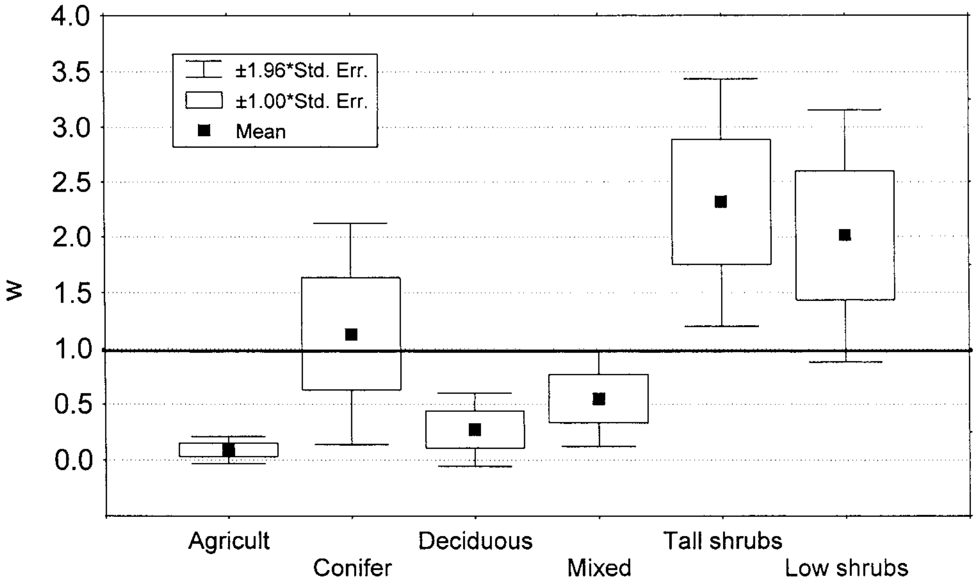

Figure 4. Mean values and variability for selection ratios (w) estimated for 13 wildfires occurring in Minho.

Table 4. Comparison of expected trends in landscape change with observed results.

Expected trends	Agreement of results
Decrease in total area of agricultural land	yes
Decrease in mean patch size for agricultural land	partial
Increase in shrubland area	yes
Increase in mean patch size of tall shrublands	yes
Increase in ratio tall/low shrublands	partial
Increase in forest area	yes
Higher increase in conifer area, within forests	no
Increase in landscape fuel accumulation	yes

The apparent importance of transitions from agricultural to urban areas was probably due to the scale-effect of small photointerpretation errors. Due to the small spatial expression of urban areas, the assignment of even a few pixels of agricultural land to urban areas represented a significant contribution to the latter. Furthemore, the different size resolution of the aerial photographs may have contributed to the observed decline in the area of urban use (it was often difficult to map dispersed farmsteads).

Forested areas, particularly deciduous, increased across the study period. This was caused by both afforestation and land abandonment leading to vegetation succession. Contrary to the predictions, the amount of conifers did not increase steadily. The observed large variations were probably due to fire or management actions such as clear cuts and afforestation of new patches. As a consequence of this recent increase in forested areas, most forest stands are currently composed of young trees (mostly 3–10 m height).

In agreement with the prediction, models of fuel accumulation suggested a 20–40% increase in fuel accumulation in the landscape. This increase certainly contributed to the three fold increase in the number of fires in the 1980–1996 period. No trend was observed for total burned area, suggesting that it is independent of the number of occurrences.

The analysis of the fire proneness index suggests that the increase in fuel accumulation in the landscape was not necessarily accompanied by a parallel increase in proneness to fire. In fact, assuming the current pattern of fire occurrence in the landscape reflects past trends, some land use types which have a large fuel accumulation and whose areas increased across the study period, namely deciduous and mixed forests, do not show a positive selection by wildfires.

In conclusion, changes in landscape structure in the Minho region in the last 40 years could be mostly predicted from major socioeconomic events. Most of the changes were driven by the decline of agricultural activities and contributed to an increased fuel accumulation and fire proneness of the landscape, which probably led to an increased number of fires. We hypothesize that the abandonment of farming activities is a major driving force of increasing fire occurrence in other Mediterranean landscapes.

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